Exploring Student Understanding Of Atoms And Radiation With The Atom Builder Simulator

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Abstract. Learning about radiation requires understanding the general structure of atoms, but many college physics students do not have such understandings.[1] In our efforts to develop inquiry based materials on radiation, we have accumulated additional evidence showing that certain students do indeed have substantial difficulties understanding the basic structure and properties of atoms, and that these difficulties impair their understandings of the simplest radiation processes - emission and ionization. This paper reports on our investigations of student difficulties in understanding basic properties of atoms and ionization and radioactivity. We also describe results from a class using a new pedagogical simulator - the Atom Builder - and provide evidence for marked improvement in student understanding.

Keywords: Radiation, Inquiry, Simulator, Student difficulties.
PACS: 01.40.gb, 01.50.ht

INTRODUCTION

The renewed push towards nuclear power is taking place within a populace that is not well informed about radiation. Few college students (who we encountered) can describe the properties and behavior of radiation or even of atoms. Prather uncovered student difficulties with radiation due to incorrect mental models of atoms [1]. When asked to draw a diagram of an atom, only 56% of non-science students in Prather's study drew Bohr-like atoms, and 23% drew atoms that had objects other than electrons orbiting the nucleus. Prather claimed that students' inabilities to correctly identify the locations and charges of parts of atoms influenced their understandings (or not) of the cause and origins of radiation.

To address the radiation literacy gap, we are developing and testing guided inquiry course materials on radiation and radioactivity for a survey-level college course or for high school physics [2] following the CPU model [3]. The content goals include identifying simple properties of radiation (particulate behavior, randomness, the natural background, no contamination by irradiation) and developing theoretical ideas (radiation ionizes atoms, radiation comes from certain nuclei, ionization by radiation causes tissue damage, and others).

In past semesters we noticed students having trouble with theoretical explanations involving atoms. We wondered, "could it be that these students just don't understand atoms?" Our answer is "they don't".

SETTING

The inquiry-based radiation materials are being developed and tested in a survey-level course in a small midwestern university.

The radiation materials currently consist of three learning cycles on different topics. Cycle 1 addresses background radiation, natural vs. man-made radioactive sources, the question of contamination by radiation, and the differences between electromagnetic and ionizing radiation. In Cycle 2 students study the structure of atoms, the interaction of radiation with matter and particularly living tissue, and the nuclear origins of radiation. Cycle 3 focuses on nuclear fission, nuclear power, and nuclear waste. Our research focused on the atom-related aspects of the content in Cycle 2.

The Atom Builder addresses learning problems that arose from trying to teach the causes of radiation and ionization by radiation. It supports inquiry by affording investigation rather than offering explanations. The intent is to allow students to figure out the properties of atoms by doing "virtual experiments" in connection with guidance by documents. It is available at http://www.camse.org/sims/Builder.

DATA AND ANALYSIS

The purpose of our research was to identify students' ideas about atoms and find out whether the Atom Builder simulator makes a difference in learning. Data collected for this project came from classroom discussions and from students' written work. Homework assignments, weekly journals, quizzes, and exams were examined for clues on how students were thinking about atoms and radiation. Notes were taken in class during discussions and group work and we interviewed all the students at the end of Cycle 2.

We targeted six basic learning goals about atoms and radiation. These targets come from issues and topics which seemed to cause difficulties in past semesters. We believe these are necessary to understand radiation.

- T1: Distinguish the parts of atoms - both components and structures
- T2: Identify the element with the number of protons in the nucleus
- T3: Use electrostatic attraction to explain what holds electrons in atoms
- T4: Distinguish atoms from ions
- T5: Distinguish ions from isotopes
- T6: Associate radioactivity with nuclei

Students' Initial Ideas

Students were introduced to general properties of radiation in Cycle 1 of the radiation materials. The observations and measurements were all "macroscopic" in scale - students measured radiation with geiger counters to answer various questions about properties of radiation. Cycle 2 brought up atoms.

T1: At the beginning of Cycle 2 students were asked to *Draw a diagram of an atom, showing what you know about the parts of atom and where these parts are.* We identified the categories in Table 1 from a sample of 16 student drawings in the Spring 2010 course. "Circles" are simply one or more circles with no details offered. "Cell-like" atoms have an outside wall or membrane with atom parts inside (and have been observed repeatedly in previous semesters). Orbital diagrams comprised about 64% of student drawings, but only about 18% of the diagrams were acceptably correct.

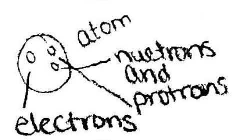
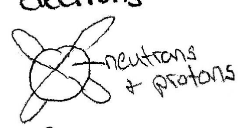
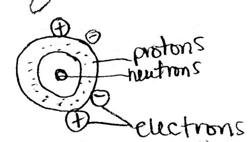
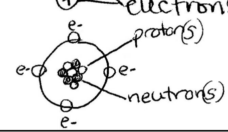
T2: When asked *What determines which chemical element an atom is?* only one student of 17 correctly pointed to protons alone. Two additional students said that the number of protons, electrons, and neutrons determined the element. Four students said that atoms are made of chemical elements. Students were not clear on the meaning of "atomic number".

T3: Students were also asked *What holds the outer and inner parts of atoms together?* Five students offered explanations that could be interpreted as attraction between protons and electrons. Another five wrote something about "bonds", two said that "shells" hold atoms together, and other individuals mentioned "walls" or "gravity".

T4, T5, T6: Specific questions were not asked of students for these targets. But responses on other questions and discussions during the class suggested very low or no understandings of ions, isotopes, or where radiation comes from.

Also, most students did not initially identify electrons as the components that hold molecules together (important in understanding radiation damage), and in fact some were not clear about the differences between "atom", "molecule", or "element", sometimes combining these words with "cell". Many students also believed that it is not possible to change an atom - representing an element - to a new element. However, a few other students believed that the number of electrons determined the type of element. And as the cycle progressed students frequently surmised that ions must be radioactive.

TABLE 1. Categories Of Student Atom Diagrams.

Category and Frequency	Diagram
Circles 3 Drawings	
Cell-like 2 Drawings	
Orbital But Vague 4 Drawings	
Orbiting Non-electrons 4 Drawings	
Reasonably Canonical 3 Drawings	

Developing Atom Ideas

After the Initial Atom Ideas Discussion, students then worked through an inquiry activity utilizing the new Atom Builder simulator [4]. This new simulator allows the user to build and modify atoms/nuclides from hydrogen to rutherfordium. It separates ionization from radiation emission and has additional pedagogical affordances.

The accompanying activity document - the first in Cycle 2 - asked students to build specific atoms and investigate particular aspects of their behavior. During this activity we observed high levels of interested engagement while students talked about the identities, roles, locations, and numbers of protons, neutrons, and electrons in the their atoms. The students spent time playing with the simulator but later demonstrated understanding of atoms. In the Testing World part of the simulator students observed electrostatic attractions and repulsions. During this activity the simulator allowed students to build and test ions but not radioactive atoms.

In their explanations of what holds electrons around the nucleus, most student groups - who had done electrostatic experiments with sticky tape [5] - changed to an electrical attraction explanation when asked why electrons in the simulator were attracted to the atom.

The first use of the simulator, (Activity 2.1) focused on the electron-proton balance (ionization). In a later use of the simulator (Activity 2.5), students studied effects of the neutron-proton relationship (radioactivity). During this second activity, students were able to create neutron-rich or large nuclei and observe radiation emission from their atoms.

Post Assessments

We used quiz & exam responses and student interviews to determine the extent to which students understood the six targeted ideas. Each idea was checked with two to seven indicators from these data sources. To satisfy each learning target a student had to answer satisfactorily on all or all but one of the indicators, most of which required application of knowledge, not just remembering facts. For example, for T4, students were presented with a neutral ^{16}O atom, asked if it was an ion, and asked to show two ways to turn that atom into an ion. On the final exam, students were given a particular combination of p, n, and e, and asked what would be different (or not) with various changes in each number of particles. A quiz question addressed ion behavior, and we included the ionizing question below. Students had to answer 3 of these 4 correctly to be considered meeting the target.

Figure 1 shows the results on indicators before and after Cycle 2 instruction with the Atom Builder simulator. While the majority of students satisfied our target indicators, we note that T5 - distinguishing ions from isotopes - seems to be a pervasive problem. We have seen the same thing in many semesters.

Ionization by radiation is tough for students to understand. An exam question, *What does the word "ionizing" mean in the phrase "ionizing radiation"?* revealed in Spring 2009 that students (who had not used the simulator) did not distinguish between ionization and radiation emission (Fig 2). To answer correctly students must describe ionization of an atom by a radiation particle. Instead, most students wrote about the source atom, and almost no students even mentioned the victim atom. Student responses to the same question on the Spring 2010 exam were much more sophisticated and many more of them clearly distinguished between the radioactive atom and the ionized victim atom. We attribute this difference to student experiences with the Atom Builder.

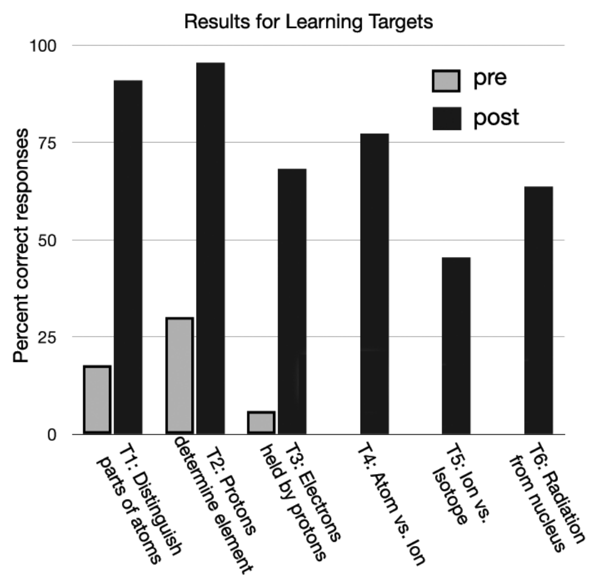


FIGURE 1. Percent Of Students Reaching Learning Targets

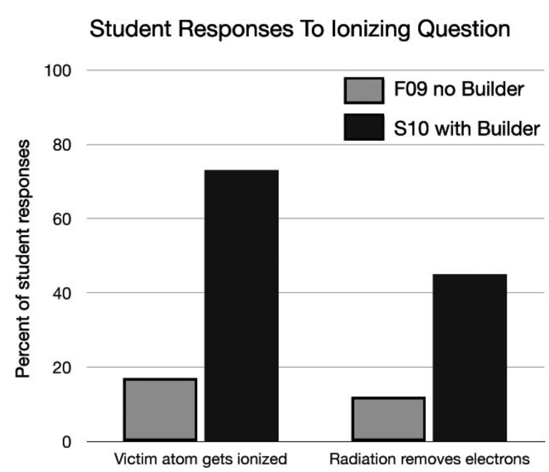


FIGURE 2. Percent Of Students Mentioning Ionization On Ionizing Radiation Question

DISCUSSION

Most Students Entering This Course Didn't Initially Understand Atoms

We believe that although they have been taught about atoms (probably multiple times by the time they arrive at our course) students in our course rarely have been expected to use atoms in formulating explanations. The majority of students in this class do not come to us viable mental models of atoms. Instead they seem to have fragments. Most students' initial explanations were in pieces, vague, or not coherent. Very few explanations were consistent with accepted ideas about atoms. (We have not yet investigated this topic with other groups of students).

Students who lack a working mental model of atoms may find it hard to understand where radiation comes from and what it does to atoms. In order to understand ionization by radiation one must know what an ion is. To understand that radiation comes from nuclei, it helps to know a little about nuclei.

We propose that students who used the Atom Builder more fully answered the "ionizing radiation" question (Figure 2 above) because they simply understood atoms and ionization better. When faced with this question in previous semesters without the Atom Builder, the word "ionizing" appeared to be nothing more than the name of the radiation for many students.

Understanding Atoms Requires Formal Reasoning - Or Concrete Experiences

Because atoms are so small and so far removed from everyday experience, formal reasoning (using Piaget's definition) [6] is required to understand them well. Ideas about atoms are abstract simply because we can't observe or handle them directly. According to Piaget, comparing or relating two abstract ideas requires formal reasoning, and understanding atoms without experiencing them involves multiple abstract ideas. Unfortunately, most college students do not reason formally [7]. Thus one can expect that teaching about atoms will raise severe difficulties. Our solution is to have students investigate representations of atoms through experiences closer to Piaget's concrete level, thus enabling them to understand some of the relationships for the first time.

The Atom Builder Supports Reasoning About Atoms

The Atom Builder simulator supports student reasoning about the atomic realm by providing an environment for concrete interactions with simulated atoms. It seems to fill a need - when our students first encountered the Atom Builder, questions fountained from student groups. We noticed each group spontaneously investigating and often answering questions that came to them. Students used it to investigate their own questions and sometimes figure out answers. (Of course, the guided investigations were helpful as well). The simulator affords a variety of different investigations. Students can decide what experiments to conduct and how to think about the results. Our results indicate that with this support students can develop useful and meaningful understandings about atoms in an inquiry setting.

ACKNOWLEDGMENTS

This project was funded by a Black Hills State University Faculty Development Mini-grant. Thanks to Forest Johnson for vitally important UI and software design and expert coding/production work. Data for the Atom Builder Simulator came from the National Nuclear Data Center website.

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