EXPERIENCE SCIENCE: THE CLICK BETWEEN SCIENCE APPS AND SCIENCE LEARNING

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Abstract

The rapid rise of tablet education provides an opportunity to promote science learning through science apps. These apps can provide important benefits for science students by:

- Developing understandings of complex and dynamic systems,
- Making the invisible visible through dynamic visual representations,
- Developing student inquiry skills through active learning,
- Motivating students to explore and learn science, and
- Assessing student content knowledge and inquiry skills.

The paper will demonstrate these benefits with specific examples from *Experience Science* apps in physics, chemistry and biology. For information on apps visit https://www.facebook.com/ExperienceScience

Introduction

The word *simulation* signifies the imitation of the operation of a real-world process or system over time (Banks, Carson, Nelson, & Nicol, 2000). This imitation can be of a physical object, physical environment, system, device or situation taken from reality. Simulating something requires *the development of a model*, which represents the key characteristics, behaviors or functions of that which is being imitated.

Simulations are commonplace in the world of science. They have been developed as well in the field of science education, in order to address many misconceptions and difficulties that students have when they learn science. Scientific phenomena usually occur on levels that are difficult or impossible to observe with the naked eye, and these phenomena are often abstract. Students typically do not have the opportunities to manipulate and test the variables associated with these phenomena. In addition, students have difficulties developing the skills of scientific inquiry, which have been shown to be central to scientific literacy (Flick & Lederman, 2004).

As we demonstrate later in this paper, science simulations have been developed to address these learning issues. In addition, as a recent literature review concluded, it has been shown that traditional instruction in science education can be successfully enhanced by using computer simulations; moreover, these simulations result in higher student satisfaction, as well as more student participation and initiative (Rutten, van Joolingen, & van der Veen, 2012). Also, some simulation-based laboratories have been shown to overcome many of the difficulties that teachers face in hands-on laboratories (Donnelly, O'Reilly, & McGarr, 2013).

Science simulations are not new. They have been around for over three decades of science education practice. However, we suggest that their success has been limited, mainly due to two main reasons, i.e., the lack of scaffolds and cognitive tools that help students with the problems they have regarding the inquiry process (de Jong & van Joolingen, 1998; de Jong, Linn, & Zacharia, 2013), as well as a lack of access to the science simulations themselves.

We suggest that both reasons can be adequately addressed by well-designed apps for cellphones and tablets, which can bring the power of science simulations to science learning, both inside and outside of schools. In addition, we believe that another advantage of using the these mobile devices is that students activate the simulations by touching the screen, which is more direct, immediate and closer to "the real world experience" of conducting experiments.

Introducing Experience Science

Experience Science is a series of dynamic simulations of scientific phenomena and concepts. Table 1 presents the current list of simulations; more are expected in the future. Each simulation includes the scientific background relating to the concepts introduced in each unit; multiple representations, such as dynamic graphs, tables, and interactive animations; investigations that help students learn by exploring inquiry questions; and thought-provoking quizzes that are ideal for individual learning, small-group work, and teacher-led class instruction.

Table 1

Titles and Descriptions of the Biology, Chemistry and Physics Apps in Experience Science

Biology apps	The Body as a System	Investigate the physiological responses (heart rate, respiration rate, body temperature, etc.) when walking or running on a treadmill.
	Cellular Respiration	Explore how the digestive, respiratory and circulatory systems work together in the process that provides energy to the body's cells.
	Pond Food Chain	Investigate simple food chain in a pond that consists of producers (algae), herbivores (tiny crustaceans), predators (one species of fish), and top predators (another species of fish).
	Journey to Biological Levels of Organization	Explore biological levels of organization, from the biosphere to atoms, in three ecosystems: the Mediterranean Scrubland, the African Savannah and the Coral Reef.

Table 1. *Titles and Descriptions (Continued)*

Chemistry apps	Floating and Density	Place cubes of different materials in water tanks and understand what causes them to float or sink.
	Changes in States of Matter	Observe the various changes that occur when water is heated and transitions from ice to liquid to gas.
	Law of Conservation of Mass	Compare the weights of the reactants and products of different chemical reactions in order to test the Law of Conservation of Matter.
	Effect of Temperature on Diffusion Rate	Remove the barrier between two parts of a vessel, each containing a different substance, and measure the resulting diffusion rate at different temperatures.
	Dissolution	Observe a microscopic view of how salt and sugar dissolve in water.
	Structure of the Atom	Construct specific atoms and ions in a partial Periodic Table of Elements by choosing the correct number of protons and electrons for each.
Physics apps	Energy of a Skateboard Rider	Investigate potential energy, kinetic energy, thermal energy, and energy transformations of a skateboard and rider, with and without friction.
	Energy of a Pendulum	Investigate potential energy, kinetic energy, thermal energy, and energy transformations of a pendulum, with and without friction.
	Energy of an Elastic Spring	Investigate potential energy, kinetic energy, thermal energy, and energy transformations of an elastic spring, with and without friction.
	Speed it Up	Explore different speeds of a vehicle, based on distance-time graphs that describe its movement.

The Learning Benefits of Science Simulations

Reviews of the educational research literature on science simulations (de Jong & van Joolingen, 1998; NRC, 2011; Rutten et al., 2012) support the claim that the main learning benefits of these simulations can be summarized as (a) developing understandings of complex and dynamic systems, (b) making the invisible visible through dynamic visual representations, (c) developing student inquiry skills by active learning, (d) motivating students to explore and learn science, and (e) assessing student content knowledge and inquiry skills. We will illustrate these learning benefits through examples from *Experience Science*.

Developing Understandings of Complex and Dynamic Systems

Most of the systems in nature are quite complex and contain many interconnected variables that do not lend themselves to isolating and testing. This means that the traditional educational methods of observation and experimentation are not possible in these cases, which prevents students to directly interact with these systems. Instead, when learning about these systems, the student usually receives abstract information in a passive manner. To address this problem, science simulations can simplify and model these complex systems, so that students can manipulate the variables and see what effects they have on the systems.

For example, the human body is composed of many complex, dynamic and interconnected systems that work together. *The Body as a System* invites students to develop an understanding of how different body systems interact with each other by modeling the effects of increased physical activity on physiological variables (heart rate, respiration rate, body temperature, oxygen consumption and blushing).

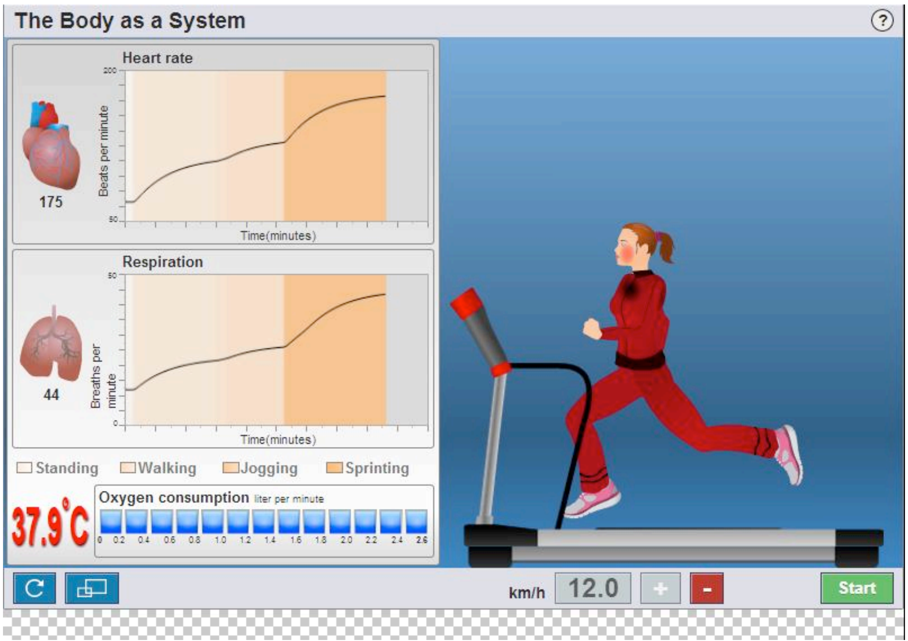

Figure 1. *The Body as a System*. This simulation simplifies the complexity of how different body systems interact with each other.

Making the Invisible Visible through Dynamic Visual Representations

Many scientific concepts are abstract and invisible, which makes these concepts difficult for students to understand. As a result, science learning can become similar to learning vocabulary words in a foreign language, instead of learning-in-context. To address this problem, science simulations can visualize abstract and invisible concepts, in a dynamic way. When students interact with such simulations, they are more likely to understand the underlying concepts.

For example, the concepts of potential, kinetic and thermal energy, as well as the energy transformations between them, are abstract and invisible concepts. *The Energy of a Skateboard Rider* invites students to investigate these concepts by interacting with a skateboard rider and skateboard, which they pull up a ramp before releasing them. The resulting energy types are dynamically represented in a histogram and pie graph. Students can slow down the simulation and/or stop it at will, in order to focus on what is happening (see Figure 2).

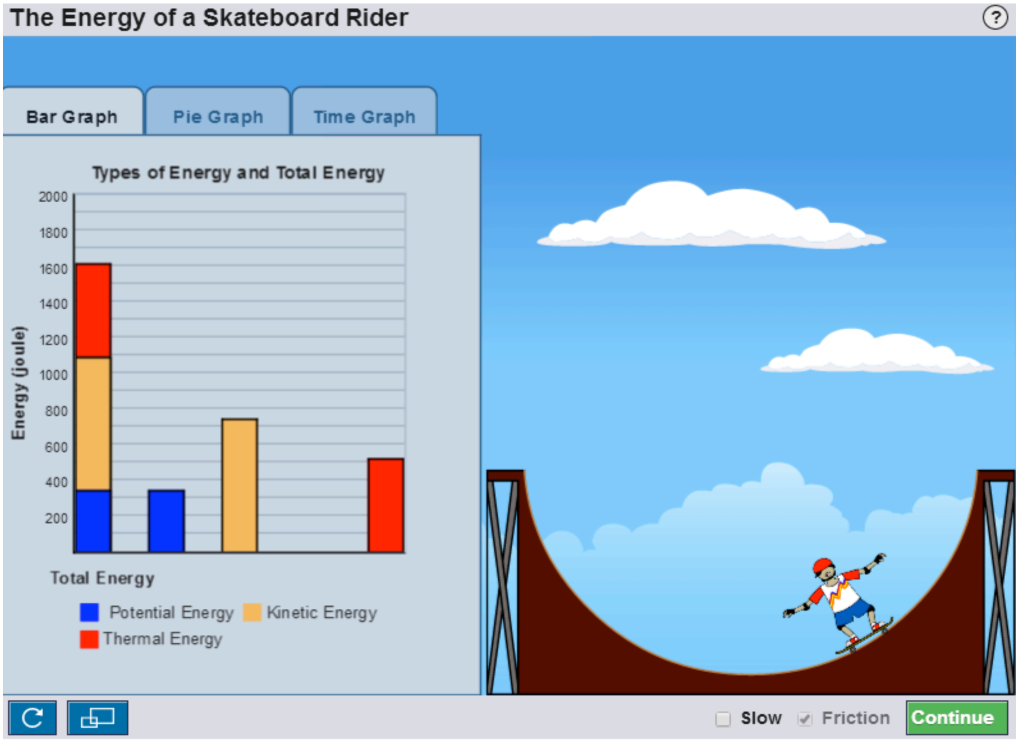

Figure 2. The Energy of a Skateboard Rider. The abstract and invisible concepts of potential, kinetic and thermal energy, as well as the energy transformations between them, are made visible in this app.

Developing Student Inquiry Skills by Active Learning.
Developing student inquiry skills has long been a major goal of science education (Flick & Lederman, 2004). However, educational research has shown that students typically have difficulties in (a) generating hypotheses, (b) designing experiments, (c) interpreting data, and (d) regulating their learning (de Jong & van Loolingen, 1998). The conclusion of this research is that simulations cannot guarantee effective learning without adequate support (also called "scaffolding") for inquiry learning. Science simulations can address this concern by providing contexts for active student inquiry and adequate support for inquiry learning.

For example, students can use the *Pond Food Chain* to investigate basic concepts relating to ecology. Students can change one of more of the population levels in the app (producers, herbivores, predators and top predators) and see what effects this has on the population levels of the other organisms. By making it possible for students to manipulate the relevant variables, this app can help students gain a better understanding of population dynamics as well as develop inquiry skills. Each Experience Science app contains support materials for students, which includes inquiry questions to investigate. The inquiry question for this app is "How can a change in the population size of one species in a food chain influence the population sizes of the other species in the same food chain?" (See Figure 3.)

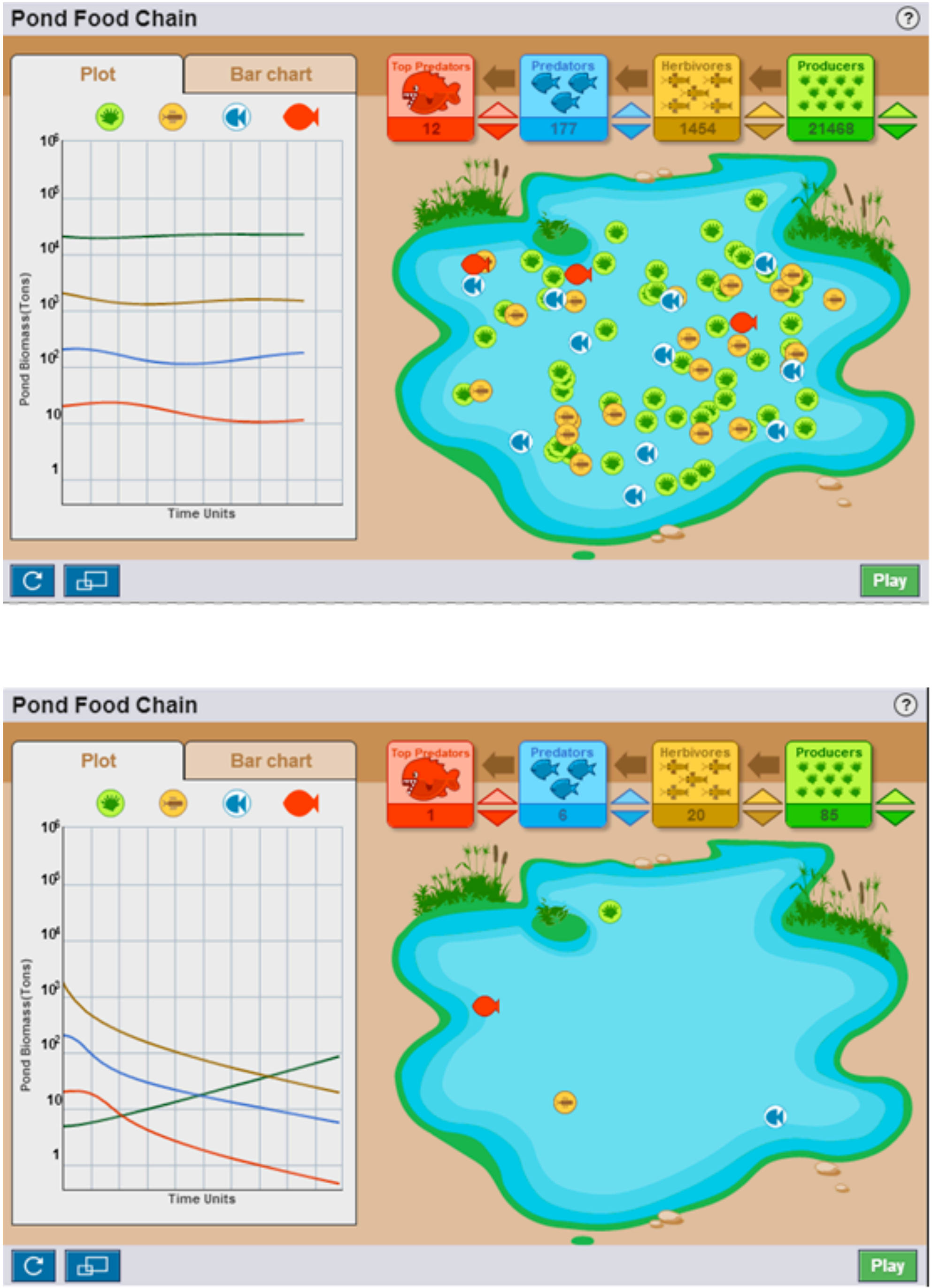

Figure 3. The Pond Food Chain. Students can change population levels, and test the effects of these changes on the ecosystem, in order to better understand population dynamics as well as develop inquiry skills, such as cause-and-effect reasoning. The two screen shots show the food chain before (top) and after (bottom) a decrease in the algae population.

Motivating Students to Explore and Learn Science

Motivation is an essential ingredient for long-term and meaningful learning. As mentioned above, simulations can help develop student motivation to learn science by modeling complex systems, making visible the invisible, and developing student inquiry skills.

In order to make the topic of atomic structure more interesting, *The Structure of the Atom* invites students to build specific atoms and ions of their choice (located in a partial periodic table), by adding or subtracting electrons and protons. After students do so, they receive appropriate feedback. By using this game-like approach, the app turns a difficult topic into a motivating one.

Figure 4. The Structure of an Atom. The game-like approach of building specific structures, and receiving appropriate feedback, turns a difficult topic into a motivating one.

Assessing Student Content Knowledge and Inquiry Skills

One of the challenges of science education lies in the area of assessment. Each of the Experience Science apps contains background information about the relevant concepts, guiding inquiry questions for investigation, as well as 10 thought provoking quiz questions. These questions provide the guidance to students to interact with each app, as well as the means for assessing student content knowledge and inquiry skills.

For example, in *The Energy of a Skateboard Rider* (see Figure 2) the guiding inquiry questions are: "What is the relationship between the skateboard's maximum potential energy, at the beginning of its movement, and its kinetic energy throughout the movement? Is this relationship the same with and without friction? If not, how does the relationship differ?" In the follow-up quiz questions, students are asked more specific questions about the relationship between different types of energy in the simulation, as well as the influence of friction. These questions help students focus on the relevant concepts, when interacting with the simulation. Teachers can use the inquiry questions and quiz questions to promote student learning in small-group work and teacher-led class instruction, as well as to assess student content knowledge and inquiry skills.

Concluding Remarks

In this paper, we have presented the claim that science simulations, designed for cell phones and tablets, can bring the power of science simulations to science learning, both inside and outside of schools. We have argued that such simulations can help students develop (a) understandings of complex and dynamic systems, (b) visualizations of invisible phenomena, (c) inquiry skills and (d) the motivation to learn science. The simulations can also (e) assess student content knowledge and inquiry skills.

In addition the above learning benefits of science simulations, it should be added that as virtual labs, these simulations are more scalable, flexible, portable and affordable than traditional labs (Sutton, 2005).

What are the benefits of using mobile apps as opposed to traditional computer-based simulations? This is a useful question, because it focuses our attention on the specific benefits of mobile apps. Our sense is that this is also an open question. As mentioned above, research has shown that the pedagogical environment of the simulations, the blending of small-group learning with individual learning, and the use of scaffolds and cognitive tools (de Jong, 2006), plays an important role in the educational effectiveness of the simulations. But we suspect that this finding is true for both mobile apps and traditional computer-based simulations. In general, although some recent studies have compared the benefits of mobile apps to traditional pedagogical methods (e.g., Robson & Kennedy, 2013), we are not aware of studies that have compared the benefits of mobile apps with those of traditional computer-based programs. Our intuitions are that the mobile apps are (a) more motivating for students, (b) provide them with a more immediate and tactile experience (and thus are closer to the experience of real-world experimentation), and (c) have greater accessibility to students and therefore are more effective than the same simulations on traditional computer platforms. However, these are conjectures that should be investigated in future research.

Science simulations have been around for over three decades, but their effect on science learning has been limited. Might the age of mobile devices open the doors to a Renaissance of science learning, by providing wide access to the science simulations, as well as the necessary pedagogical tools to help guide students in the inquiry process? Time will tell.

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