FOR STUDENTS WITH DISABILITIES
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ISLAND 2021 ARTICLE

Implementing Tactile Learning to Aid Students Understanding of the Bohr Model

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Abstract

It is essential for introductory level chemistry students to understand atomic models and how atoms interact to form chemical bonds. The tactile model in this article utilizes marbles to represent subatomic particles, a cup to represent the nucleus and wooden rings to simulate the electron orbitals. These inexpensive items can be combined to construct models in which students can build foundational knowledge of atomic structure and how subatomic particles interact. Students were asked to provide feedback comparing the use of this tactile model to atomic computer simulations, videos and their textbook regarding the method they felt was most useful to learn atomic structure.

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Background

Definition of Neurodiversity

Neurodiversity is a social ideal based on a biological fact. The human brain is the most complex thing on Earth, and every brain is different. Neurodiversity is about what that should mean. Instead of separating people into normal and abnormal, neurodiversity asks us to accept variation. To us, it means that autism, ADHD, and learning disabilities are valuable forms of humanity that enrich culture. New ideas, insights, and unique ways of viewing the world come from diverse minds. This is a strength. (Center for Neurodiversity, n.d.)

Chemistry students tend to struggle with the abstract nature of the atomic structure because these structures can only be seen with the most powerful electron microscopes.(Netzell, 2014) Instead, models can aid students with visualizing and manipulating challenging microscopic structures. Following the discoveries of JJ Thompson and Ernest Rutherford in the mid-19th and early 20th centuries, respectively, the Bohr atom was developed in 1913 by Niels Bohr.(Neth et al. 2018) There has been some controversy as to whether the Bohr atom should be introduced and emphasized in Chemistry curriculum (for both secondary and postsecondary students), due to the possible misconceptions that can result.(Netzell, 2014),(Georgios Georgios, 2009) Also, there is no agreement on a methodology to teach atomic structure.(Derman et al., 2019)

However, the Bohr atom can be an effective visual teaching aid as long as: 1) it is sufficiently compared and contrasted with other models, particularly the Schro dinger model and 2) limitations and potential misconceptions are identified and explored prior to introducing of the model.(McKagan et al., 2008) The Bohr model can also be used to help students make predictions about chemical behaviors.(Derman et al., 2019)

A tactile Bohr atom model, made of marbles and inexpensive wood, allows students to visualize atoms isotopes and ions as large as neodymium with 60 electron divots within the same inclusive model.

Likely due to the rise in popularity of computer-generated models, there are few physical model kits that can be used in the classroom to teach the Bohr model in a tactile way.(Smiar Mendez, 2016) One study shows how 3D printed models of the Bohr atom can be created.(Smiar Mendez, 2016) 3D printing can be time consuming and limited to one atom at a time. The model kit presented herein is similar to others utilizing household materials to represent various chemical concepts, such as the octet rule(Lin et al., 2018) and periodicity (in the periodic table)(Melaku et al., 2016).

Demonstrated use of models can help students gain an understanding of how scientists practice their thought-processes.(McKagan et al., 2008) Models have also been shown to increase communication and boost student understanding of complex scientific concepts.(Harrison Treagust, 2000) The simplicity of this model and the way in which it gives students the ability to physically manipulate it themselves (with explicit instructions) can decrease cognitive load. Decreasing cognitive load can lead to enhanced learning, especially for students with learning differences.(Carlson et al., 2003) Students with language disabilities can also greatly benefit from the incorporation of visual and tactile models. (Hudson, 2017)

The model presented in this article shows a multimodal approach where students are able to use the Bohr atom to: 1) manipulate the model using tactile functionality, 2) demonstrate

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their understanding by drawing the models they have created and 3) engage in dialogue with the instructor and their peers.

Inspiration and Development

Cynthia Tolman, the developer of the hands-on Bohr model, was inspired to create this model to provide students with a three-dimensional tool. The idea for making the models three-dimensional rather than flat allows the lower energy levels to be physically lower, showing that excited electrons "fall" to a lower energy level when they re-emit their excess energy as light. The first model was made from Styrofoam which was cut by hand into rings with an exacto knife, shown in figure 1. The Styrofoam was messy to work with and took a long time to cut through with the tools available. A second attempt using cardboard was easier to make but too flimsy for classroom use, shown in figure 2. The final design uses a CNC milling machine with "Easel" software from Inventables. The design can be cut in wood or plastic and multiple models can be cut fairly quickly. The base is three stair-step blocks upon which the rings are glued or screwed. A plastic cup fits into the center ring to represent the nucleus and as in the previous designs, colored marbles represent protons, neutrons and electrons.

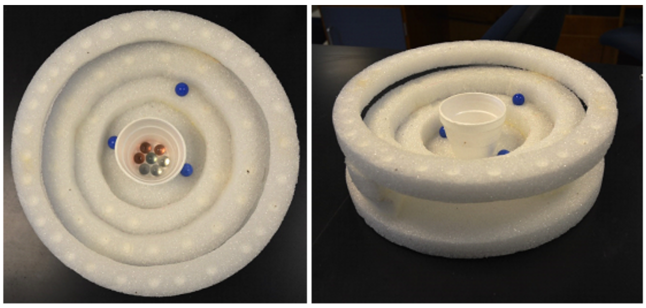

Figure 1: Second iteration of the hands-on Bohr model using Styrofoam and colored marbles.

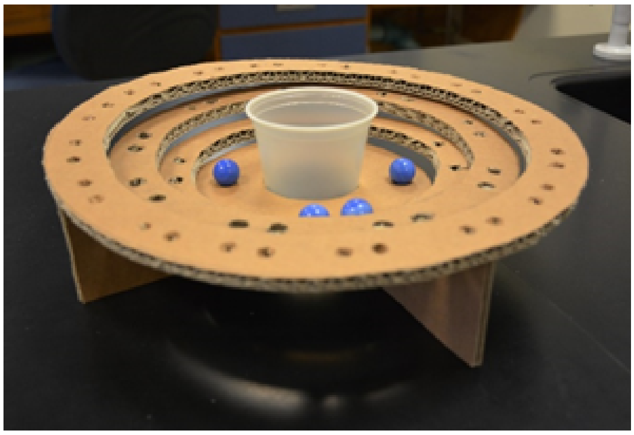

Figure 2: Third iteration of the hands-on Bohr model using cardboard and colored marbles.

Uses of the Model

Representing Subatomic Particles

Having a general understanding of the structure of the atom is critical to understanding central chemical concepts. The proper placement and understanding of how subatomic particles (protons, neutrons, and electrons) are related to one another in the atomic model is essential to understanding how and why ions form and the mechanics involved in the formation of ionic compounds. The microscopic nature of subatomic particles prevents their direct observation which can be a challenging for students who thrive with visual and tactile learning.

In this model, each subatomic particle is represented by a different colored marble (protons: pink, electrons: blue and neutrons: clear). Students are initially instructed to build a hydrogen atom and a deuterium atom placing proton(s) and neutron(s) in the central cup representing the nucleus and electron(s) in the outer rings that surround the nucleus, as shown in Figure 3.

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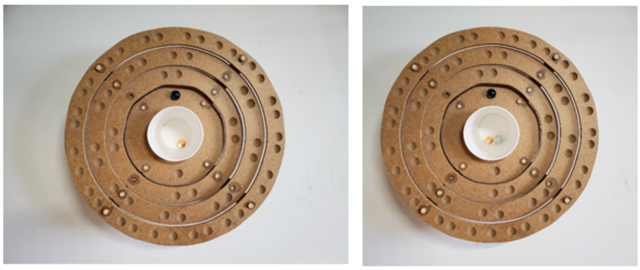

Figure 3: Two isotopes of hydrogen. Left: protium and Right: deuterium. Marbles represent subatomic particles. Blue represents electrons, pink represents protons and clear represents neutrons.

Ions vs. Isotopes

Understanding how changing the numbers of different subatomic particles affects the identity of the element is often challenging for students, especially when differentiating between ions (modifying the number of electrons) and isotopes (modifying the number of neutrons). Students can be asked to change the number of protons, neutrons and electrons using this model. Changing the number of protons changes the identity of the atom, and keeping the protons in the nucleus (central cup) visually demonstrates that gain/ loss of protons is very unlikely. Changing the number of neutrons in the nucleus leads to the formation of a different isotope, but this is another process that does not commonly happen. Electrons, that surround the nucleus, are the easiest subatomic particle to add/ subtract and the removal/ addition of electrons is the only way to change the overall charge of the ion. If the total protons and electrons are not equal, the atom is either positively charged (cation) or negative charged (anion).

Ion Formation Examples

Ions form to attain stable (electron) configurations by gaining or losing of electrons. After students are introduced to the concept of valance electrons and stable electron configurations, they can use the models to predict chemical behaviors. For example, the types of ions that would form to attain the most stable electron configuration. This model allows students to use visual cues to observe how electrons surround the nucleus. Figure 4 shows a lithium atom in comparison to a lithium ion. When students observe the lithium atom, they work through the process of determining how best to achieve a stable electron configuration, either removal of 1 electron or addition of 7 electrons.

Figure 4: Comparison of a lithium atom (left) to a lithium ion (right).

Quantization and Atomic Spectra

The concept of quantization (the idea that electrons can only absorb and emit certain energy levels and discrete energy levels) can first be introduced by showing the atomic spectra of various elements to students. Each element has a unique atomic spectrum, and each element has a unique distribution of electrons. In the Bohr model, there are specific locations where electrons can be located surrounding the nucleus, and this helps students grasp the quantization concept. In the model, there are divots on each energy level (circle surrounding the nucleus) that hold the electron marbles and represent the locations that electrons can occupy. The limitation of introducing quantization in this model is that all energy levels surrounding the nucleus are distributed evenly, but, the energy levels that surround the nucleus are not evenly distributed. This is a limitation that

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needs to be clearly stated as students are introduced to this concept. This can also be connected to atomic orbitals and the idea that no two electrons can occupy the same space. In this model, all energy levels are distributed evenly around the nucleus which is helpful conceptually but does not represent true electron distribution. This limits the introduction of quantization and requires an explicit explanation.

Excited vs. Ground States

The Bohr model can also be used to teach students to visualize the differences between an excited state vs. a ground state electron configuration. Students are first introduced to the idea that it takes energy to move negatively charge electrons away from the positively charged nucleus, because opposite charges attract. When enough energy is put into the system it will excite an electron, and it will move into a higher energy level (farther from the nucleus). As this concept is introduced it is again helpful to show students the atomic spectra of an element, so they can try to connect the unique spectra observed to the allowed excited states for a given element.

Assessment of Student Learning

This model has been used with both introductory biology and introductory chemistry students. Student learning was assessed by having students draw the Bohr models for at least three of the atoms they were asked to create. It has been shown that drawings are an effective way of determining students strengths and weaknesses in learning.(Gunstone, R. F., White, 2000) Students can also be provided with a premade drawing for them to fill in the proper placements of electrons. To assess student understanding of prediction of chemical properties, students were asked to use the model to identify valance electrons and whether the ion donates or accepts electrons to form a stable electron configuration. During these exercises, instructors are encouraged to circulate throughout the room to provide feedback to students as they place the marbles and fill in the written handout to represent the assigned atom.

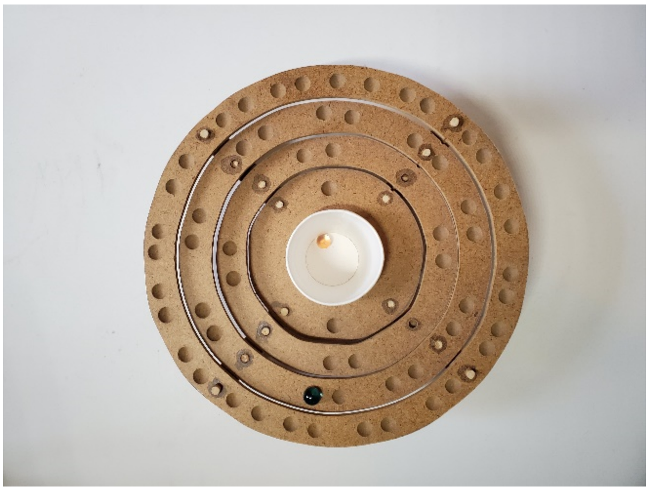

Figure 5: A hydrogen atom in an excited state.

Response from Students

All procedures and materials were approved by a college IRB.

All students that were asked to participate in the Likert style survey (see Appendix) have been diagnosed as neurodiverse, as previously defined. Students were asked in class to complete a written survey. Of the 24 students in the class, 15 (63 % response rate) participated in the survey. The results of the 26 Likert scale sets of questions are summarized in Figure 6. Students found the hands-on model and computer simulations to be beneficial, with 74-77 % of respondents "strongly agreeing" or "agreeing" that the resources were helpful. Only 60 % of respondents found reading assignments help-

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ful. By a large margin, more students (30 %) strongly agreed that the hands-on model was useful, compared to 15 % for computer simulations and 14 % for reading assignments. 87 % of respondents either agreed or strongly agreed that having access to all three resources would be their choice. 100 % of respondents agreed or strongly agreed that the hands-on Bohr model helped them understand atomic structure.

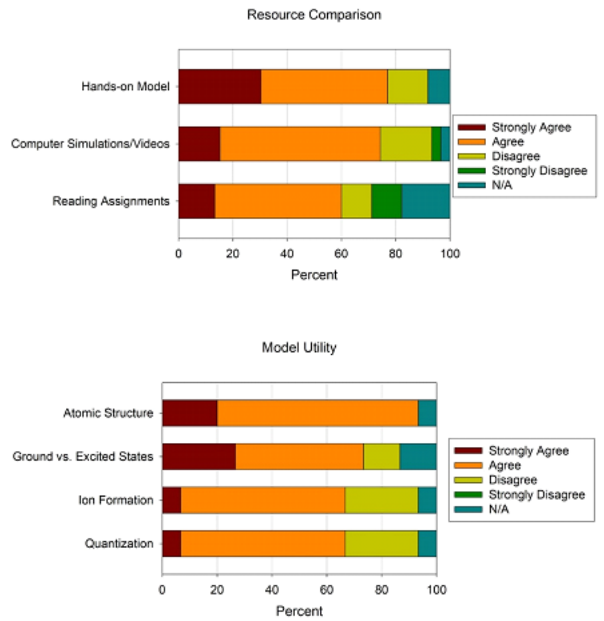

Figure 6: Responses to survey questions given as the fraction of respondents selecting each Likert scale rating (participation count n=15). The top graph represents a summary of student responses assessing the usefulness of each teaching method to their learning style. The bottom graph represents responses to assess the usefulness of the hands-on Bohr model for each of the listed categories.

Future Directions Response

The Bohr atomic model discussed in this paper was presented at the 2015 Annual Flipped Learning and the 2021 Inclusion in Science Learning in a New Direction (ISLAND) conferences, where it received positive feedback and comments. Some of the feedback related to expanding the sensory experience for students utilizing the Bohr model. Currently, ideas of etching the marbles are being considered to incorporate the sense of touch into the learning experience. This would also allow for students with visual impairments to benefit from the model. Figure 7 shows some initial ideas of how the marbles would be modified. Blue marbles, which depict electrons, would remain unchanged, for two reasons: 1) the marbles representing the electrons must be able to fit into the grooves of the atomic structure and 2) electrons are typically depicted as spheres or circles in textbooks, so the goal is to be as consistent as possible with traditional textbook depictions. Pink marbles (representing protons) could be etched through the center of the marble, or have two perpendicular rings that are etched into the marble, as depicted in figure 7a. The perpendicular etches resemble a "plus sign", which would make it easy for students to associate the crossed-etched marbles with protons. Colorless marbles (representing neutrons) could have two or four sides etched, show in figure 7b. Each side would have a circular flat edge, resembling a zero. The circular flat edge would help students associate the marbles with the neutral (net zero) charge of neutrons.

Conclusions

This article demonstrates that a tactile and manipulatable Bohr atom model can aid students with of visualizing microscopic subatomic particles. This model can be used with students of diverse learning styles to understand a variety of concepts including: 1) subatomic particle placement in the atom, 2) distinguishing between ions and isotopes, 3) relating quantization to atomic spectra and 4) distinguishing between ground and excited states of atoms and ions. Overall, the student surveyed felt they learned best using either computational models

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Figure 7: Etch patterns for proton (middle; represented by pink marbles that have single or double perpendicular etching around the center of the marble) and neutrons (right; represented by colorless marbles with circular flat edges on each side of the marble). Electrons (left; represented blue non-etched marble).

or the hands-on model to reading assignments. Based upon the data, using a universal model, where students are exposed to multiple methods for teaching the Bohr model appears to be the most beneficial, based upon student feedback.

Acknowledgements

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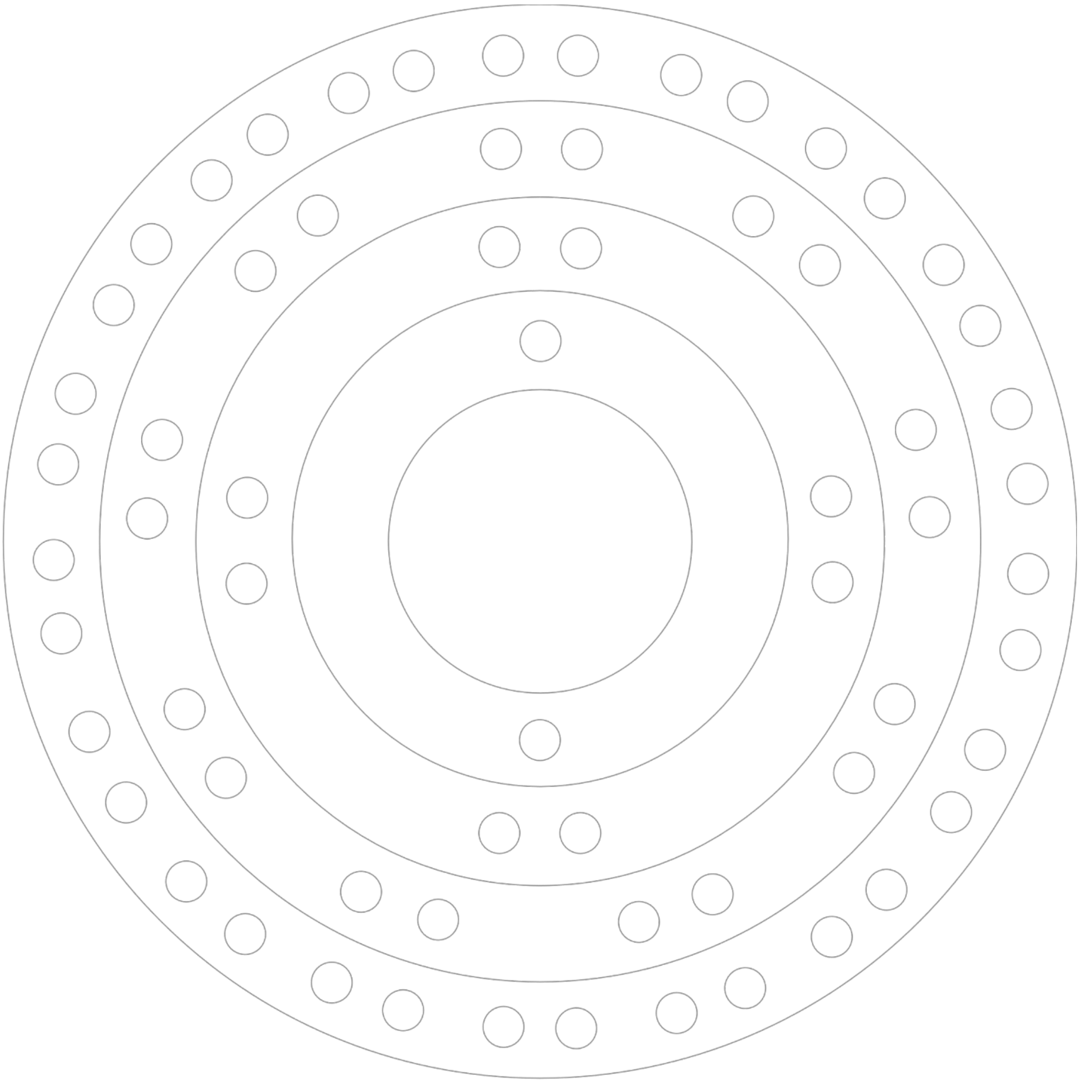
Supplementary Information

CNC Patterns

Material type: Two-Color HDPE
Material dimensions: 12 in x 12 in x 0.25 in
Bit: 0.125 in, Straight cut



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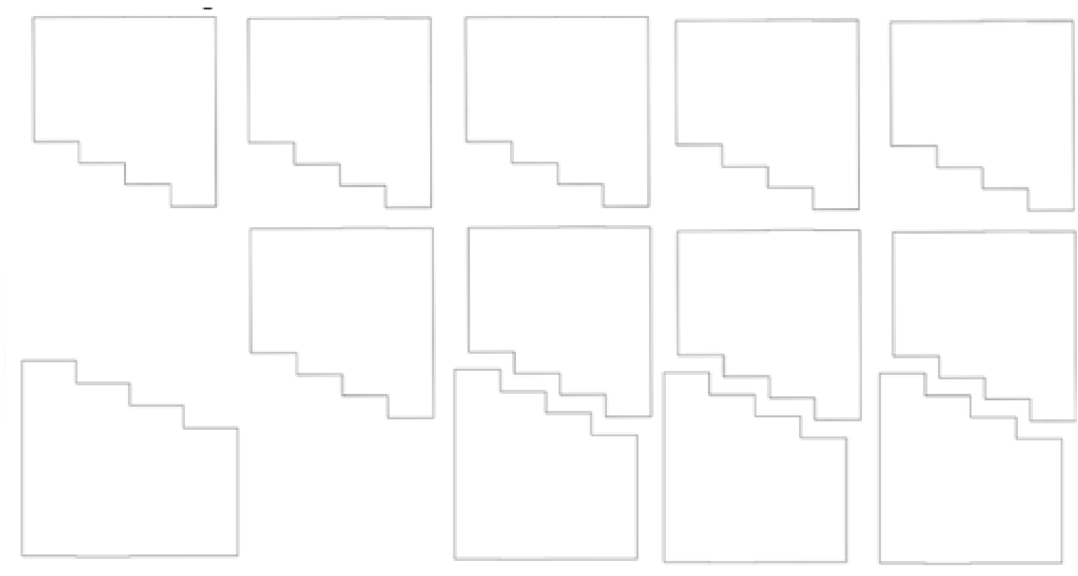

One-Color HDPE
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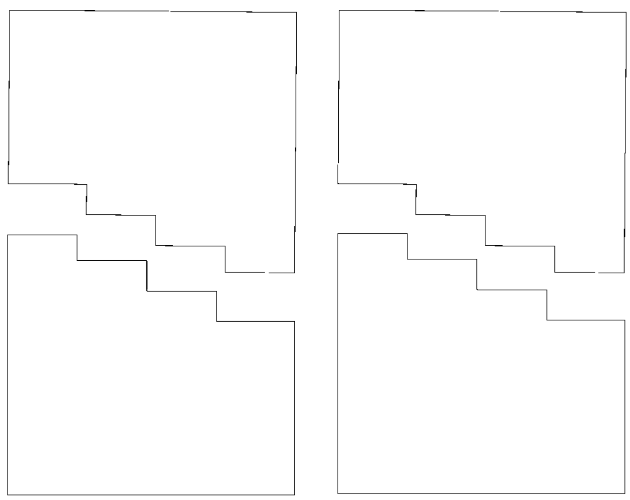

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Student Consent Form

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DESCRIPTION OF STUDY *M*y name is Dr. Christin Monroe and I am a Visiting Assistant Professor of Chemistry at Landmark College. I am conducting a study with the purpose of comparing the use of tactile learning techniques vs. computer simulations for learning about atomic structure. I am asking for your voluntary consent to complete a single survey that should last no longer than 15 minutes. The goal of this study is to understand which techniques are more meaningful for students learning about atomic structure, not to evaluate your abilities.

SURVEY

If you agree to participate, after the completion of the atomic structure component of Introduction to Chemistry or Principles of Chemistry I/II you will be asked to take a short survey that will last no longer than 15 minutes that will ask you to compare computer simulations about atomic structure to the hands-on Bohr model. All surveys will be submitted anonymously. You will only be asked to compare the two types of learning with your own learning style.

RISKS

There are no known risks to participating in this study.

BENEFITS

Your feedback will contribute to the academic conversation regarding how the atom is taught in the undergraduate chemistry classroom. If you are interested, you will be provided access to the final report once this study has been completed and documented. **CONFIDENTIALITY** All data collected in this study will remain confidential, and all person-identifiable data (e.g. IP address tracking) will disabled so you cannot be personally identified. Data from this study will be kept in a password protected account in SurveyMonkey or in a locked file cabinet in a locked room until it is destroyed. Data will not be retained for more than 5 years.

PARTICIPATION

Your participation is voluntary, and you may withdraw from the study for any reason at any time. There is no penalty for withdrawing from the study or choosing not to participate.

CONTACT

This study is being conducted by the History Department at Landmark College. The lead evaluator is Dr. Christin Monroe, who can be reached by calling 802.387.1640, or by email at (christinmonroe@landmark.edu).

If you have questions about the research process or your rights as a human subject, please contact Dr. Adam Lalor, Chair, Institutional Review Board of Landmark College, at 802-387-6735 or https://intranet.landmark.edu/research-office/irb.cfm.

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CONSENT

I have read this form and indicate my decision to participate or not participate as follows: __I am 18 years old or over

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___I agree to participate in this study.

___I do not agree to participate in this study.

Signature: ______________________ Date: ______________________ Print name: ______________________

I have read this form and indicate my decision to participate or not participate as follows:

___I am 18 years old or over

___I **agree** to participate in this study.

___I **do not agree** to participate in this study.

Signature: ______________________ Date: ______________________ Print name: ______________________

Likert Student Questionnaire

Material type: One-Color HDPE
Material dimensions: 24 in x 12 in x 0.5 in
Bit: 0.125 in, Straight cut

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		Strongly Agree	Agree	Disagree	Strongly Disagree	Neither or N/A
1.	I find it easy to visualize microscopic concepts (ie, cells, atoms, chemical reactions) when using text and computer simulations.	4	3	2	1	0
2.	After reading the textbook, I felt I had a strong understanding of atomic structure.	4	3	2	1	0
3.	I find computer simulations make it easier to understand microscopic concepts.	4	3	2	1	0
4.	If given a choice, I would prefer to use hands-on activities to learn about microscopic concepts.	4	3	2	1	0
5.	I do not feel that I can fully understand a microscopic concept unless the lesson involves a model that involves tactile learning techniques.	4	3	2	1	0
6.	If given a choice, I would prefer to use computer simulations to learn about microscopic concepts.	4	3	2	1	0
7.	After watching videos I felt I had a strong understanding of atomic structure.	4	3	2	1	0
8.	I find that hands-on activities make it easier to understand microscopic concepts.	4	3	2	1	0
9.	If given a choice, I would prefer to use all three (text, hands on activities and computer simulations to learn) about microscopic concepts.	4	3	2	1	0
10.	Before using the computer simulation I understood atomic structure.	4	3	2	1	0
11.	After using the computer simulation I understood atomic structure.	4	3	2	1	0
12.	Before using the hands-on Bohr model I understood atomic structure.	4	3	2	1	0
13.	After using the hands-on Bohr model I understood atomic structure.	4	3	2	1	0
14.	The computer simulation helped me to understand how ions form.	4	3	2	1	0
15.	The hands-on Bohr model helped me to understand how ions form.	4	3	2	1	0
16.	Before using the hands-on Bohr model I understood how subatomic particles (protons, neutrons, electrons) were placed around the nucleus.	4	3	2	1	0
17.	I learn best when a variety of techniques are combined to teach microscopic concepts.	4	3	2	1	0
18.	Before using the hands-on Bohr model I understood the concept of quantization.	4	3	2	1	0
19.	I find I learn best when working with models using my hands.	4	3	2	1	0
20.	After using the hands-on Bohr model I understood the concept of quantization.	4	3	2	1	0
21.	I find I learn best when watching videos.	4	3	2	1	0
22.	Using the hands-on Bohr model helped me to understand the difference between ground and excited states.	4	3	2	1	0
23.	I find I learn best when reading the textbook.	4	3	2	1	0
24.	I find I learn best when doing computer simulations.	4	3	2	1	0
25.	I find microscopic concepts easier to understand when I have a hands-on model that allows me to visualize the concept.	4	3	2	1	0
26.	I find it challenging to learn concepts taught on the computer (such as interactive videos and simulations).	4	3	2	1	0
27.	Before using the hands-on Bohr model I DID NOT feel that I understood atomic structure.	4	3	2	1	0

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