Chapter 8
Fostering Students' Understanding with Web-Based Simulations in an Inquiry Continuum Framework

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Introduction

Technological tools, such as simulations, give prominence to the potentials and advantages of educational theories. Through them, teachers can benefit and make use of the advantages that these models offer (Esquembre 2003). Despite all, educational technology is not an a priori solution for the learning process; not all technologies can be used for educational purposes (Salomon 2000). Simulations must evolve and be combined with innovative methodologies and pedagogical strategies that promote inquiry.

The goal of this project was the effective and better understanding of the Physics phenomena. This should be accomplished through the interaction with educational methods that use simulations as pedagogical tools. It is proven that blended learning education programs increase students' understanding (Garrison and Kanuka 2004). Blended learning, combined with simulations, provides a framework which enhances problem-solving skills in all aspects of instruction (Kirkley and Kirkley 2004).

In the first section, simulations and their advantages in education are described. Then, the process of creating educational simulations for promoting inquiry and students' active participation is explained. The inquiry continuum (IC) is also explained, which can be used as a map road for classifying all levels of inquiry that help students acquire knowledge and skills. Afterward, Illustrations–Explorations–Problems (IEP) approach is described, which combines with simulations, as

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Predict–Observe–Explain (POE) strategy does with worksheets. Finally, we present the results of a research that took place in Greece, in order to test the effectiveness of these methods in the educational process.

Simulations as an Educational Tool

Simulations are representations of real processes, and they have gained their place in education (Wieman and Perkins 2005). Students have better understanding of a phenomenon when they use more senses (Hertel and Millis 2002). Within a simulation, students observe the evolution of a phenomenon and interact with it by changing the initial conditions and monitor the effects of this change.

Simulations are valuable to instruction, from a pedagogical perspective, as they provide useful and effective learning activities (Christian and Belloni 2001). They help students combine all types of representations into a unified theoretical framework and make sense of the physics. Students can watch the phenomenon, interact with it, modify the initial conditions, and play it again. These help them understand the role of equations, link them with theory, and use them as a general tool for study, not just for solving exercises (Simkins et al. 2002).

Another benefit of using simulations is that students who lack imagination or experience can create a realistic image of what they hear or read and combine this information into a concrete framework (Buehl 2009). The production of images and motions through simulations can help in the creation of a strong knowledge background and mental models (Mayer 2005). Simulations can play a role of "note of thoughts" which students use to describe and explain what they learned.

Use of Simulations in Science Instruction

Simulations are useful for pre-class, in-class, and after-class instruction. Pre-class assignments prepare students for the classroom activities, give feedback to teacher about students' current knowledge in order to organize and design the next classroom session, construct the out-of-class time, and create a team spirit. All of the above fit perfectly in just-in-time teaching (JiTT) strategy (Novak et al. 1999). JiTT mainly uses Web-based assignments, but it is proven that it can also blend with simulations for increasing students' level of understanding.

Simulations are also very helpful for in-class instruction. Physics education research has shown that simulations and instructional graphics in general must satisfy five purposes: cosmetic, motivation, attention getting, presentation, and practice (Rieber 1994). There are many researches that focus in the advantages of using simulations in classrooms (Moore et al. 2013).

This work focuses on Web-based simulations for after-class activities. The Web-based part is chosen due to the fact that they are easily distributed, platform independent, and always available. The after-class activities give us a lot of benefits. The size, in time, of typical introductory classes can be a significant barrier to implement successful simulation-based instructional units (Bernstein et al. 2010). Students can have access to Web simulations anytime, anywhere. Brant et al. (1991) found out that simulations are equally effective and students score higher when used as an integrating activity following formal instruction.

After-class Web-based simulations provide students with a powerful tool which continues to offer knowledge and comprehension of the phenomena, long after the in-class instruction is finished (Mackinnon and Brett 2010). Dealing with simulations after class can eliminate any misconceptions and misunderstandings that might appear in-class or during the at-home study from text books. For instance, by changing the value of the initial velocity of a horizontal throw and pressing play, students can see that the body will always fall from a certain height to the ground at the same time, but the throw will not have the same range.

In contrast to classic homework, students can obtain all the benefits simulations offer for in-class teaching, such as attention getting and practice, understanding of the role of equations and link them with graphic plots, etc.

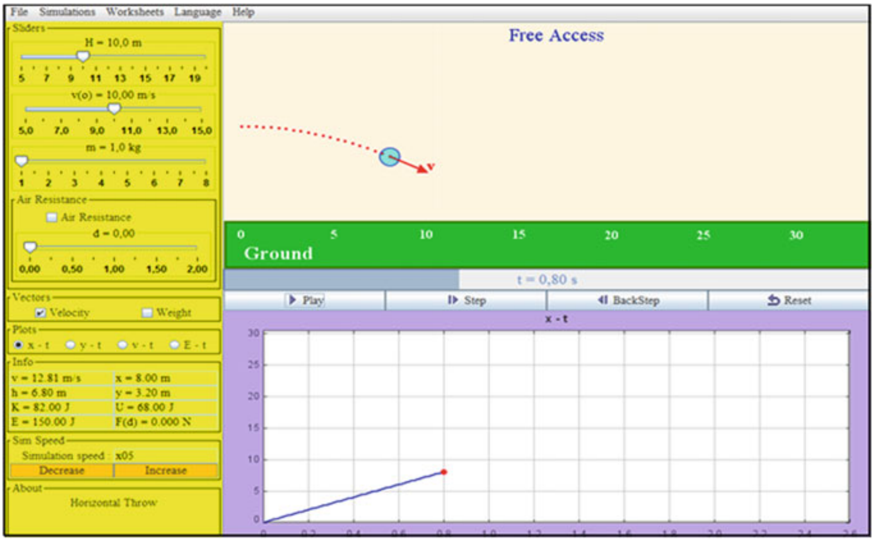
Creation of Educational Simulations

Simulations were created by one of the authors with the use of the program Easy Java Simulations (Fig. 8.1). Each simulation contains three panels, action panel, graphics panel, and control panel (Jones 1998).

In action panel, we can see the evolution of the phenomenon. In graphics panel, plots are created. This is done simultaneously with the evolution of the motion so that students realize which condition is linked to every single point of the graphic plot. In control panel, the ability to change the initial conditions is given. Also, there is the ability of showing or hiding vectors in action panel, making a graphic plot visible, etc. A time bar provides the feeling of time evolution. Underneath time bar, handling buttons are placed. Nevertheless, the most important thing in the design of a simulation is an open environment that can fully describe a phenomenon and supports educational methodologies that promote inquiry.

Theoretical Framework and Educational Methodologies

The context of simulations must be within a pedagogical framework, which should promote inquiry. Simulations are combined with an educational approach, such as IEP. The framework of this approach is an inquiry continuum (IC), which classifies the level of inquiry in each activity and describes the tasks distributed to teacher and



H = 10,0 m
v(o) = 10,00 m/s
m = 1,0 kg
☐ Air Resistance
d = 0,00
☑ Velocity ☐ Weight
● x - t ○ y - t ○ v - t ○ E - t
v = 12.81 m/s x = 8.00 m
h = 6.80 m y = 3.20 m
K = 82.00 J U = 68.00 J
E = 150.00 J F(d) = 0.000 N
Simulation speed : x05
Horizontal Throw
t = 0,80 s

Fig. 8.1 Horizontal throw simulation

students. Worksheets also define the level of inquiry, so students have the appropriate descending scaffolding to help them succeed in the desired goals, gain knowledge, acquire skills, and increase their confidence. To do so, our worksheets follow the POE strategy.

The Inquiry Continuum

Inquiry-based science is an approach to science education that is student-constructed as opposed to teacher-transmitted (Wilfred 2010). Inquiry learning uses questions about a theme and to answer them it engages students into various activities. The inquiry continuum (IC) is a scheme that describes every experiment or activity can be done according to inquiry-based learning.

Many researchers have created an IC to describe the levels of inquiry in many educational procedures, such as laboratory experiments and in-class lectures. Du et al. (2005) describe a six-level IC that is suitable for engineering experiments and can be used in order to understand what processes and skills are needed to design an experiment. Although this IC refers to engineering experiments, it was originated for middle school classroom inquiry. Our approach uses a four-level IC, originated by Bell et al. (2005). It was proposed for in-class inquiry instruction, but we find it an excellent framework for Web-based simulations. Korr (2013), in her research, used the same framework for in-class science instruction with the implementation of simulations to support inquiry.

The levels of inquiry are closed, structured, guided, and open. As we move along the scale, we also move from teacher-centered teaching to student-directed and the responsibility of the tasks gradually shifts from teacher to students. The level of inquiry is critical for the learning experience and the skills we expect from students, such as critical thinking and problem-solving analysis. In closed level, professor is responsible for every aspect of the procedure and students watch teacher perform, collect information, or follow instructions. Moving gradually to the next levels of the IC, students take charge of the process and are obligated to take more initiatives. This way they gain important skills.

In closed level, teacher poses the questions that have to be answered, selects the appropriate procedure, and analyzes data. In structured level, teacher lets students to analyze data and find the answers. In guided level, students select the procedure that will lead them to the correct answers. In open level, students are responsible for all aspects of the concept: pose questions, select procedure, analyze data, and find answers.

Inquiry-based simulations are considered of a higher educational quality, as students take initiative on what to learn, how to identify the problem, formulate questions, design and carry out procedures. Let us take a phenomenon like the horizontal throw (Fig. 8.1). If we permit students to have free access to simulation and ask them to define the parameters in order for the ball to reach the ground at a distance of 20 m, with no explanations or instructions, this is an open level inquiry. This way teacher sets the goal and students should pose the right questions about this concept, design a procedure to collect data, analyze, and reach to a conclusion. If teacher poses hint-like questions to help students identify the problem, but let them decide for the appropriate procedure, it is a guided level inquiry. Furthermore, if teacher locks all the parameters but one to specific values and ask them to test all values of that one parameter or give detailed instructions for the procedure, it is a structured level inquiry. Finally, if teacher asks students to enter some specific values to all parameters, just to see that these are the correct ones, we have a closed level inquiry. Teacher sets the framework, and the level of freedom given to students sets the level of inquiry.

Inquiry continuum is the framework which supports inquiry. To benefit from it, we must use a method for presenting the topic to students, such as Illustrations–Explorations–Problems (IEP) .

Illustrations–Explorations–Problems (IEP)

The method IEP (Christian and Belloni 2003) can succeed in the presentation of a phenomenon to students with an easy and comprehensible way. The IEP approach is based on media-focused problems, where students observe a phenomenon, apply appropriate procedures, and measure the important parameters in order to solve a problem, not just analyze it mathematically (Titus 1998). Although IEP method, as

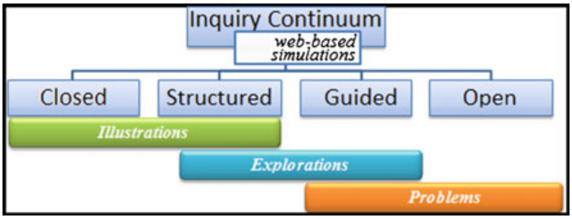


Fig. 8.2 IEP method and inquiry continuum

introduced by Christian and Belloni, was not connected directly to an inquiry continuum, there is a strong connection between them.

In Illustrations, students pay attention to a physical quantity or a graph and run the simulation, altering each time the initial conditions and observing for differentiations. The answer is easily determined from the interaction with the simulation, in view of IC. Illustrations are from the closed to structured levels of inquiry, depending on the level of guidance and instructions given.

In Explorations, students are urged to explore the relation between the involved physical quantities or the form of a graphic plot and describe the evolution of a phenomenon. Explorations are hint-like and teacher helps students by providing the questions and even the process of finding the answers. Explorations are at the levels of structured to guided of the inquiry continuum.

In Problems, the required knowledge is examined and students take charge of the whole process and analysis of the problem. At the same time, skills are granted, such as analyzing the general concept into simple questions, designing procedures to examine those questions, and finding answers. Problems are constructed in a way so that students have a more active role in the procedure and take control of their knowledge. This fact places Problems to open inquiry.

IEP can be applied to each concept of physics individually, not only in a whole chapter. Every step of the IEP approach can be corresponded to some levels of the IC (Fig. 8.2). The beginning and the end of each step is not absolutely specified; there is a small overlap between steps, which makes the transition from one step to the next smoother and easier for the students to adapt.

Predict–Observe–Explain (POE)

Worksheets follow the POE strategy (White and Gunstone 1992) and are given to students as homework. POE strategy helps students to contrast their existing knowledge and perceptions with new ones and highlights the conflicted opinions in order to lead students to the correct conclusions, in such a way that they accept them because they participate in the process (Mthembu 2006). POE provides the framework which guides students' thinking and is essential for improving their conceptual thinking and problem-solving abilities (Theodorakakos et al. 2010).

In Predict, students are asked to predict the evolution in a specific relational change and they usually answer based on the knowledge that they already have, or the respective theory's study. The purpose is the enhancement of the existing student's knowledge.

In Observe, students watch a phenomenon. This step also contains the experimental part. Students not only observe the simulation, but they perform other actions too, as explained at the IC. Students are given instructions on how to execute some actions to the simulation. How much of these instructions and information are given in Observe can give prominence to a simulation that promotes inquiry and lets students develop their own procedures, or restrict its capabilities in order to create a scene with less inquiry-oriented, such as the closed level. This way, a worksheet can cover all the range of the IC.

In Explain, students are asked to explain what they understood in Observe, proving they gained the desired knowledge. If there are discrepancies between the answers in Predict and Explain, students should explain why they changed their answer; if not, they should reinforce their prediction with the data from Observe.

Our research's worksheets follow the POE strategy, but each step is refined so that the inquiry continuum is implemented. Simulation has many parameters, but each worksheet force students to use some or all of them, depending on the level of inquiry we want to achieve. As mentioned before, worksheets play a critical role in the way students will handle the simulation. A well designed, fully featured simulation is desirable, but this is also true for worksheets. No matter how good a simulation is and how many features has, students would not make use of them if it is accompanied by a poor designed worksheet. Designers and professors may try to create a simulation that promotes inquiry but the accompanied worksheet may restrict simulations' capabilities. It is understood that the question in Predict and the instructions in Observe step of a POE worksheet are very significant for the level of inquiry. A question with a not very obvious answer in Predict and a "hint-like," as opposed to "do-like," Observe part can trigger an inquiry procedure and challenge students. If the question in Predict has a complex answer, which cannot be based in a single equation, students will be urged to use an inquiry-based procedure and design a process which will lead them to the right conclusions. On the contrary, a well-designed worksheet can only exploit the advantages of a well-designed simulation, not the other way around.

Research About the Effectiveness of Simulations

In the past 4 years (2011–2015), a research was conducted for studying the effect of simulations and the above methods in students' performance. Sixty-three students from various schools in Thessaloniki, Greece, participated in the research.

Students were given worksheets to complete along with the simulations; a total of 343 worksheets were collected. Teacher made an introduction to simulations and the way they work, as well as how to complete the worksheets. Each student

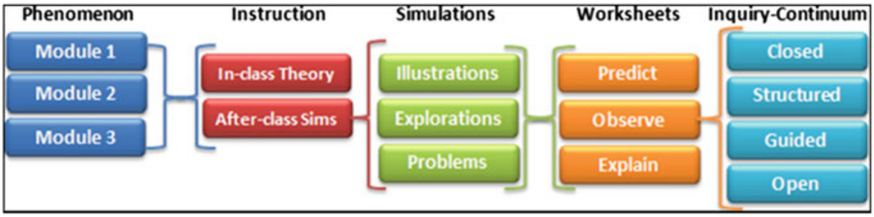


Fig. 8.3 The unfolding structure of the sequence

worked individually from his home, through Internet connection in order to have access to simulations. For this purpose, a Web site was created (hosted on server). Students had been supported by a Facebook's group created for the research.

Our teaching learning sequence on horizontal throw is shown in Fig. 8.3. The instruction of a phenomenon is divided into modules. Each module consists of in-class theory instruction and after-class homework with Web-based simulations. Simulations use the IEP method. Each step is accompanied with worksheets that use the POE strategy. The Observe part follows the IC as a framework.

Another parameter of the POE method is the certainty of the answers given in Predict and in Explain steps (Dalziel 2010). This is measured in a forced Likert-type scale in order to force students to give a positive or negative answer.

Answers not only were studied as a whole, but also were separated into groups in order to see whether there is a factor which affects the learning ability:

- Student's age: 3rd Grade (33)—2nd Grade (21)—1st Grade (9)
- Students' sex: Girls (30)—Boys (33)
- School: Public (52)—Private (11)
- Field of Study: Physical (35)—Social (19)—Not Specified (9)

The parameters in which research was focused were the following:

1. Can students follow alternative teaching methods?

   Check whether they completed worksheets, no matter what answer they gave.

2. Can students achieve higher levels of knowledge with these methods?

   Check whether they answered correctly, especially in Explain step.

3. How do students feel about these methods?

   Check time for completing the worksheets and whether they liked the method.

4. Do simulations increase students' certitude about their answers?

   Compare the level of certainty in Predict and Explain.

Statistical Analysis and Research Results

All worksheets were analyzed with IBM's tool SPSS, version 22. At first, data were analyzed to check the frequencies of the correct answers given. After that, a set of independent t-tests were applied, in order to examine whether there were any differences between groups. All t-tests were conducted independently for Predict and Explain. Worksheets were divided into groups according to age, gender, type of school, field of study, and the certainty of the given answer.

The general conclusion is that all students completed the worksheets and were able to follow the instructions. The total number of correct answers in Predict was 138. In Explain, the total number of correct answers was 287, an increment of 108 %, alongside with the decrement of the wrong answers (109 in Predict, 16 in Explain). Students increased their knowledge and also their confidence about this knowledge. Seventy-three students answered they were certain about their answer in Predict, but 193 students were certain about their answer in Explain (Fig. 8.8).

Despite not having any previous experience with simulations, students adapted quickly and performed well; the use of computers did not affect their performance negatively, but helped them understand the phenomena, as well as attracted their interest. At the end of this research, all students could answer to questions that demanded personal judgment and a more complicated way of thinking.

In Fig. 8.4, we can see the total results for Predict and Explain. The number above each bar shows the total number of worksheets for the current answer. At first sight, we see that correct answers were doubled at explain.

Next step was to compare Predict and Explain answers by gender (Fig. 8.5). SPSS analysis showed no significant difference between answers given by gender (sig. = 0.347). Again, the increase in correct answers was obvious at both genders.

Examining the answers given in worksheets by type of school (public or private) was our next query (Fig. 8.6). In Predict, students of public schools had more correct answers than students of private schools. In Explain, it seems that both public and private school students increased the percentage of correct answers to the same level. SPSS shows a statistically significant difference in Predict (sig. = 0.043), but not

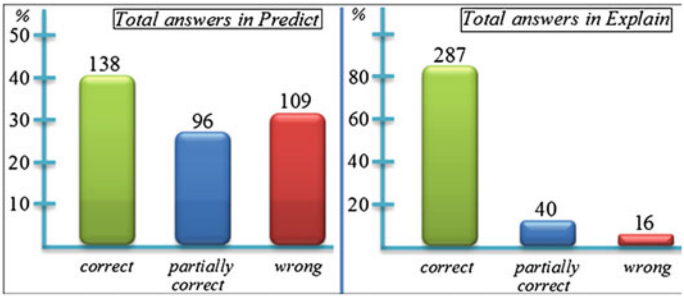


Fig. 8.4 Total answers in predict and explain

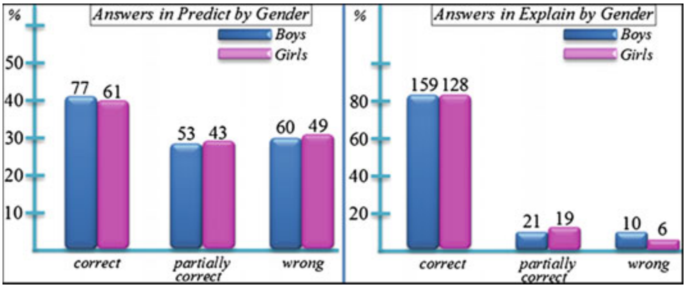


Fig. 8.5 Answers in predict and explain by gender

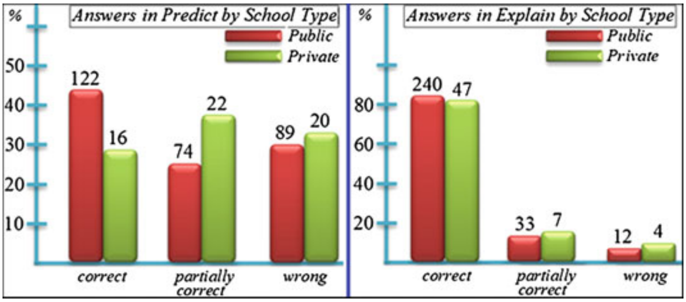


Fig. 8.6 Answers in predict and explain by school type

significant in Explain (sig. = 0.593). This result is under question because the number of students from private schools who participated in the research was very small, so no safe conclusions can be made regarding school type.

The last separation was between students who have not decided the field of study yet, those who have chosen physical sciences and those who have chosen social sciences (Fig. 8.7). SPSS showed a significant difference between physical and social sciences (sig. = 0.017). This seems to be understandable, as students of physical sciences have generally more knowledge about physics.

Every Predict and Explain step was followed by the question “how certain are you?” Students should circle one of the following: uncertain, somewhat uncertain, somewhat certain, and certain. The results indicated that simulations can increase student’s confidence (Fig. 8.8). What is also important to notice is that some students who answered correctly in Predict were not very confident about their answer. In Explain, they answered correctly but they were more certain about it.

Students were also asked to mark how much time took them to fill the worksheets. Answers vary from 2 min to 20; the method is not time-consuming. What is also important to notice is that playing a simulation usually takes 5–10 s to complete, but managing the simulation takes more time.

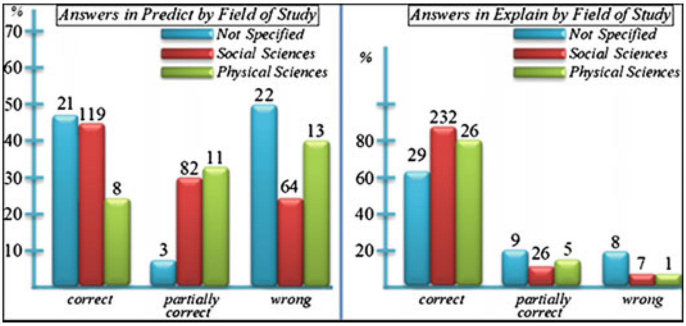


Fig. 8.7 Answers in predict and explain by field of study

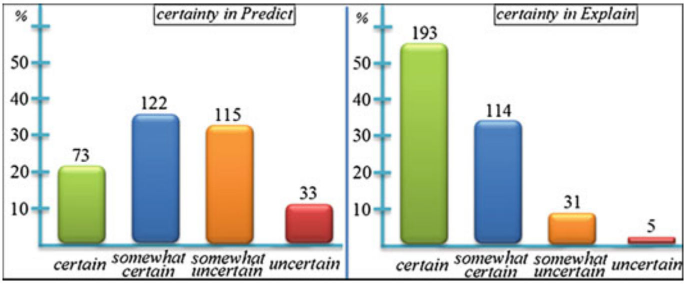


Fig. 8.8 Certainty of answers in predict and explain

Results regarding the 1st parameter show that students can follow new methods. Also, students showed a positive stance, as most comments were positive.

As for the 2nd parameter, we observed that each student individually increased his knowledge about the phenomena. The total correct answers in Explain are much higher than the total correct answers in Predict, with a simultaneous decrement of the wrong answers. This increment was noticed in every separation that was made, between genders, type of school, fields of study.

As for the 3rd parameter, students think that studying with the use of computer simulations is easier, faster, and pleasant. Most students were excited with the fact that they would do homework from their computers, whereas many comment the simultaneous vision of the movement and graphs as very useful.

As for the 4th parameter, the certainty of the answers was increased at Explain, contrary to Predict (Fig. 8.8). This means that simulations give to students a hands-on experience which increases their confidence about the gained knowledge.

Conclusions

This teaching method manages to provide students with a holistic learning experience which improves their performance independently of their level of knowledge. Along with the help of simulations, teachers have all the tools and resources they need in order to guide students and let them discover knowledge by their own. The use of computers and Internet gives an extra motivation to students. Additionally, simulations succeed in helping students understand the graphs, as they have declared. Finally, the short time which is demanded for the worksheets does not function contradictorily, mainly for the least capable students.

This process could be applied simultaneously with the existed curriculum of Physics teaching, for a comprehensive and integrated learning experience.

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