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Pensaqui: A Learning Object about Chemical Transformations

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Supporting Information

ABSTRACT: As a proposal for a methodological strategy for teaching and learning chemical transformations in science or chemistry classes, this paper presents the learning object Pensaqui. It was developed through joint work between teachers and students at the IFRS—Canoas and UFRGS—(both located in Southern Brazil), integrating the areas of Chemistry and Design. In a recreational and contextualized fashion, Pensaqui proposes students to expose their ideas on two problem situations through the use of different levels of representation (macroscopic, symbolic and submicroscopic). The pedagogical aim proposed is to help students to be aware of their individual theories, differentiating them from the scientifically correct theories, where the understanding of matter as something discontinuous and the conservation of nonobservable properties are essential core concepts for the understanding of chemical transformations

KEYWORDS: *First-Year Undergraduate/General, High School/Introductory Chemistry, Computer-Based Learning, Misconceptions/Discrepant Events, Reactions*

Many students confuse the processes that involve chemical transformations with changes in the physical state backed by their senses, without making use of the scientific models studied in chemistry classes.[1−3]. This way, in the pursuit of alternatives for teachers to be able to identify and discuss students' implicit theories,[4] we have developed a learning object, Pensaqui. A learning object is any resource that may be reused to support learning.[5] Such definition is broadened by the addition of the technological dimension of remote access, the social dimension of interaction, and the pedagogical dimension of exploring.[6] Learning objects have been used in Chemistry teaching with great success, as per examples[7,8] that describe the VIPER (Virtual Inorganic Pedagogical Electronic Resource) repository. Colorado University's PHET repository also offers several examples of educational objects for teaching chemistry. Moreover, since the phenomena studied by Chemistry are difficult to observe, demanding that students be skilled in translating one form of representation into another,[9,10] games, simulations and learning objects have proven to be important tools for learning.[11−16]

PENSAQUI: EXPLORING DIFFERENCES BETWEEN CHEMICAL AND PHYSICAL TRANSFORMATIONS

Pensaqui, the learning object presented in this article, represents a partnership between professionals and students from a federal technical school and a federal university, both Brazilian, resulting in an interdisciplinary group comprising teachers, researchers and scholarship holders from the areas of Chemistry and Design.

Pensaqui is an interactive animation, and is available online.[17]

The script in Pensaqui shows the story of a group of school colleagues that must find a research theme from their daily routine for a science fair. The main character (Maria Clara) is in doubt about the difference between the bubbles that are formed when water boils in a pot and those that are formed when an antacid pill is placed in a cup of water.

Pensaqui has the following aims:

- To present the phenomenon through different forms of representation in order to mediate the construction of more complex, efficient models to understand properties and transformations of matter;
- To create conditions for students to present their ideas (implicit theories) about the phenomena being studied.

The following presumptions are deemed fundamental for the organization of Pensaqui (Figure 1):

The *Forms of Approach* refer to the representational nature of Chemistry[18,19] with its three levels of representation: (a) macro or tangible, i.e., what can be seen, touched or smelled; (b) submicroscopic, i.e., atoms, molecules, ions and structures; and (c) representational or symbolic, i.e., symbols, formulas, equations, molarity, mathematical handling and graphs. Students using Pensaqui see the formation of bubbles in the

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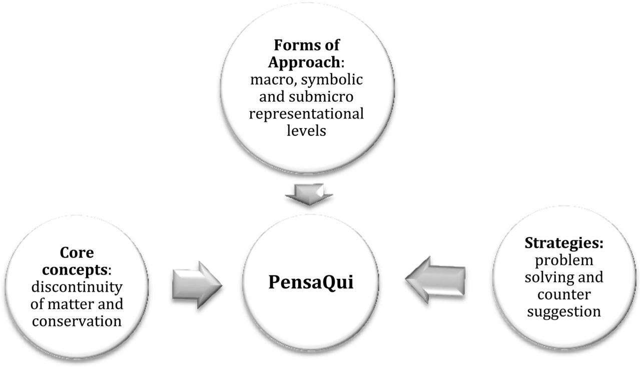

Figure 1. Presumptions that constitute the educational object Pensaqui.

pot and in the cup (macro), which intrigues Maria Clara; the chemical formulas and equations that represent the substances and processes being studied (symbolic); and the interaction between molecules and/or atoms in the representation of solid, liquid and gaseous water (submicroscopic). The latter two levels of representation are shown in the text materials collected by Maria Clara and her friends.

The *Concepts* refer to the two core concepts required to understand the vast majority of contents studied in chemistry throughout elementary education:[20] understanding of matter as being discontinuous and the conservation of nonobservable properties.

As *Pedagogical Strategies*, we offer counter suggestion[21−23] and problem solving,[24,25] adapted and organized so that when students use Pensaqui they may expose their ideas in written form. Problem solving comprises questioning by the character Maria Clara, who experiences a situation that results in a doubt, which in turn becomes the object of research by her and her colleagues. The hypotheses formulated by the other characters (her friends) are a form of counter suggestion, inasmuch as they propose different ideas about the likely cause for the formation of bubbles in each fact observed by Maria Clara. These counter suggestions are supposed to encourage the students who are using Pensaqui to further elaborate on their initial explanations. It should be pointed out that the hypotheses presented by Maria Clara's friends were collected by the first author, during a research activity with students entering "medium schooling" in which they analyzed the same phenomena approached by Pensaqui. In Brazil, the preuniversity schooling system has 12 years: the first 9 years are called "fundamental schooling" and the last 3 are called "medium schooling".

Pensaqui's Storyline

The first action is for students to create a user to access Pensaqui. This will allow them to save their progress and their teacher to read what was written. Teachers can also create a profile so they may access students' data. Teacher profiles allow to create or join "schools" and "classes", so when students create a profile they can choose their school, class, and teacher from a dropdown menu.

After registering, students enter Pensaqui. The first scene shows the school environment where Maria Clara and her colleagues, Caroline and Ricardo, are interested in a sign advertising a scientific initiation fair that will take place at the school. They arrange to meet at Maria Clara's house to develop a project and take part in the fair. The figures of these three characters represent fashion styles usually adopted by teenagers: a grunge/shaved-hair girl (Maria Clara); a hip-hop/skater boy (Ricardo); and a plain looking, long haired girl (Caroline).

In the second scene, Maria Clara arrives home and faces the scenario that will become the research theme for the group: the formation of bubbles in two different situations; in the pot with water boiling to make soup (Figure 2,left) and in the cup of water in which her mother drops an effervescent pill (Figure 2, right). Maria Clara then asks herself "both the pot and the cup have bubbles, but why was it necessary to apply heat in one case and not in the other?" During this stage, students see the formation of bubbles through animations (macroscopic level).

By clicking the "Continue" button (Figure 2) students are asked to answer the question posed by Maria Clara: "why does the water in the pot need heating but not the water in the glass?" This text, as well as all text inputs by students, is then saved under the students' login.

After the kitchen scene, Maria Clara, Caroline, and Ricardo meet up to develop their project, and each one presents their hypothesis for the case of the pot. Here students must choose one of three explanations (Figure 3). One represents the

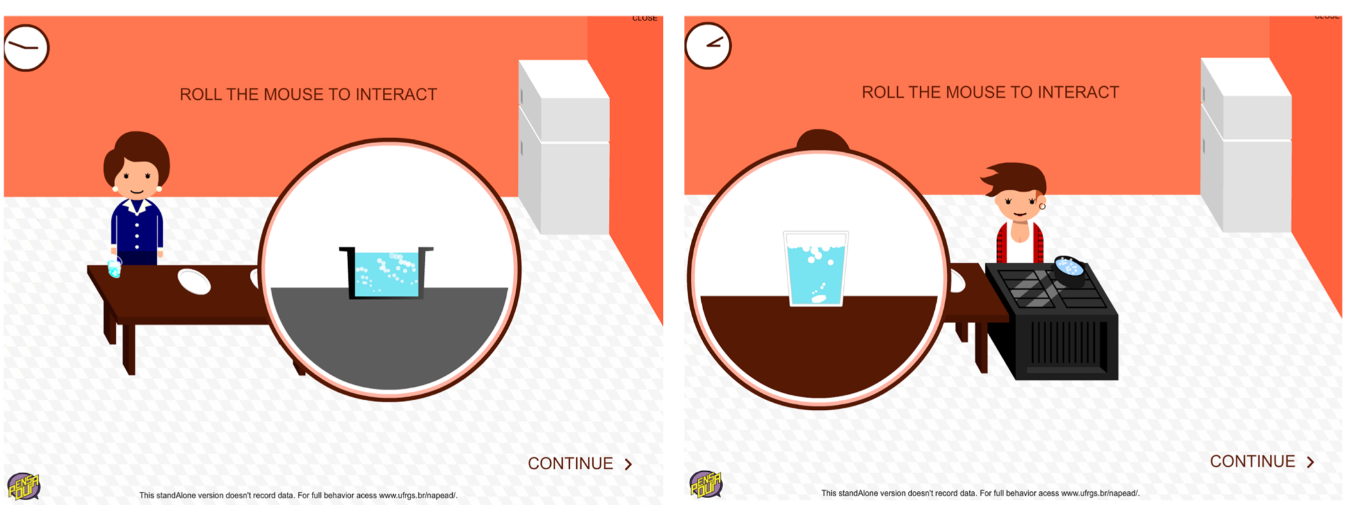

Figure 2. Maria Clara in the kitchen, at home.

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Figure 3. Hypotheses raised by the characters about the formation of bubbles in the pot and the space for students' written elaboration.

correct answer, and the other two are incomplete theories—wrong, yet plausible. The rationale behind offering two wrong answers is to allow students to confront their incomplete theories (if any) in later stages of the tool. Maria Clara's and Ricardo's answers are examples of incomplete theories about substance conservation. He hypothesizes that the bubbles are hydrogen (H_2) and oxygen (O_2) in gaseous form out of the water molecule. She hypothesizes that there is air mixed in the water, and when the solution is heated, the air forms bubbles (because "air" is usually in gaseous form). The correct answer is given by Caroline (not Maria Clara) to prevent students from choosing Maria Clara's only because she is the main character. However, it is possible that students choose one of the characters based on appearance or by pure chance, and not because they think it is the best explanation for the phenomenon. Pensaqui does not provide feedback on whether students made the right choice, but every choice is stored.

After that, each character sets off on their research about "the water boiling in the pot", and come up with three texts highlighting the core concepts: substance conservation during changes in the physical state of matter, and discontinuity of matter. All three texts are correct, and present a pedagogically relevant aspect of the problem.

Maria Clara's text emphasizes the representational nature of Chemistry. Caroline's text contains information about the transformations in the physical state, showing that the molecular formula of the water is the same in both liquid and gaseous states. Her text emphasizes that there is a "change in the physical appearance, but not in its composition". Her text is an example of the core concept of "conservation of matter". Ricardo's text has an explanation about discontinuity of matter, with an animation representing water in the three physical states at the submicroscopic level. From this animation, it is possible to see that water in the liquid state occupies a bigger volume than in the solid state. His text exemplifies the core concept of "discontinuity of matter". These texts can be read in any order; they are complementary but independent. After that, students may, as required, further elaborate on their explanations for the phenomenon of the appearance of bubbles in the pot through writing. A very proactive attitude from students is expected, as they should actively question their theories and try to find coherence between their answer and the three texts. Should this coherence be impossible to achieve (because the answer is wrong), students should change their answer, and try to modify their theories.

In the next stage, the focus shifts to the appearance of bubbles in the cup with the antacid pill, following the same sequence. Pensaqui proposes that students write their ideas about the phenomenon to later on expose the characters' hypotheses (counter suggestions).

As in the previous block, the three characters follow on with their research individually. Each one's research results make up three texts that cover: the chemical reaction that occurs in the cup where an effervescent pill was placed represented at the symbolic level; the conservation of matter and nonconservation of the substance as a characteristic of chemical reactions; and one more example of the chemical reaction with representations at the symbolic and submicroscopic levels. Another opportunity is provided for students to further elaborate on their ideas, and the interaction between students and Pensaqui ends. All the conversations between the 3 characters, as well as the texts they found on their researches are supplied in the Supporting Information section of this paper.

It is expected that after reading the six texts covering relevant aspects of the pill and the pot problems, students will be able to not only identify how these two problems differentiate, but also

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question why their previous answers were wrong. With students being prompted to write their thoughts after each new information is presented, the teacher can follow the path of their conceptual evolution. Should students face difficulties identifying the inconsistencies between their answer and the correct scientific explanation, the teacher is well informed to interfere and advise students in a suitable fashion. As mentioned above, Pensaqui provides no feedback for students; that is up to the teacher, who is expected to follow the history of students' interaction with the tool. Pensaqui only stores information; it is available for students via the learning object, who can change their answers at any time, as well for the teacher, who can see the changes in the answers. The teacher can access all reports either as a PDF file or an XLS spreadsheet.[26]

■ CONCLUSION

All choices made and texts written by the students at different instances may be viewed in a report that can be accessed by teachers. This way, teachers have the opportunity to evaluate the explanations presented by students, the evolution of their understanding and diagnose what needs to be discussed during the continuation of studies on the theme in class. It should be stressed that the learning object comprises one of many tools teachers may use as a methodological strategy within a context of building knowledge, in which students are seen as active subjects capable of learning and continuously broadening their knowledge. That is why Pensaqui does not provide feedback; it is the teacher's role to identify the proper way to help each student identify gaps in their conceptual understanding of discontinuity and conservation of matter. And students must proactively question their theories, searching for conceptual evolution.

■ ASSOCIATED CONTENT

Supporting Information

The Supporting Information is available on the ACS Publications website at DOI: 10.1021/acs.jchemed.5b00764. To use Pensaqui, as well as the database system, only an Internet connection and the Flash Player plug-in are required.

The lines of each character in Pensaqui to be used as an aid for the teacher who does not know Pensaqui (PDF, DOCX)

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Notes

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