Rutherford's enlarged: a content-embedded activity to teach about nature of science

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Abstract
This paper describes an activity that could be used to help middle and secondary school students develop more informed understandings of some important aspects of nature of science in the context of teaching them about Rutherford's experiments and atomic structure.

Keywords: M, H, A; Nuc, TLA

Introduction

Preparing scientifically literate students is a perennial goal for science education. Moreover, having informed views of nature of science (NOS) is a central component of scientific literacy. Indeed, the goal of helping pre-college students develop a functional understanding of NOS has been a central and common theme in recent reform efforts in science education (American Association for the Advancement of Science 1990, 1993, Millar and Osborne 1998, National Research Council 1996).

Research indicates that students do not develop NOS understandings implicitly through learning science content or engaging in science-based inquiry activities. NOS instruction should be explicit. In this regard, an explicit activity-based approach and an explicit historical approach were found to be most effective in developing learners' NOS understandings (Abd-El-Khalick and Lederman 2000). Lederman and Abd-El-Khalick (1998) have developed several generic activities to help science teachers introduce students to some basic aspects of NOS. However, teaching about NOS might be most effective and feasible when embedded in the context of learning science content. First, such embeddedness might make learning about NOS more meaningful for students. Second, teaching about NOS is often impeded by time constraints imposed on teachers by having to cover some set body of science content. Intertwining NOS and content instruction might help teachers overcome such constraints.

The following activity is of the black-box variety. It could be used to introduce middle and secondary students to atomic structure and help them develop understandings of some important aspects of NOS. These aspects include (a) the observational and inferential nature of scientific knowledge, (b) the distinction between observation and inference, (c) the nature of scientific models, (d) the role of creativity and imagination in generating scientific models, and (e) the tentative nature of scientific knowledge. The activity could also be used to address the naïve conception that scientists learn about atomic structure by 'observing' atoms under 'powerful microscopes'. Research has shown that many school as well as college students hold this naïve conception (Abd-El-Khalick 1998, Khishfe and Abd-El-Khalick 2000).

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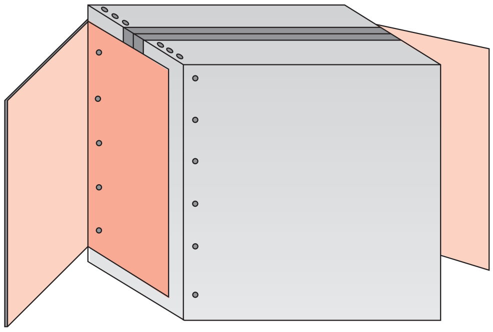

Figure 1. Preparing the cardboard box.

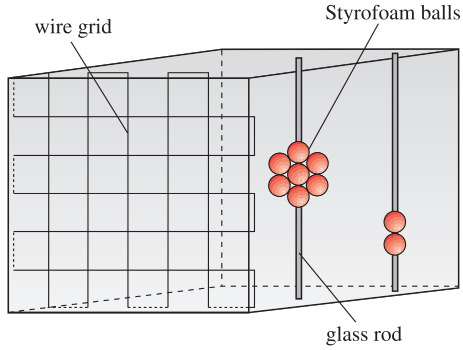

Figure 2. Schematic diagram of the box.

Materials

- A large cardboard box (side = 45 cm)
- Two 45 cm glass rods
- About 5 m of thin wire
- Several Styrofoam or wooden balls
- Ping-Pong gun and balls (available at toy stores)
- Butcher paper or greaseproof paper
- Masking tape
- Paper clips

Construction

1. Tape the cardboard box closed using masking tape. Leaving about 1 cm from the edges of the box, use a cutter to make three cuts along two horizontal and one vertical edge to get one side of the box to flap open. Repeat this step for the opposite side of the box (see figure 1).

2. Leaving about 1 cm from one edge of the box, use a sharp pencil to punch small holes at 7 cm intervals around the edges of the box surrounding one of the open flaps (see figure 1).

3. Tie the thin wire to a paper clip and pass it through the uppermost left hole. Use the wire to knit a 6 × 6 grid along one side of the box (see figure 2). Use a paperclip to fasten the other loose end of the wire.

4. Use a sharp pencil to punch two holes in the top of the box. One hole could be in the centre and the other at any other location. Punch two holes at the same locations in the bottom of the box. Pass the two glass rods through the holes and fasten them using masking tape if necessary. Use masking tape to tape several Styrofoam balls to the two glass rods. Tape the balls in any configuration you choose. One possible configuration is shown in figure 2.

5. Use butcher paper and masking tape to wrap the whole set-up.

Safety

Care should be taken when punching holes through the box using the sharp pencil and when using the cutter. Also, make sure that the glass rods are fire-polished before handling them.

Procedure

1. Place the set-up in front of the class as shown in figure 3. Students should not be able to see the inside of the box. On a paper stand or the wall, tape butcher paper to form a screen facing the open side of the box (see figure 3).

2. Tell students that there is something inside the box and that they will have to figure out its shape without looking inside the box. Tell students that you will use the Ping-Pong gun to shoot balls through one side of the box. By observing whether the balls pass through the other side of the box and hit the screen or not, students will attempt to figure out the shape of the object inside the box. Tell students about the wire grid and inform them that you will shoot one ball through each cell of the grid to systematize data collection.

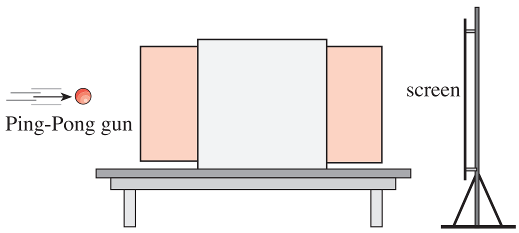

Figure 3. The set-up from the students' point of view.

	a	b	c	d	e	f
1	√	√	√	√	√	√
2	√	√	X	√	√	√
3	√	X	X	X	√	√
4	√	√	X	X	X	√
5	√	√	√	√	X	√
6	√	√	√	√	√	√

Figure 4. One possible configuration of the data.

3. Elicit student ideas about an efficient way to communicate and record the data. Guide students to realize the usefulness of constructing 6 × 6 grids in their notebooks to record the data. A grid can have numbers along one axis and letters along the others (see figure 4). In this way, you could pinpoint the grid cell through which the next Ping-Pong ball will be shot. Another coding system could be constructed through a whole-class discussion to facilitate the recording of observations. For example, a tick and a cross could be used to indicate whether a ball passed through the box or not.

4. Go through the data collection process. After having filled their grids, divide students into groups of four or five. Provide each group with an overhead transparency and marker. Ask students in each group to discuss their data and depict on their overhead an image of the object inside the box.

5. Using the transparency, have one student from each group present the final image of the object to the class. The images produced by students are often quite different.

6. Following the presentations engage students in a whole-class discussion to highlight relevant aspects of NOS and ideas relevant to atomic structure.

7. Do not allow students to examine the inside of the box at any point during the activity or the ensuing discussion. Suspend all judgments regarding the 'correctness' of students' images.

Discussion

By now, the parallels between the present activity and Rutherford's scattering experiments are hopefully apparent. Describe Rutherford's experiment and elicit student ideas about the similarities and differences between the components of this experiment and the activity in which they were engaged.

1. Ask students what the marks on their paper grids represent and what the images they depicted on their transparencies represent. Guide students to realize that, on the one hand, the marks on their papers represent observations of whether the balls passed through the box or not. *Observations* are descriptions of objects or events that are accessible to the senses or extensions of the senses, and about which several observers could reach consensus fairly easily. On the other hand, the images that students produced are *inferences*, which are not amenable to confirmation by observation. Students could 'see' whether a Ping-Pong ball passed through the box or not. However, they could only infer that there is an object inside the box. They could also make inferences about the shape of that object.

2. Guide students to realize that, even though they could not 'peek' in, they were able to tell that there is something inside the box and to make inferences about its shape. In many cases, 'knowing' is not equivalent to 'seeing,' as many students believe. For example, scientists are not able to split the Earth or the Sun open and examine their interiors. Yet, scientists are able to generate fairly reliable and consistent bodies of knowledge about the structure of the Earth and the nuclear reactions that fuel the Sun. Similarly, scientists are not able to 'see' an atom or 'examine' its structure. (The claim that scientists could see atoms using a scanning tunnelling microscope has come under severe criticism. See for example Hoffmann (1993).) Nonetheless, through inferences and indirect evidence generated from experiments such as those performed by Rutherford, scientists were able to generate a fairly robust *model* of the structure of the atom. Rutherford, for one, established a few fundamental propositions about subatomic structure, such as, "by far the greater part of the atomic mass was concentrated in a minute fraction of its volume, to form a positively charged central core or 'nucleus' " (Toulmin and Goodfield 1982, p 277).

3. Student observations are recorded on a two-dimensional grid. These observations give no information about the three-dimensional structure of the object(s) inside the box. Yet, students often depict different three-dimensional objects to account for their observations of the behaviour

of the Ping-Pong balls. Elicit student ideas in this regard and guide them to realize that there is a 'leap' from observations to inferences. A similar leap, for example, was involved when Bohr derived his model of atomic structure starting with data on atomic spectral lines. Such leaps in science often involve imagination and creativity. Emphasize that scientific knowledge, such as the model of the atom, is *partly* the product of human imagination and creativity.

4. On discussing the role of inference, imagination and creativity in generating scientific knowledge, students might adopt an 'anything goes' view of science. It is crucial to emphasize that inferences should be *based on* and *consistent with* empirical observations. At this point, the class could examine the images produced by students and attempt to decide whether some are *more* consistent with student observations than others. Rule out as unacceptable any images that are inconsistent with the data. Guide students to realize that even though all these images are inferences and partly the product of imagination and creativity, not all are 'equally valid'.

5. Often, after eliminating a few inferences, several of the student-generated images serve to *explain* the recorded observations equally well. Ask students whether they could tell which of these images is 'correct' or is an 'exact' copy of the object(s) inside the box. Guide students to realize that, like scientific models, their images are not exact copies of what is inside the box. Students often come to believe that atomic models depicted in their textbooks are 'real'. Emphasize that, given their inferential nature, scientific models could not be, and are not meant to be, 'exact' replicas of natural phenomena. These models are representations that serve to account for the available data on, and explain the workings of, target phenomena. More importantly, models serve to guide further investigations of these phenomena. Thus, scientific models are *tentative* and liable to change when new evidence is brought to bear or when extant evidence is reinterpreted in the light of advances in theory. For example, ask students whether they expect their models to change if a 100×100 grid is constructed inside the box and you used a BB gun[1] to fire 1000 shots through the box.

[1] A BB gun is an air-pressure-powered gun that shoots soft black pellets. It is often used in amusement parks to take aim at moving targets for the purpose of winning prizes.

6. At this point, you might decide to let students 'look' inside the box. Many are often surprised at how far off their inferences were. Help students to realize that scientists do not have the luxury of 'examining' natural phenomena first-hand and that they have to rely only on indirect evidence and inference in their attempts to understand and explain such phenomena. Not allowing students to look inside the box makes the experience more genuine and helps them develop a keen sense of the tentative nature of scientific knowledge. This is possible in the case of older students. Younger students often get frustrated and demand to look inside the box.

It should be emphasized that the above discussion is suggestive and not meant to be prescriptive. Teachers might decide to emphasize some points and not others, or to discuss different points depending on their students' level and interests, and the depth at which the content is being presented.

Evidence for effectiveness

Over the course of the past four years, some colleagues and myself have used this activity in our own teaching and research and in a variety of settings. We used the activity in the context of (a) science methods courses for preservice secondary science and elementary teachers, (b) a conceptual physics course for preservice elementary teachers and (c) teaching middle and high school students about atomic structure (e.g. Abd-El-Khalick 2001, Akerson *et al* 2000, Khishfe and Abd-El-Khalick 2000). Our data, which are derived from participants' responses to different versions of an open-ended questionnaire coupled with follow-up individual interviews (Abd-El-Khalick *et al* 2001), indicate that the activity was effective in helping learners develop more informed views of several important aspects of NOS, including the tentative, empirical, inferential and creative nature of scientific knowledge. For example, at the outset of our studies and in response to a question that asked them whether scientists were 'certain' about atomic structure and the sort of evidence that scientists used to derive such structure, an alarmingly high percentage (30–60%) of high school students, preservice teachers and even college science students (see Abd-El-Khalick 1998) indicated that scientists 'are 100% sure of the structure of the atom because they have seen atoms and orbitals under the electron microscope' (preservice elementary teacher). As one middle school student noted, 'I cannot see an atom, but scientists can… by the microscope for tiny things.' These and similar quotes serve to show that many of our participants subscribed to a 'knowing is seeing' view of generating scientific claims. As a result, these participants harboured an absolutist view of scientific knowledge, did not make the distinction between inferences (claims about natural phenomena) and observations (evidence supporting such claims) and dismissed any role for inference and imagination in the development of scientific claims.

Following instruction that used the activity described above and other similar activities, many of our young participants (35–55%) explicated a more tentative view of scientific knowledge and started to make the crucial distinction between observation and inference: 'Scientists can't be certain because they didn't observe atoms, they only inferred that they exist. … Like when we did the thing about the box, we know there is something in the middle of the box, but we didn't observe it, we inferred it only' (middle school student). Additionally, the majority of our older participants (50–70%) demonstrated an appreciation of the role of creativity and imagination in the development of scientific claims, while simultaneously emphasizing the empirical content of these claims. For example, several preservice secondary and elementary teachers noted that 'scientists use their imaginations in creating models. … Scientists use the knowledge gained from their experiments and observations, but their creativity and imagination are also important in looking at the data and coming up with a conclusion. … Like with the Ping-Pong activity, every group came with a different image of what was inside. We accepted only the ones that agreed with what we observed and there were a few like that. But I believe that we will change many of them if we make more observations' (preservice secondary science teacher). These are a few illustrative examples of the impact that this activity had on learners' views of NOS. The reader is referred to the aforementioned studies for more complete descriptions of the studies, data and nature of changes that were evident in participants' views.

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