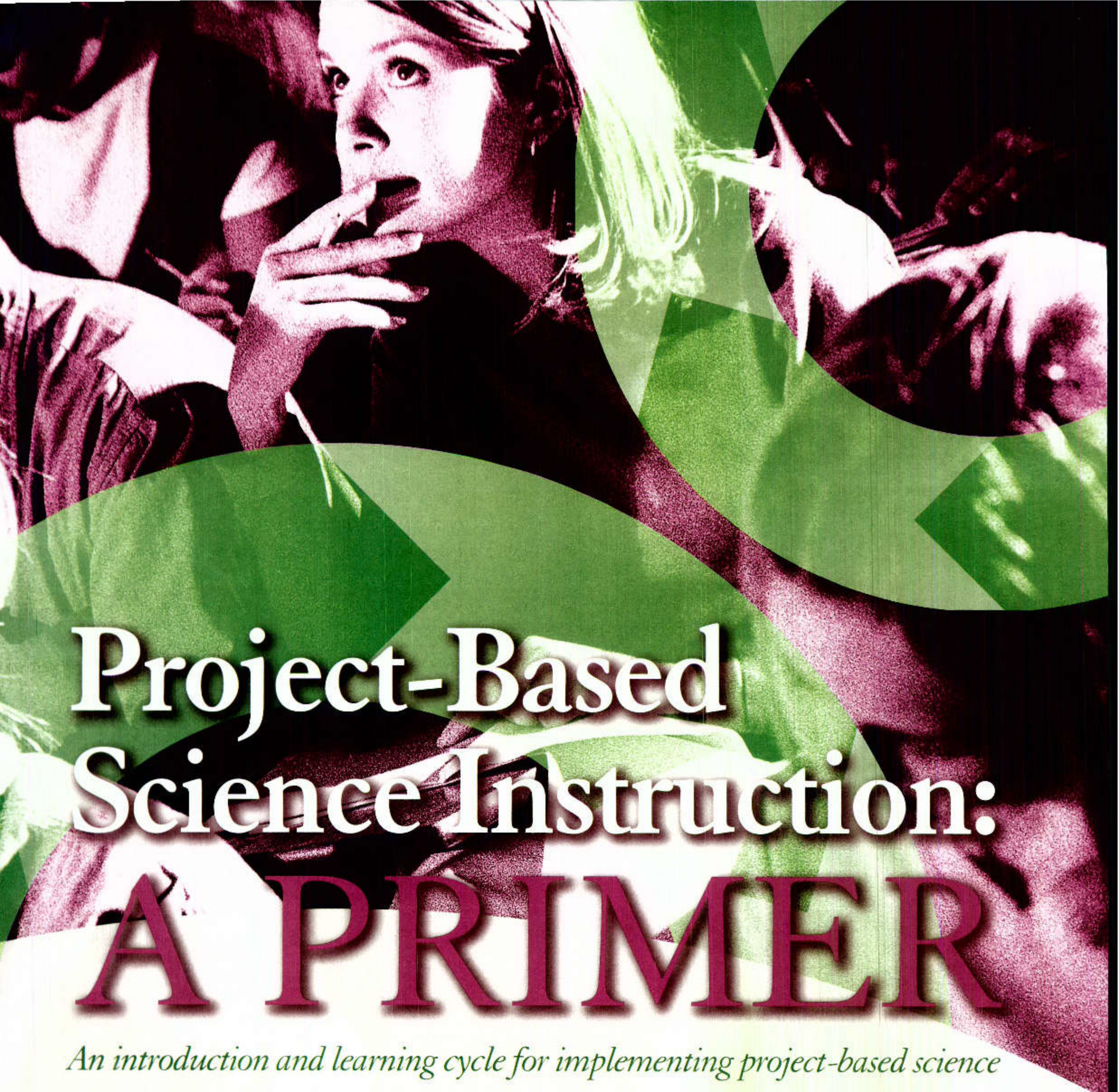


Project-Based Science Instruction: A PRIMER

An introduction and learning cycle for implementing project-based science

Kabba Colley

Different groups of science educators and researchers have provided working definitions of the term *project-based science (PBS) instruction* (Figure 1, p. 24). While these definitions may vary, they do share some commonalities, including the use of learner-centered instruction, driving questions, student collaboration, technology, the production of artifacts, and an extended time frame.

PBS instruction can simply be defined as a student-centered science teaching approach, in which students produce tangible learning outcomes by posing and answering research questions that are relevant to their own lives and communities. In a PBS classroom, students are encouraged to take responsibility for their own learning. They are provided with resources, and guided and mentored throughout the learning process by a supportive teacher who holds them accountable at various points in the project (Figure 2, p. 25). This article provides an introduction to PBS instruction for both beginning and veteran science teachers who are interested in implementing this approach in their classrooms.

The history of PBS

Dewey and other progressive educators laid the curricular and psychological foundations for PBS instruction. In *The Child and the Curriculum*, Dewey notes that the "child is the starting point, the center, and the end" and that the most natural way for children to learn is by doing (1902, p. 187). However, he also observes that children must be guided and provided with appropriate learning experiences if they are to develop a habit of "critical examination and inquiry" (Dewey 1902, p. 29).

From a historical perspective, the use of projects in science instruction dates back to 1908, when Rufus Stimson, a teacher at Smith Agricultural School in Northampton, Massachusetts, coined the term *home projects* (Stevenson 1928). The purpose of these projects was to provide students with the opportunity to apply the school's teachings in their farm work at home.

"Child-centered learning," "learning by doing," and "applying school's teachings in the home" are the core values of PBS instruction. This method was further strengthened by the work of constructivists such as Piaget (1969, 1970) and Vygotsky (1978). Both focused their work on child-centered learning and knowledge construction through practice and reflection. The work of progressive and constructivist science educators laid the foundation for PBS instruction in the United States.

PBS and PBL

Although this article focuses on PBS, it is important to note the difference between *project*-based and *problem*-based learning (PBL), as many people confuse the two terms and approaches. Indeed, even the acronym *PBL* is often used for both, further confusing the issue (see "Other terms for PBS" at the end of this article). PBS instruction and PBL are similar in that they are both forms of inquiry-based science instruction, and there is some overlap between the two. However, they differ in their historical context and pedagogical emphasis. For instance, PBS instruction grew out of the progressive education movement and constructivist science-education reform, while PBL grew out of the medical education reform of the 1970s (see "More on PBL" at the end of this article). PBS instruction emphasizes learning based on students choosing and investigating their own questions, and typically producing a tangible product, whereas PBL focuses on learning how to understand and solve problems using ill-defined cases. Choosing between the PBS and PBL approaches depends on the specific context and purpose of instruction, teacher knowledge and experience, students' backgrounds, and resources available.

Types of projects

PBS projects can be defined based on their intended student outcome:

- Problem-solving projects are designed to teach problem-solving and critical-thinking skills.
- Process-skill projects help students acquire science-process skills such as the ability to pose a researchable question, identify and formulate a hypothesis, design and conduct an investigation, collect and analyze data, draw valid conclusions, and document and report findings.
- Design and engineering projects teach design,

FIGURE 1

Definitions of PBS instruction.

Science educators and researchers	Definition of PBS instruction
Tinker 1992	"Projects are what scientists do. Students who are thoroughly engaged in a project—having selected the topic, decided on the approach, performed the experiment, drawn conclusions, and communicated the results—are doing science. They are seeing science not as a noun, an object consisting of facts and formulas, but as a verb, a process, a set of activities, a way of proceeding and thinking" (p. 33).
Laffey et al. 1998	"Project-based learning is a form of contextual instruction that places great emphasis on student problem-finding and framing and that is often carried out over extended periods of time" (p. 74).
Krajcik, Czerniak, and Berger 1999	"PBS has several fundamental features. First, driving questions or problems serve to organize and guide instruction. Second, students engage in investigations to answer their questions. Third, communities of students, teachers, and members of society collaborate on questions or problems. Fourth, students use technology to investigate and develop artifacts or products. Finally, the result is a series of artifacts or products that address the questions or problems" (p. 9).
Moje et al. 2001	"Typically, the features of what is often called 'project-based pedagogy' include: questions that encompass worthwhile and meaningful content anchored in authentic or real-world problems; investigations and artifacts creation that allow students to learn, apply concepts, represent knowledge, and receive ongoing feedback; collaboration among students, teachers, and others in the community; and use of literacy and technological tools" (p. 469).

testing, and production of tools, technology, structures, and materials.

- Content or subject-matter projects are designed to teach science concepts, knowledge, facts, history, and the nature of science.

Methods used in conducting successful projects (regardless of type) include experimentation, internet or library research, observations, interviews, and surveys.

Furthermore, one type of project could result in more than one student outcome. For instance, in conducting a project with the intended outcome of problem-solving and critical-thinking skills, students may also learn science content, biographies of famous scientists, and the nature of science. It is important for science teachers who intend to implement PBS instruction to understand the different types of projects and possible learning outcomes so that they can guide their students in selecting the right kinds of projects.

Guiding principles

In PBS instruction, there are a few principles that guide teachers' and students' experiences in the classroom. It is helpful to review the following list before introducing PBS instruction:

1. The teacher's role is to facilitate, advise, guide, monitor, and mentor students, not just to conduct lecture and laboratory work.
2. The student's role is to be an active learner who contributes to the learning process.
3. The classroom is a dynamic learning environment in which roles constantly change. For instance, in some cases, the teacher becomes a student and the students become teachers. During presentations of students' project work, for example, the teacher does not instruct, but listens and learns about students' science process and product. Students on the other hand, assume the role of the teacher during this part of the project.
4. Lesson planning is not only focused on the method of delivering and assessing science content, but also on
   - defining the area of study,
   - identifying the learning environment and process,
   - selecting the resources and time required,
   - identifying possible learning challenges, and
   - selecting the appropriate formative and summative methods of assessing learning outcomes.
5. Science learning is based on relevance to students' lives and communities, in addition to textbooks, curriculum guides, and content standards.
6. PBS instruction requires extensive preparatory work on the part of the teacher, although this is usually at the beginning of the learning cycle. When students are used to taking responsibility for their own learning, there is ample time for the teacher to work on related tasks, such as researching resources and new topics and developing assessments.

FIGURE 2

PBS elements.

Good PBS experiences include the following essential elements:

- A rich, complex driving question that is relevant to students' lives
- Production of artifacts
- Student-centered learning
- Collaboration
- Accountability
- Authentic use of technology
- Interdisciplinary and cross-disciplinary inquiry
- Extended time frame
- Valid and reliable performance-based assessment

The project cycle

The project cycle is a conceptual tool that is used to organize project work in the science classroom (Figure 3, p. 26). Although it is sequential, the point of entry for each science teacher and his or her students will depend on the context, learning needs, experience, and background of students.

Orientation

The first thing to do before implementing PBS in the science classroom is to conduct a general orientation to PBS instruction, a process whereby the science teacher and his or her students spend time discussing expectations, requirements, roles, and responsibilities. It should not be simply assumed that students will be interested or actively participate in PBS. Students should be instructed on

- the expectations of project work,
- the importance of collaboration in science,
- information sharing,
- safety issues,
- responsibilities and roles expected of them,
- how they will relate to each other, and
- how their learning will be assessed.

A general orientation to PBS instruction only needs to be completed for the first project undertaken. For subsequent project cycles, a brief orientation should focus on safety issues and other considerations unique to the new project.

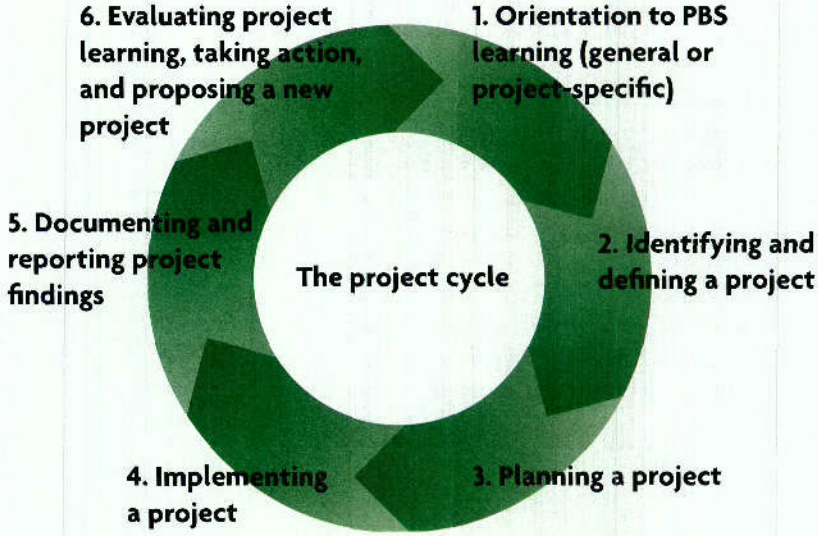
Identifying and defining a project

After orientation, the next step is identifying and defining a project. One way to identify a project is to have students, working in groups, think of an area of study that is full of interesting problems or challenges and is both related to their current science-course content and relevant to their lives. Once the area of study is identified, have students write down on a piece of paper possible questions to investigate. Out of students' possible questions, the group must select one and test it by answering the following:

1. Is our question clear?
2. Can we investigate it in the amount of time available?
3. Can we do it at a reasonable cost, without purchasing expensive materials?
4. Will the results benefit other people?
5. Will our question contribute new knowledge to the field?

FIGURE 3

The project cycle.



If the answer is "yes" to all five questions, then students should move on to the next step. If the answer to any question is "no," students should go back and restate their question or explore a different one.

Planning a project

Planning a project is a process of thinking, discussing, and documenting how the question is going to be investigated. The final product of the planning process is a project plan. This plan serves two main functions:

1. To propose what and how students are going to learn, and what artifacts to produce as evidence of their learning.
2. To provide a framework for evaluating what and how students learned.

There is no single way to prepare a project plan. However, a typical project plan includes the following: title; question; purpose; methods or procedure; list of tools; materials, technology, and time required; roles and responsibilities; and assessment activities.

Figure 4 shows an example of a modified project plan from a high school science class in which students implemented a water-quality investigation project. In some situations, a science teacher may want to organize project work around small groups of two to five students, with each group pursuing its own questions or similar questions related to the overall driving question. The complexity and level of detail in students' project plans will vary depending on grade, ability level, maturity, subject matter, curricula goals, teacher's time, and resources available.

Implementing a project

Once project plans are thoroughly vetted by the teacher, students can then be allowed to implement them. Implementing a project is a very hands-on, practical matter. Students use tools, materials, and technology to collect and record data. They analyze this data and prepare reports, which may have to be rewritten in multiple drafts before they are ready for presentation. During the implementation process, students are expected to work collaboratively in a spirit of cooperation and mutual respect.

This is the time when the science teacher will have the most work to do in terms of supervising group work by mentoring and modeling behavior that is essential for success in science (i.e., patience, observing things closely and recognizing patterns, taking multiple measurements, recording data accurately, using tools appropriately, and looking for alternative explanations of data). The teacher should also monitor how different groups are progressing and work closely with those who need help so that no group is left behind.

Documenting and reporting project findings

Upon completion of their data analysis and report writing, student groups present their reports for peer review. This step documents and reports project findings. During this step, students are expected to do a verbal presentation and answer questions from other students and the teacher. The teacher's role during presentations is to ask questions to make sure students understand the science process they were engaged in, check for understanding of science concepts, and clarify and emphasize important learning points. In addition, the teacher is also respon-

FIGURE 4

Example project plan.

Student project plan
Names: ______________________________
____
Project title: ______________________________
Date: ____/____/____

1. **Project question:** What are the physical, chemical, and biological properties of the water that flows through Greenfield Park?
2. **Purpose and importance:** We want to research this question because we want to learn about how healthy the water is in our local park. Living things cannot live without water, and we hope our project will bring more awareness to the importance of keeping the water in our park clean and the need to protect it from pollution.
3. **Methods or procedure** (list how your project will be carried out step by step):
   a. First the samples will be collected (e.g., samples from different parts of the park's lake).
   b. Samples will be tested for physical, chemical, and biological properties.
   c. Physical, chemical, and biological observations will be made as water testing is conducted.
   d. Different reactions during testing will be recorded.
   e. Results from testing will be recorded and proper documents written.
4. **List the tools, materials, and technology required:**
   - Water samples to be tested
   - Water-testing kit
   - Beakers, measuring cylinder, pipettes, and sampling bottles
   - Rope, bucket, and measuring tape
   - Goggles, apron, and gloves
   - Digital camera
5. **Timeline** (When will the project start and end? How long will it take? Days, weeks, or months?):
   - The project will take two block periods.
6. **Identification of roles and responsibilities** (Who will do what? When? How? What safety considerations are involved?):
   - Miguel, Kojo, Jackie, and Fatima will collect, measure, and label water samples.
   - Nicole, Tanesha, Carol, and Paul will test water samples for chemical pollutants.
   - Janet, Maria, Valerie, and Joey will test water samples for bacteria and other microorganisms.
   - Eugene, Tariq, and Kenya will walk around the park and write down the different physical things they observe.
   - Kim, Jose, and Uma will collect all results and sections and type the final report.
   - All investigations will be carried out wearing gloves, goggles, and other protective equipment. All procedures will be vetted by the teacher for safety before being performed.
7. **How will your project be assessed or evaluated?**
   - Each group member will keep a journal of his or her activities during the project.
   - Each group member will submit a one-page paper about what he or she learns from the project.
   - Each group member will write a section of the final report.
   - Each group member will take part in presenting the final report to the class.

sible for assessing students' artifacts, which could include project plans, data sheets, models, materials, improvised tools, multimedia, or final reports. A holistic or criterion-based scoring procedure could be employed to evaluate the quality of these artifacts; the results of the assessment could be discussed with students with an emphasis on what makes a good artifact and what students can do to create them in their project work.

After the presentations, students should be asked to reflect on the process. They should think about group dynamics, individual participation, and how they might become more successful in future projects. In addition, students should individually reflect on what they knew prior to and after conducting their projects in terms of science concepts and process skills.

Evaluating and taking action

Sometimes PBS assignments conclude at the previous step. In other cases, students are encouraged to put into practice what they have learned from their project. This step involves evaluating and taking action. For instance, in one school, students' project work on indoor air quality led to action by the school authorities, who revamped the whole ventilation system in that school. This happened only after the students and their teacher organized and took on an advocacy role to have school authorities fix the problem.

When students' project outcomes are inconclusive, they cannot take action. Rather, these students should be encouraged to go back and identify which step they need to work on further, what new questions they need to ask, and what new plans they need to develop.

Conclusion

Some science teachers may wonder how this approach to science teaching can be implemented in present standards-based, assessment-driven, and No Child Left Behind–driven classrooms, where a lot of pressure exists for teachers to meet state standards. However, it should be noted that when conducted appropriately, PBS instruction will capture most science-process and content-related standards.

PBS instruction is a science teaching approach through which students learn by conducting projects that are relevant to their lives and communities. They select and investigate authentic research questions, and are expected to take responsibility for their own learning. A PBS classroom is a dynamic learning environment where roles constantly change.

Although teaching using PBS instruction has its challenges, teachers who have employed this method share how professionally transformative it has been for them. They often note that since they started using it, they experience less discipline and behavior problems. In PBS instruction, teachers become lifelong learners because they constantly research new topics and learn new things from their students.

For their part, students learn to collaborate and work together as a team. There is even some evidence that students in project-based classrooms also tend to perform better in national science assessments compared to those who learn in a traditional science setting (Schneider et al. 2002). It is my hope that this primer will inspire science teachers to use PBS instruction in their own classrooms. ■

Kabba Colley (kabba.colley@goddard.edu) *is the guest editor for this issue and the academic vice president and dean at Goddard College in Plainfield, Vermont.*

Other terms for PBS.

Project-based science (PBS) is sometimes referred to as *project-based learning* (*PBL* or *PjBL*, to avoid confusion with *problem*-based learning), *project-based instruction (PBI)*, or *project-based science instruction (PBSI)*. In this issue, we consistently use the term *PBS*.

More on PBL.

Prior to the introduction of problem-based learning (PBL), the lecture-laboratory model dominated medical education. Barrows and Tamblyn (1985), however, felt that the system was producing physicians who knew their subject, but did not necessarily have the skills to use their knowledge effectively or apply that knowledge in different contexts or situations to solve medical problems.

In the 1960s, Barrows and his colleagues developed PBL, an instructional model in which students working in small groups were assigned medical cases that required them to problem-solve and come up with possible solutions. They defined PBL as:

> "The learning that results from the process of working toward the understanding or resolution of a problem. The problem is encountered first in the learning process and serves as a focus or stimulus for the application of problem-solving or reasoning skills, as well as for the search for or study of information or knowledge needed to understand the mechanisms responsible for the problem and how it might be resolved" (Barrows and Tamblyn 1980, p. 18).

Through this student-centered, case-based approach, students played the role of physicians, patients, and advocates, and faculty were the facilitators, coaches, and resource persons.

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