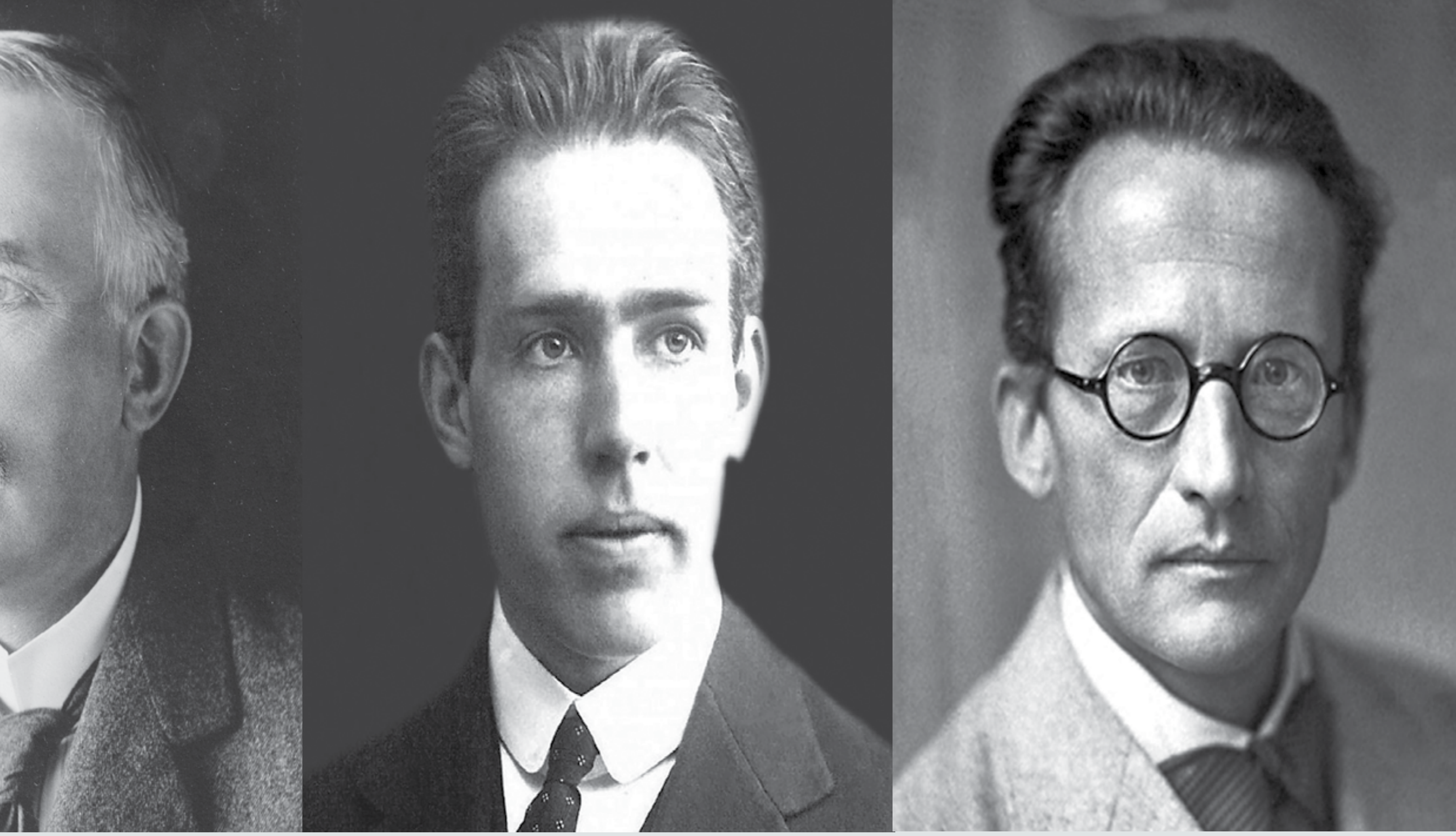
Short-Form Science

A "close reading" unit on the history of the atom

Beth Murphy, Melissa Hedwall, Andrew Dirks, and Elizabeth Stretch

Close reading is the practice of investigating a short (ranging from one or two paragraphs to three pages) piece of high-quality text. The text should be complex enough to be worthy of multiple readings and sufficiently supportive of learning goals (Brown and Kappes 2012, p. 2). In this article, we share a lesson plan and strategies that we used to implement close reading in a physical science class. Students spanned a wide range of reading ability, including multilingual learners.

Close reading is an effective core practice for engaging deeply with text. Characteristics of close reading include (Brown and Kappes 2012, p. 3):



- Multiple readings: This often occurs over multiple class periods. Teachers can model active reading and students can read independently, in pairs, or in small groups (Frey and Fisher 2013, pp. 33–38).
- Annotation: Students use text-marking strategies to note unknown words or phrases, important ideas, connections to prior knowledge, and questions.
- Text-dependent questions: Teachers can use these to guide students in making meaning of what they read (for online guides for writing questions, see “On the web”).
- Writing and discussion: Discussion is critical to student understanding. Students should reference the text to support their claims and arguments (Fisher et al. 2015, pp. 26–27; Frey and Fisher 2013, Chapter 3).

Close reading requires science students to engage text in new ways and teachers to model best practices and gradually transfer responsibility. Teachers can remove scaffolds at their discretion, based on individual student needs, as students may understand close reading practices at different rates—even if they are investigating the same text. Examples of teaching strategies to enable differentiation include

- The teacher works with a group of struggling readers to guide and model close-reading practices while other groups work independently.
- Assigned reading pairs annotate together while taking turns reading aloud.
- Based on each student group’s level of understanding, groups receive different text-dependent questions of varying complexity. After each group answers its questions, students rearrange into mixed groups to share their responses and discuss other questions with classmates.

Selecting text is a complex process. Many factors contribute to a text’s difficulty level (Frey and Fisher 2013, p. 9; see “On the web”). Factors that make scientific text complex include vocabulary and technical language, prior knowledge demands, and the norms of scientific communication. Texts for science also include data tables, graphs, and scientific illustrations.

Atomic structure unit

Students often turn to Wikipedia for information; however, even though this information is easily accessible, students have a difficult time understanding it. For this reason, we chose to revamp our existing atomic structure unit to incorporate modified Wikipedia readings (see “On the web” for a list of articles) about key developments in the understanding of atomic structure. The revised five-day unit centers on close reading about the work of John Dalton, J.J. Thomson, Ernest Rutherford, Niels Bohr, and Erwin Schrödinger. To reinforce the learning that students gain through reading, we also incorporate demonstrations, interactive games, and mini lectures.

John Dalton: Day 1

Teachers first use John Dalton’s drawings of atoms and molecules (Figure 1, p. 36) to lead the class through the Critical

Response Protocol. Critical response is an arts-based technique for engaging students in equitable and critical discourse (Ellingson et al. 2016). The complex visuals can elicit important insights and support the *Common Core State Standards* (*CCSS*) for literacy in science (NGAC and CCSSO 2010). Important characteristics of the Critical Response Protocol are that teachers ensure that all students contribute, document all student responses, and encourage students to engage with the visual without the teacher front-loading information. Five successive teacher prompts ask students to:

John Dalton

1. share observations without judgment or inference,
2. explain what the visual reminds them of,
3. describe how it makes them feel,
4. ask what questions it raises, and
5. infer the intended meaning or understanding.

In our classrooms, critical response lays the foundation for future classroom discourse, reinforcing the importance of curiosity, observation, uncertainty, attention to detail, and the fact that there isn't always a single right answer. (Note: See Ellingson et al. 2016 for a thorough description of the Critical Response Protocol in the high school science classroom.)

Next, we perform a "think aloud" using a Wikipedia entry about John Dalton (see "On the web"). A think aloud is a strategy for modeling active reading for students (Frey and Fisher 2013, pp. 33–35). While the teacher models, students can practice annotating on their own copy. Tips for effective think alouds (Frey and Fisher 2013, p. 34) are:

- choose a short piece of text;
- plan the teaching points of the text in advance;
- use an informal, conversational tone and keep the think alouds authentic;
- think like a scientist; and
- name the strategies as you read (e.g., connecting to prior knowledge, using context clues to infer the meaning of an unknown word, and explaining your annotations).

Students follow up the think aloud with independent reading, working on teacher-provided, text-dependent questions in pairs (see "On the web" for a link to the "History of the Atom" worksheet), and discussion.

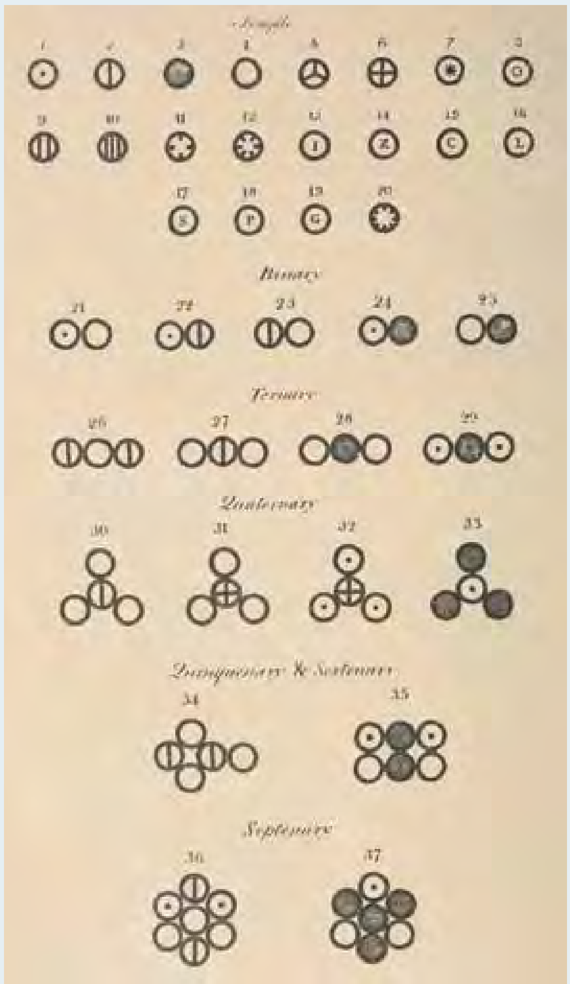
Days 2–5

Over the remaining four days of the unit, students explore the work of Thomson, Rutherford, Bohr, and Shrödinger—one scientist per day. We followed the steps listed below on each of the four days, progressively removing scaffolds and releasing responsibility for reading to students.

1. Students read independently.
2. Students reread and annotate—circling words or phrases they don't know, underlining important information, and marking passages they have questions about with a "?" and then writing the corresponding question in the margin. During this time, the teacher walks around the room to observe what students annotate. When students are first learning close-reading strategies, an annotation key, such as the one described above, helps students mark the text.

FIGURE 1

John Dalton's model for atoms and molecules used for the Critical Response Protocol (Dalton 1808).



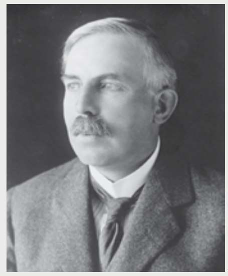
3. Teachers conduct think alouds to address vocabulary, important ideas, and questions informed by observations made while students were annotating.
4. Students read one last time, answering teacher-provided, text-dependent questions (see "On the web" for a link to the "History of the Atom" worksheet). Students can answer questions independently or in pairs or small groups. Discussion follows—in pairs, small groups, or as a class.

As students gain experience, teachers can remove scaffolds to shift responsibility for employing close-reading strategies, encouraging students to become skilled, independent readers.

J.J. Thomson

Each day of the unit also includes demonstrations, interactive games, or mini lectures to reinforce concepts. These supplemental activities reinforce understanding developed through reading. Sometimes, through reading, students generate questions that these activities help to answer; other times an activity motivates students to go back to text.

Day 2: J.J. Thomson



Ernest Rutherford

Students apply close-reading practices to Wikipedia excerpts on J.J. Thomson and his plum pudding model for the atom (see "On the web"). Students complete the related text-dependent questions on the "History of the Atom" worksheet (see "On the web"). Afterward, the teacher performs a demonstration with a cathode ray tube to engage students more deeply in the evidence that led Thomson to his model (Figure 2). Students may engage with text more quickly than expected, connecting to prior knowledge and asking questions.

Day 3: Ernest Rutherford

On Day 3, students apply their reading strategy to the Wikipedia excerpt about Rutherford's work (see "On the web") and complete the appropriate worksheet section. Teachers can

FIGURE 2

Activities and guiding questions to supplement reading on each scientist.

Thomson activity:

Cathode ray tube demonstration

Cathode rays result when a high voltage is applied to a vacuum tube. J.J. Thomson discovered that electric and magnetic fields bend the ray, which led him to discover that cathode rays are made up of electrons with a mass-to-charge ratio much smaller than that of a hydrogen atom (ion).

Safety note: Students should not handle cathode ray tubes, and teachers should have proper training before handling. Videos of this demonstration are available online (see "On the web.")

Thomson guiding questions:

- Why did Thomson believe that the cathode ray was made up of charged particles?
- Why did he believe that the particles in cathode rays are smaller than atoms?

Rutherford activities:

Black box experiment

One-foot-square boards with various wood shapes glued to them are set upside down on a table, obscuring the shapes. Students roll marbles under the board from various angles and observe how they exit to infer the shape, size, and location of the hidden wood pieces.

Military tank dramatization

Teacher performs a dramatization of Rutherford's quote to help students appreciate how surprising it would be to fire a tank shell at a piece of paper only to have it bounce back: "It was almost as incredible as if you fired a 15-inch shell at a piece of paper and it came back and hit you."

Rutherford guiding questions:

- How is the black box experiment similar to Ernest Rutherford's experiment?
- How did evidence lead Rutherford to his model of the atom?

Bohr activities:

Flame test

The teacher heats lithium chloride, sodium chloride, and strontium chloride in a burner flame, producing different colors, reinforcing the concept of electron energy levels.

Niels Bohr game

- Students draw cards to move "electron" game pieces up or down energy levels on a playing board, similar to in the game Sorry.

Bohr guiding questions:

- Why do different substances give off different colors when heated?
- How are these findings consistent with Bohr's model of the atom?

supplement the reading with a dramatization and a black-box activity (Figure 2) to demonstrate how one can infer the internal structure of something by controlling inputs and observing outputs.

Niels Bohr

Days 4 and 5: Niels Bohr and Erwin Schrödinger

On the fourth and fifth days of the unit, students read Wikipedia excerpts (see "On the web") about the work of Bohr and Schrödinger, using the same close-reading processes. Teachers can supplement these lessons with activities that reinforce the concept of quantized energy levels in atoms (Figure 2, p. 37). Figure 3 shows a sample of a completed student worksheet.

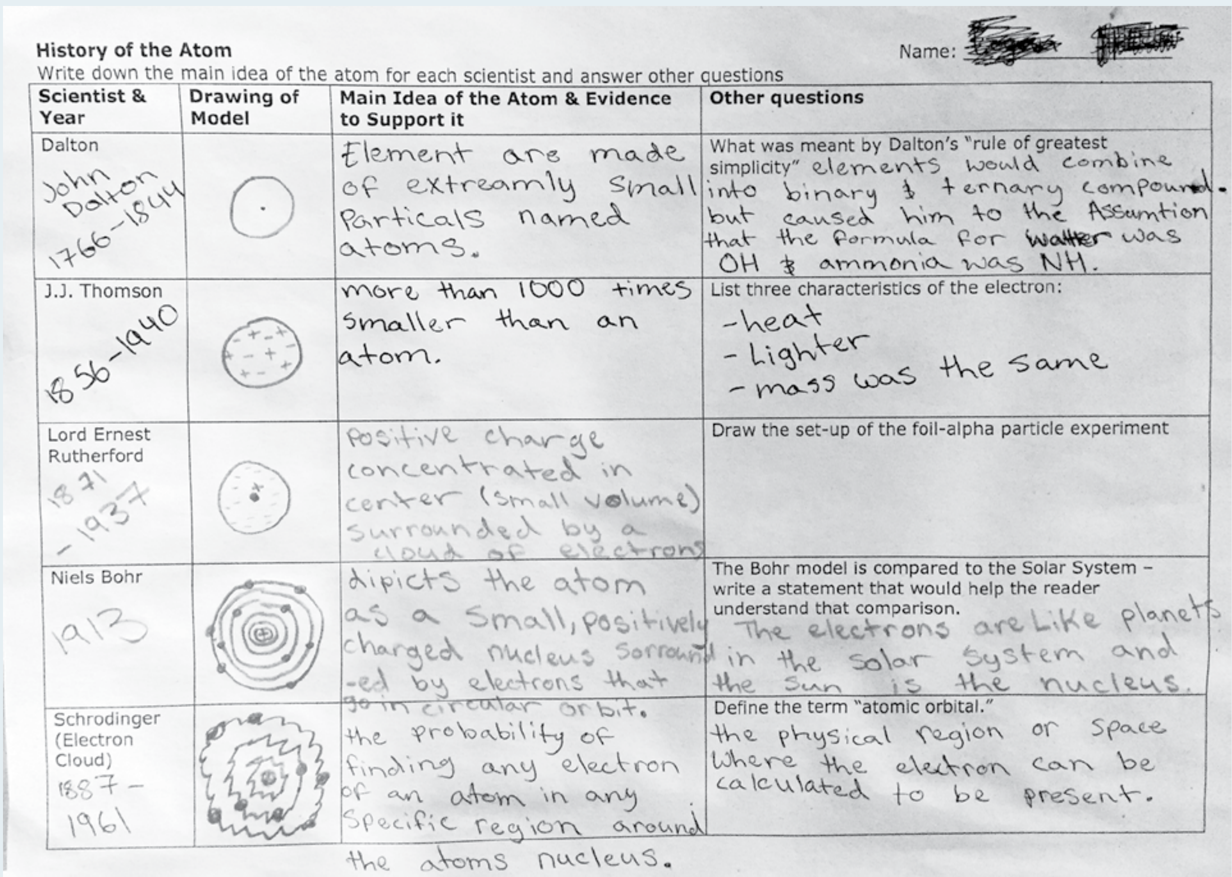
Summative assessment

We discovered that, with the addition of reading to the unit, our typical end-of-unit test was no longer appropriate. Thus, we have converted a timeline assignment our students completed this year in small groups (Figure 4) into a summative assessment (see "On the web" for a link to this assessment with new instructions and a scoring rubric). Although this assessment has not yet been tested with students, it has been vetted and improved by science teachers familiar with close-reading practices. In our classrooms, students will complete this summative assessment in pairs, however, some teachers may find it appropriate for students to do the assessment individually. Another option for differentiation, or for a more advanced class, is to ask students to write an essay about the practice of science that illustrates how scientific understanding generally develops in incremental steps, incorporating new evidence that builds on and challenges accepted models and theories, based on and citing specific examples from their readings on the history of the atom.

FIGURE 3

"History of the Atom" worksheet completed by a student.

Each row includes questions for students to answer about the work of each scientist in conjunction with close reading of text.



History of the Atom Name: [redacted]

Write down the main idea of the atom for each scientist and answer other questions

Scientist & Year	Drawing of Model	Main Idea of the Atom & Evidence to Support it	Other questions
Dalton John Dalton 1766–1844		Element are made of extreamly Small Particals named atoms.	What was meant by Dalton's "rule of greatest simplicity" elements would combine into binary & ternary compound. but caused him to the Assumtion that the formula for ~~walter~~ was OH & ammonia was NH.
J.J. Thomson 1856-1940		more than 1000 times smaller than an atom.	List three characteristics of the electron: -heat - Lighter - mass was the same
Lord Ernest Rutherford 1871 -1937		positive charge concentrated in center (small volume) surrounded by a cloud of electrons	Draw the set-up of the foil-alpha particle experiment
Niels Bohr 1913		dipicts the atom as a Small, positively charged nucleus Sorround-ed by electrons that go in circular orbit.	The Bohr model is compared to the Solar System – write a statement that would help the reader understand that comparison. The electrons are Like planets in the solar system and the Sun is the nucleus.
Schrodinger (Electron Cloud) 1887 – 1961		the probability of finding any electron of an atom in any Specific region around the atoms nucleus.	Define the term "atomic orbital." the physical region or Space Where the electron can be calculated to be present.

Reflections and findings from action research

Andrew Dirks (third author) asked one of his students how she liked reading in her science class. She answered, "This is more fun than labs. I'd rather do this." He was surprised and asked her to clarify. She responded, "When we read it on our own, and then you read it, and then we talk about it, I understand way more than [if we only do] labs. It's interesting to see how it all fits together." When Dirks asked another student about the usefulness of the strategies, she replied, "The underlining and circling and question marking—those are things that I can use other places."

Before using close reading in his classroom, Dirks was skeptical about its utility for teaching science but now sees how combining reading with other science activities can support student learning.

Similarly, Melissa Hedwall (second author) used to view reading activities as simply time-fillers or activities for a substitute teacher. She now sees how purposeful questions paired with complex readings can guide students to make meaning, reflect, and inquire, thus bringing learning to a higher level.

Dirks and Hedwall administered a post-reflective survey with students. Of their 72 students, 18% said they felt "much more confident and have more strategies for understanding," 38% said they felt "more confident and have some strategies," 30% reported no confidence change but said they have more strategies, and 14% reported no change in confidence nor strategies. Hedwall also noticed an overall increase in student participation in class, which she believes is consistent with increased confidence.

For example, one student who typically disengaged was fully attentive with the close reading work. When Hedwall asked the student what she liked about the tasks, she replied that the tasks were direct and the strategies guided her to read purposefully.

Erwin Schrödinger

Modifications and further questions

Alternative texts

Teachers can use primary source materials as alternatives to Wikipedia excerpts. For example, in *The Corpuscular Theory of Matter,* Thomson describes how he came to his model that atoms consists of small negative charges distributed throughout a uniform sphere of positive charge—what we often refer to as the plum pudding model (Thomson 1907, pp. 103–104; see "On the web").

"The Development of the Theory of Atomic Structure," which is a transcript of a lecture given by Rutherford, provides students with a different style of scientific communication (Rutherford 1938, pp. 68–69; see "On the web"). In his lecture, Rutherford also describes the work of Niels Bohr (Rutherford 1938, pp. 71–72).

With these more complex and longer excerpts from primary source materials, teachers may want to consider conducting the steps for close reading over multiple classes. Additional text-dependent questions (outside of those on the worksheet) are likely warranted to guide students to engage with these texts.

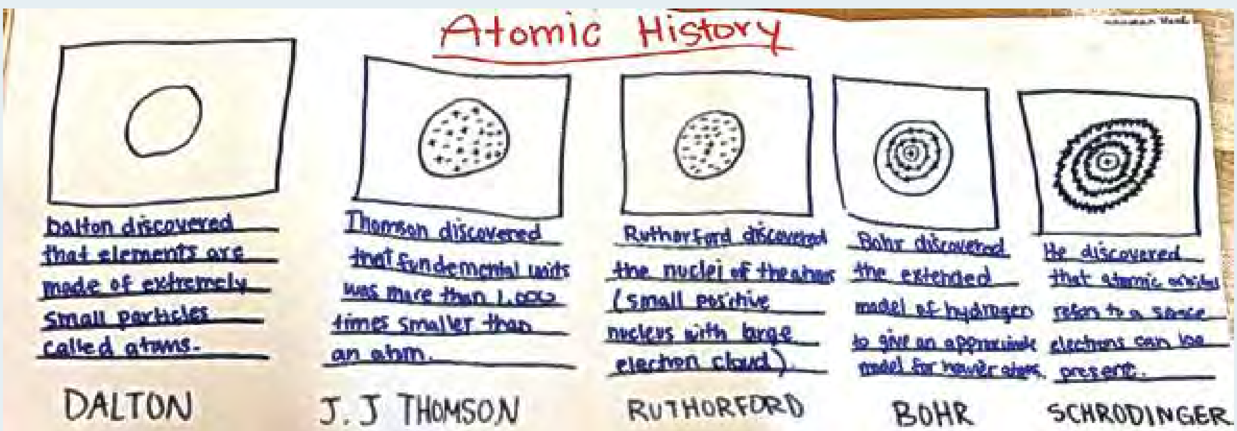
Teacher notes for improvement

Students had a hard time drawing sketches of Rutherford's experiment, based on the reading. Next time around, we'll include a diagram and ask students to label it, using what they gleaned from the reading. We'll also add an activity to go along with the Schrödinger reading and possibly a reading about James Chadwick's discovery of the

FIGURE 4

Example student timeline of the history of the atom.

Students created timelines in small groups to demonstrate conceptual understanding at the end of the unit.



neutron in 1932. It would be interesting to go beyond investigating confidence to explore how close reading, especially when paired with other activities, contributes to student understanding of science content.

Conclusion

Reading provides a unique window into the history and nature of science and the norms of scientific communication and supports students in developing critical-reading skills in engaging ways. Effective use of reading promotes a spirit of inquiry and an understanding of science concepts while also addressing expectations of the *CCSS* for literacy in science. This article demonstrates how teachers can blend close reading of challenging text with traditional science instruction to achieve these goals. Close reading also has the potential to engage and challenge all students as it defines processes and strategies that are effective at both encouraging advanced readers to slow down and deeply engage with text and providing less confident readers with a step-by-step process for approaching challenging reading. ■

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Acknowledgment

This activity was developed by Melissa Hedwall and Andrew Dirks while participating in a yearlong professional development program called The Bakken Teacher Academy: Science Learning From the Works of Scientists. Beth Murphy and Elizabeth Stretch facilitate this program for The Bakken Museum in partnership with the Minneapolis Public Schools and Hamline University (see "On the web"). The federal Improving Teacher Quality Program of the No Child Left Behind Act provides funding, which is administered by the Minnesota Office of Higher Education.

On the web

The Bakken Museum: *https://thebakken.org/teacher-academy*

Cathode ray tube demonstration: *www.youtube.com/watch?v=O9Goyscbazk*

Excerpt from Thomson's *The Corpuscular Theory of Matter: www.nsta.org/highschool/connections.aspx*

Excerpt from Rutherford's lecture on the Development of the Theory of Atomic Structure: *www.nsta.org/highschool/connections.aspx*

"History of the Atom" worksheet: *www.nsta.org/highschool/connections.aspx*

Summative assessment: *www.nsta.org/highschool/connections.aspx*

Text complexity video: *http://bit.ly/2eey8nO*

Text-dependent questions:

http://bit.ly/2ePRKA8 (Pook)

http://bit.ly/2ez4wV6 (Frey 2013, p. 52)

Wikipedia articles:

Bohr, first two paragraphs: *https://en.wikipedia.org/wiki/Bohr_model*

Dalton, "Atomic Theory" section: *https://en.wikipedia.org/wiki/John_Dalton#Atomic_theory*

Rutherford, "The Outcome of the Experiments" section: *http://bit.ly/2dLCXJ6*

Shrödinger, first paragraph: *https://en.wikipedia.org/wiki/Atomic_orbital*

Thomson, "Discovery of the Electron" section: *https://en.wikipedia.org/wiki/J._J._Thomson#Discovery_of_the_electron*

First paragraph of "Overview": *https://en.wikipedia.org/wiki/Plum_pudding_model*

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Thomson, J.J. 1907. *The corpuscular theory of matter,* 103–104. New York: Scribner's Sons. *https://archive.org/details/corpusculartheory00thomrich*

Connecting to the *Next Generation Science Standards* (NGSS Lead States 2013).

Standards
HS-PS1 Matter and Its Interactions

Performance expectation
The chart below makes one set of connections between the instruction outlined in this article and the *NGSS*. Other valid connections are likely; however, space restrictions prevent us from listing all possibilities. The materials, lessons, and activities outlined in this article are just one step toward reaching the performance expectation listed below.

HS-PS1-1. Use the periodic table as a model to predict the relative properties of elements based on the patterns of electrons in the outermost energy level of atoms.

Dimension	Name and *NGSS* code/citation	Specific connections to classroom activity
Science and Engineering Practices	**Developing and Using Models** • Evaluate merits and limitations of two different models of the same proposed system to select or revise a model that best fits the evidence. • Use a model to provide mechanistic accounts of phenomena. • Use a model to predict the relationships between systems or components of a system. (HS-PS1-1) **Engaging in Argument From Evidence** • Evaluate the claims, evidence, and reasoning behind currently accepted explanations or solutions to determine the merits of arguments. **Connections to Nature of Science** Scientific knowledge is open to revision in light of new evidence. • Most scientific knowledge is quite durable but is, in principle, subject to change based on new evidence or reinterpretation of existing evidence. • Scientific argumentation is a mode of logical discourse used to clarify the strength of relationships between ideas and evidence that may result in revision of an explanation.	Students investigate written documents to identify the evidence supporting different models for the atom that emerged over time. Students create drawings to represent each model for the atom they study, noting the changes between each. Through reading, students explore and discuss how the model for the structure of the atom changed over time based on analysis of new experimental evidence. Student groups create a timeline to represent and describe the development of the atom over time.
Disciplinary Core Ideas	**HS-PS1.A: Structure and Properties of Matter** • Each atom has a charged substructure consisting of a nucleus, which is made of protons and neutrons and surrounded by electrons. (HS-PS1-1) **HS-PS2.B: Types of Interactions** • Attraction and repulsion between electric charges at the atomic scale explain the structure, properties, and transformations of matter and the contact forces between material objects.	Students use evidence from written documents by scientists or about the work of scientists to construct a historical progression for the model of an atom.
Crosscutting Concepts	**Patterns** • Different patterns may be observed at each of the scales at which a system is studied and can provide evidence for causality in explanations of phenomena. • Empirical evidence is needed to identify patterns.	Students study and investigate how evidential patterns led scientists to propose models for the atom and how new evidence led to changes of previous models.