
# DEVELOPING THE CONCEPTUAL GROUNDWORK NEEDED TO UNDERSTAND MOLECULAR MOTION

by **Scott M. Moore, Jr.** and **Kara Victorsen**

**ABSTRACT:** The activity described in this article introduces students to the concept of molecular motion and how it is affected by temperature using two simple ingredients: water and food coloring. In the hands of a highly effective science teacher, this activity will promote student inquiry, creative and critical thinking, effective communication, and cooperative learning. This activity is appropriate for use in both physical science and chemistry. *The activity described here promotes National Science Education Content Standards A, B, and G, and Iowa Teaching Standards 1, 2, 3, and 5.*

Understanding the notion of molecules and molecular motion is important for making sense of how matter behaves. However, helping students develop a deep and robust understanding of these very abstract concepts is challenging. The difficulty lies in the inability to directly observe molecules and their motion. The behavior of dye in containers of water at varying temperatures is a common activity to illustrate the effect of temperature on molecular motion.

When introduced via inquiry, as illustrated here, students are far more interested and mentally engaged. Because students are creating their own strategies for answering questions that arise, they are more engaged in the activity. The questions students pose, the procedures they develop to answer particular questions, and the teacher's important role in helping students make sense of their work enables students to develop a deep understanding of several fundamental science ideas. Just as important, the inquiry approach presented here demands detailed observation, problem solving, analysis, interpretation, creativity, collaboration, cooperation, and effective communication. These outcomes are important in learning and doing science, and in everyday life.

Inquiry also presents an opportunity to more accurately represent how science works. When doing authentic research, scientists do not follow a prescribed step-by-step procedure (Finley, 1983; Klapper, 1995). The challenge, joy and frustration of doing science is the need to solve problems, be creative, and critically think. Scientists also rarely work alone, instead they often have a team with whom they discuss and share ideas and findings. Many opportunities exist in this activity, some explicitly identified, where discussions about the nature of science should occur.

These goals reflect what we want for our students, and reflect desired outcomes consistent with the National Science Education Standards. The Standards specifically targeted in this activity include students working to develop the skills needed to do scientific inquiry, understanding motions and forces, and understanding the history and nature of science (NRC, 1996).

## Beginning the Activity

The activity begins with students working in pairs with two clear containers placed in front of them. This activity can be done as a whole class demonstration if the necessary materials are not available for the entire class, but ensure that the inquiry approach is maintained. Each of the two containers should be identical, being the same size and containing the same volume of water. The only difference is that one container holds warm water, the other cold water. Do not tell students that the containers are at different temperatures. Walk around and place 3-5 drops of food coloring in each container. As the mixing of dye in the water occurs, students will likely begin observing their containers without being told to do so. When all students have observed the phenomena in front of them, ask questions such as

- "What do you observe happening?"
- "What are the similarities and differences, if any, between how the dye is behaving in the two containers?"
- "What might be responsible for the dye's movement?"

We find that these questions and others that will be suggested encourage critical thinking, extended answers, and reasoning. Appropriate wait time I and II (Rowe, 1986), encouraging non-verbal behaviors, and acknowledgment of all relevant ideas are important for encouraging thoughtful responses. Provide students with another set of containers as before and again have them make observations, ensuring that safe laboratory procedures are followed. Walk around observing students and listening to what they say. If this activity is done early in the school year, you may need to encourage students to make more detailed observations. After this second trial, hold a whole class discussion and share what was observed. Write students' observations on the board. If contradictory observations exist between groups, ask questions such as:

- "How can we account for these disparate observations?"
- "How can we resolve these discrepancies?"
- "What's the importance of attempting to resolve discrepancies?"
- "Why do we expect to have consistent data?"

At this point we create another list on the board and ensure all relevant ideas are noted. This is an ideal time to address key ideas about the nature of science. These include: how two individuals or groups can look at the same phenomena, but for a variety of reasons not see the same thing because observation is not and cannot be entirely objective, and that a fundamental assumption of science is that the natural world behaves in an orderly fashion. The consequence of this assumption is that discrepancies can and should be resolved.

## Student Inquiry

After students' observations and ideas have been exhausted, we lead with a question such as, "What questions might we investigate related to what you are observing?" Students are directed to work with their partner and develop researchable questions. Some students have noticed the different temperatures of the two containers and pose the question, "Does the temperature difference account for the behavior difference of the dye in the two containers?" Other students are curious whether the amount of dye placed in the two containers is the same and if that might account for the different behavior noted in the two containers." Be prepared for other questions that students wish to investigate. We try to not limit the direction students go in their investigation, so long as their question is relevant to the topic and no safety concerns arise. As students are developing these researchable questions, walk around the classroom listening to students. If particular students appear to be struggling, ask those students to again tell you what they have observed. Follow this with questions such as:

- "What do you think might be causing the different behavior of the dye in the two containers?"
- "How can you test [select one of the possibilities generated by the students]?"
- "If you did choose to do this test, what do you predict might happen?"
- "How can you test [select a second possibility generated by the students]?"

As students develop their research question, inform them that they must submit a written proposal of their investigation and have it approved by the teacher prior to starting. To help students think through the steps of preparing their written proposal, ask a question such as, "What information must be in your written proposal so that a reader clearly understands what you will do?" Students typically offer "the researchable question", "the procedure", and "the materials required to conduct the investigation". If they don't, additional questioning may be needed to help them understand the need for this information. After having had their proposal accepted, students will be performing and completing their investigation. While students work, walk around closely observing what they are doing and what they are saying. We find that if students are working productively, we do not interrupt their work. However, if we note a problem, we ask questions such as:

- "What are you testing?"
- "How is this procedure testing the variable associated with your question?"
- "What other factors could be affecting the outcome?"

These questions along with your movement among students will ensure students remain focused, engaged, and thinking about what their question, procedure, and making sense of their resulting data. Other question starters that might be appropriate include:

- "How can you adjust for…?"
- "How else might you go about testing …?"
- "If you think ____________________, then what would you expect to see happening?"

Two 40-50 minute class periods are typically required for students to complete their work and share their investigations and data.

We have noticed that using this investigation to arrive at the conclusion that different temperatures are responsible for the different mixing rate is not as straight-forward to students as might be expected. Some groups of students stir their water while others place significantly more dye in one container than the other. Other groups alter two or more variables at the same time. These behaviors may indicate that students are not thinking deeply about what they are doing, or it may convey conceptual difficulties. Both these undesirable situations would likely be masked by a cookbook activity where the students simply followed directions. By contrast, the activity described here requires students to make decisions regarding the design and implementation of an investigative question, with many opportunities for the teacher to probe student thinking through questioning.

In order to encourage deeper thinking and help students resolve conceptual difficulties, we ask questions such as:

- "What variable are you attempting to test?"
- "What are the pros and cons of stirring the liquid in one or both container?"
- "What variables are you testing when you stir the liquid?"
- "What variables are you testing when you let the water sit still?"

No prescribed list of questions addresses all possible situations, so we are continually prepared to ask questions based on what students do and say.

As you walk around, you will likely hear some students using vocabulary they have heard in the past. This may include talking about molecular motion. We never assume that students' use of science vocabulary means they understand what the words represent. Instead, we probe further to determine whether they truly understand what they are saying. For example:

- "What do you mean by 'molecular motion'?"
- "What does molecular motion have to do with the mixing of the dye in the water?"
- "What would change the speed of molecules?"

After students have completed their investigations, we have each group prepare and give a short presentation that makes use of their individual white boards. These are 2' by 2' boards made of the same material as large white boards that are increasingly replacing chalk boards in school classrooms. Having the groups use their individual white boards promotes more effective presentations and helps the entire class follow along. After each presentation, have students in the class pose at least one question to the presenting group. Students must often be taught how to ask productive and appropriate questions to their classmates, so when asking questions we often explicitly draw students' attention to the phrasing of our questions, the information we seek, and why that information is important. Some examples of questions we often ask are:

- "What problems did you face in attempting to answer your question?"
- "What did you do to address these problems?"
- "How effectively did that action reduce or eliminate that problem?"

## Making Sense of the Investigations

When all groups have presented their work, move into consolidating their conclusions and helping students making sense of them. Ask, "What variable or variables have we determined are responsible for the different behavior of the dye?" Often, but not always, water temperature is determined by students to be the significant variable affecting the behavior of the dye. However, be prepared for disagreement. When consensus does not exist, ask, "What do we need to do to resolve this disagreement?" This may entail a return to the lab, but if this is appropriate, ask questions that ensure this is a productive experience that will address existing problems.

At the appropriate time during the consolidation phase of this activity, ask students for evidence supporting the contention that temperature, and not other factors (e.g., water, food coloring, mechanical mixing), is responsible for the different mixing rate of the dye. Only after students understand this should you begin scaffolding to a deeper explanation for this generalization. Ask questions that help students clarify their explanation of why the dye mixed in the water. For example:

- "What happens to the mixing rate when you increase/decrease the temperature of the water?"
- "From a chemical perspective, what is water?"
- "What evidence do you have that water moves even when you do not stir it?"
- "As the temperature of a substance such as water increases, what do you suppose happens to the speed of the molecules?"
- "How might this explain the faster mixing of the dye in warmer water?"

## Conclusion

Students should now be ready to link both their investigation observations and classroom discussions to the concept of molecular motion. The activity presented here can be implemented by science teachers of any level of teaching experience. The success of the activity depends largely on using an inquiry approach so that greater cognitive responsibility and decision making is put into the hands of students. The benefit of this activity is that it provides a concrete experience which then can be used to scaffold to ideas about molecular motion. So what comes next? We recommend discussion, an activity, or other experiences designed to offer students an opportunity to apply the knowledge they have constructed thus far. This is a perfect way to help students solidify their understanding while providing you with a tool to assess their thinking.

## References

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**Scott M. Moore, Jr.** teaches biology, chemistry, and AP chemistry at Valley High School in Des Moines. **Kara Victorsen** teaches geology at Streamwood High School in Streamwood, Illinois. Both Scott and Kara have been active members of the National Science Teachers Association and the Iowa Science Teachers Section. Scott can be contacted at scottmoore96@gmail.com, and Kara at kara.victorsen@gmail.com.