view from my classroom

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Frank Cardulla
Niles Township High School
Skokie, IL 60077

Stoogiometry: A Cognitive Approach to Teaching Stoichiometry

Carla R. Krieger
Pleasant Valley High School, Route 209, Brodheadsville, PA 18322

I first encountered the mole in a college prep chemistry class as a high school student in 1977. I vividly recall my approach when required to apply this concept in exercise after exercise, chapter after chapter: I simply memorized discrete solutions to the various types of exercises I was asked to solve, never fully grasping the importance of the mole to anything but my grade. As a teacher, I often returned to this memory whenever my current high school chemistry classes began the mole unit. Even with handy-dandy mole charts, carefully sketched, reproduced, distributed, and then even more carefully explained, I had come to dread this moment in my students' academic lives. I knew, and soon so would they, that some of them would become irretrievably lost. And so it remained until I discovered Moe's Mall.

Moe's Mall is a locational device designed to be used by learners as a simple algorithm for solving mole-based exercises efficiently and accurately using dimensional analysis. The phrase "locational device" refers to a mnemonic based on a place familiar to all of our students: a shopping mall. On the face of it, Moe's Mall would appear to be just another mole chart. In fact, it is much more. Moe's Mall is a motivating, humorous, and memorable approach to the study of the mole. It clears the cognitive decks of students' easily overburdened short-term memory space, allowing them to focus on the versatility of the mole, rather than stepwise solutions to meaningless exercises. Thus liberated, many students develop the motivation and memory space to devote to the deeper processing of the mole concept. Once students have been to the mall, several in each section can be counted on to anticipate the solution method for exercises that have not yet been modeled. Each new group of chemistry students comes to class in September with the question, "How soon until we get to do Moe's Mall?" Every year, returning graduates stop by to thank Moe for helping them to succeed in freshman chemistry.

About the Author

Carla R. Krieger has been a teacher for 12 years, the last 10 at Pleasant Valley High School in Brodheadsville, PA, where she teaches honors and college prep chemistry. Krieger earned the BS from Muhlenberg College and the MS from the University of Pennsylvania. She is currently a doctoral candidate in the educational technology program at Lehigh University. Krieger has been a presenter at National Science Teachers Association, Pennsylvania Science Teachers Association, and Pocono Area Educators' Forum conventions. She is a member of Phi Beta Kappa and Pi Lambda Theta, an honorary fraternity of educators.

I use a distributed practice approach to stoichiometry. That is, students return to the mole and the mall again and again throughout the year, each time elaborating on the basic design. They first encounter the mole after learning compound nomenclature and formula writing. After learning to write and balance chemical equations, we return to the mole in a stoichiometry unit. The students revisit Moe's Mall with their studies of gases and acids and bases. By the end of the year, they have gained a clear picture of the versatility and flexibility of the mall and, by extension, the mole. Let's go to the mall!

A Trip to the Mall

Before describing the mall in detail, we must first review a few basic guidelines for implementing Moe's Mall in your classroom:

- Present the material in small chunks to minimize cognitive load.
- Immediately after presenting each chunk of information, question your students about the new information.
- With each addition to the mall, you should review all of the previous pieces, and then add the new information. This process may seem time-consuming, but it will ultimately improve your students' retention of the device. Retention is further increased by reviewing the chunks in the same order each time.

When introducing Moe's Mall, enhance processing and retention by having students draw the mall at their seats as it is described to them. Do not draw the mall on the board until you are ready to review the basic plan. Open by explaining that Moe, Shemp, Curly, and Larry have built a new mall in New York state, on the border between the United States and Canada. Tell students that this mall is very popular with chemistry students because it is useful for solving all kinds of exercises. Then describe the basic design. Moe's Mall has a central square. This is the only place where you can enter and exit. Emphasize that they cannot cut through the parking lot at any time. There are three hallways radiating out from the central square like spokes on a wheel. One hallway extends from the northeast corner of the square, one from the northwest corner, and one from the southwest corner. At the end of each of these hallways is a store; there are three stores altogether in Moe's Mall. The stores can have any shape at all. At this point, review the design. The drawings should resemble Figure 1.

Continue with a description of the stores in the mall. The store extending from the northeast corner is a car parts store. The store connected to the northwest corner is a snack store that sells bulk food (food by the pound). The southwest store is an audio store that sells records, tapes, and CDs.

We are ready to tour the mall. As you enter the double doors on the south face of the central square, you notice that Moe himself is there to greet you. Moe leads you down the northeast hallway. There, you see Shemp selling avocados from a cart. As you pass by with Moe, he stops, picks up the avocados one by one, and tosses them into his mouth, swallowing them whole. Moe continues eating until he has consumed 6.022×10^{23} avocados. You and Moe continue down the hallway to the car parts store. A sign proclaims its motto: "Parts is parts." This is a very unusual store. No matter what part you ask for, the clerks will hand you any old part; it doesn't matter to them what you ask for (hence the motto). You and Moe walk back down the northeast hallway. When you pass Shemp's cart, Moe stops and eats 6.022×10^{23} avocados again. When Moe finishes, you exit the northeast hallway and return to center square. Emphasize that whenever Moe passes by Shemp's cart, he must eat the same number of avocados. The students must remember that there are 6.022×10^{23} avocados in one Moe. Later, they will have little trouble remembering that a mole contains Avogadro's number of particles.

Moe now leads you to the northwest hallway. At the entrance to the hallway you encounter Curly. It is important to remember that both Moe and Curly must lead you to the food store. The sign outside the food store flashes its motto: "Consume mass quantities." Moe and Curly take you back to center square.

You and Moe walk to the southwest hallway, where you meet Larry. As you and Moe walk up to Larry, he takes out a bottle and sprays Moe with some sort of solution. It is important to remember that both Moe and Larry lead you to the audio store. The sign outside of the store says, "Pump up the volume." This store sells records, tapes, and CDs by volume (the louder the music, the higher the price). Moe and Larry return you to center square. You exit the mall.

Figure 1 illustrates the significance of each part of the mall. Moe's Mall employs tactics such as word play, familiar characters, and unique merchandising techniques to make the image more memorable and therefore more easily encoded in the learner's long-term memory. I require my students to draw the mall themselves, rather than supplying them with handouts. This approach increases retention and eliminates the need to provide a handout for use on tests and quizzes. The ultimate goal is to have students employ this device without having to draw it. By the end of the year, this wish usually becomes reality.

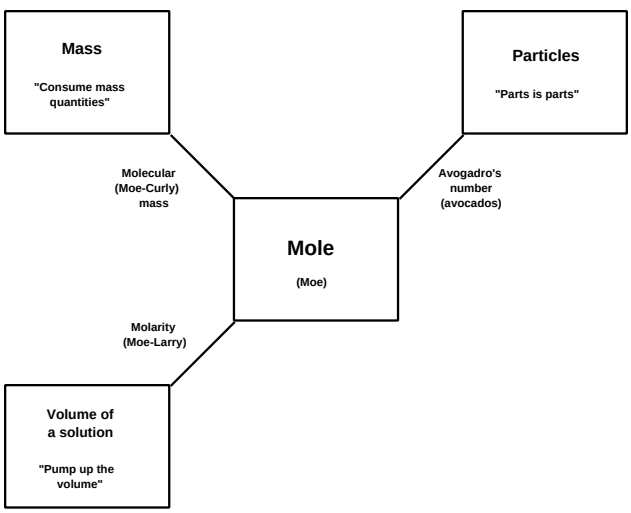

Figure 1. Basic plan of Moe's Mall, with its bulk foods store (mass), car parts store (particles), and audio store (volume).

Using the Mall

The mall functions as a map for setting up solutions to mole-based exercises using dimensional analysis. When teaching solution methods, always start with the mall, demonstrating where you are beginning (remind students that "You are here") and where you want to end. Students will quickly see that each hallway represents one conversion factor. For example, suppose you want to find the number of moles contained in 10.0 grams of oxygen gas. You must start at the mass (bulk food) store and end at the mole (Moe). Since only one hallway connects the two, only one conversion factor is required. The preliminary setup should look like this:

$$? \text{ mol } O_2 = \frac{10.0 \text{ g } O_2 \quad |}{|}$$

The hallway between the two stores represents molecular mass in grams (Moe-Curly mass). In this case, 1 mole of O_2 contains 32.0 grams. Use the units to place the conversion factor in the frame. The final setup should appear as follows:

$$? \text{ mol } O_2 = \frac{10.0 \text{ g } O_2 \quad | 1 \text{ mol } O_2}{| 32.0 \text{ g } O_2}$$

Answer: 0.313 mole O_2

The answer is obtained by multiplying the top factors and dividing the result by the bottom number.

Use the same procedure for more elaborate problems. For example, suppose you want to find the number of grams contained in 7.35×10^{24} molecules of oxygen gas. You must start at the particles (parts) store and end at the mass (food) store. Since two hallways connect these stores, two conversion factors are required. The preliminary setup should look like this:

$$? \text{ mol } O_2 = \frac{7.35 \times 10^{24} \text{ molecules } O_2 \quad | \qquad |}{| \qquad |}$$

The hallway between particles and the mole (Moe) represents Avogadro's number (avocados). The hallway between the mole and mass represents molecular mass in grams. Use the units to place each conversion factor in the frame. The final setup should appear as follows:

$$? \text{ mol } O_2 = \frac{7.35{\times}10^{24} \text{ molecules } O_2 \,|\, 1 \text{ mol } O_2 \,|\, 32.0 \text{ g } O_2}{|\, 6.022{\times}10^{23} \text{ molecules } O_2 \,|\, 1 \text{ mol } O_2}$$

Answer: 391 grams O_2

The answer is obtained by multiplying the top factors, multiplying the bottom factors, and dividing the resulting numerator by the resulting denominator.

One caveat bears mentioning when using the mall to solve for molarity: since the students will be solving for a compound unit (moles per liter), they must start at two stores simultaneously (usually mass and volume) and meet in the hallway. Whenever you plan to end your visit in a hallway, you must begin at two stores in the mall and with two units in dimensional analysis. For example, suppose you want to find the molarity of a solution prepared by using 35.0 g of NaOH to make 500.0 mL of solution. You must start at the mass and volume (audio) stores and end in the molarity (Moe-Larry) hallway. Since volume must appear

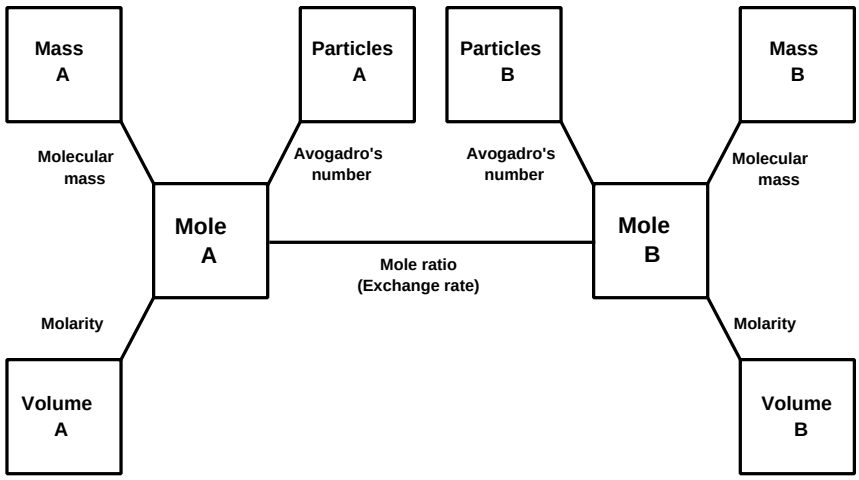

Figure 2. Expanded mall, for solution of mole–mole, mass–mass, and solution stoichiometry problems. A mirror image of the original mall has been built in Canada. The bridge between the two halves represents the exchange rate between the countries (mole ratio).

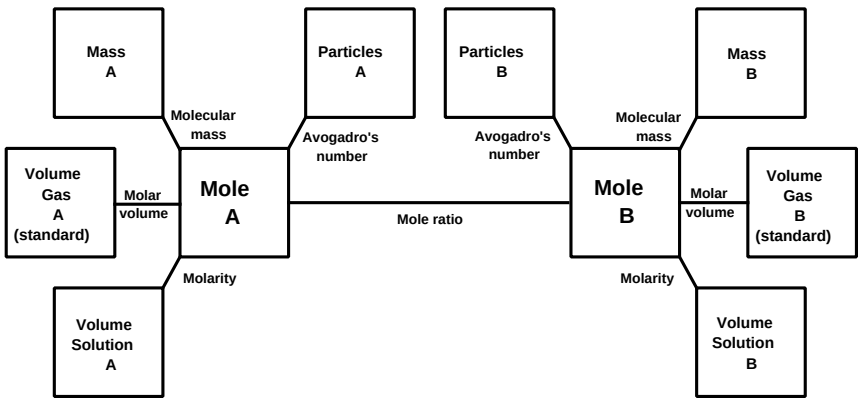

Figure 3. Further expansion of the mall shown in Figure 2, for solution of gas stoichiometry problems under standard conditions.

in the denominator of the answer, you should begin with volume in the bottom position. Because you can use mass to get to moles, you should place the mass in the top position. The preliminary setup should look like this:

$$? \frac{\text{mol NaOH}}{\text{L soln}} = \frac{35.0\text{ g NaOH}\ |\ \ \ |}{500.0\text{ mL soln}\ |\ \ \ |}$$

Convert the milliliters to liters and then use the mall to convert grams to moles. Use the units to place each conversion factor in the frame. The final setup should appear as follows:

$$? \frac{\text{mol NaOH}}{\text{L soln}} = \frac{35.0\text{ g NaOH}\ |\ 1000\text{ mL}\ |\ 1\text{ mol NaOH}}{500.0\text{ mL soln}\ |\ \ 1\text{ L}\ \ |\ 40.0\text{ g NaOH}}$$

Answer: 1.75 M NaOH

Suggestions for Implementing Moe's Mall

You can enhance the retention and transfer of this lesson by extending the Three Stooges theme throughout the unit. The simplest method is to pepper your use of the device with Stooge-isms: characteristic phrases like "Coitainly" or quintessential routines like Curly's two-handed snap will make this lesson memorable and fun for you as well as your students. You may be able to obtain Stooge stamps or clip art at specialty stores. Use the stamps on quizzes and homework. Create your own reward stickers or buttons, with lines such as: "I survived Moe's Mall", "Ask me about Stoogiometry", or "My kid went to Moe's Mall and all I got was this lousy sticker". Create certificates for superior achievement on homework, quizzes, or tests; use clip art or stamps here as well. Wear Stooge T-shirts or decorate the room with them. I display a "Just say Moe" T-shirt on the classroom skeleton. Hang Stooge posters around the room. Flinn Scientific sells "Mole Toons", a packet of mole-related cartoons that includes a plate referring to the Three Stooges. Students will find your dedication to the theme of Moe's Mall amusing and memorable.

You may wish to open or close the Stoogiometry lesson with a tape or video of "The Curly Shuffle", a song popular in the 1980s. Consult your local audio or video store to obtain copies of the song or video. It is currently available as part of a Dr. Demento anthology on tape or CD. I "treat" my students at the end of the first mole unit by showing the Three Stooges video *Fuelin' Around*. This episode has the boys trying to develop a rocket fuel in a chemistry lab. Their antics could provide material for hours of discussion about laboratory techniques and safety issues. Be sure to discuss your plans with your supervisor and/or principal before showing the video; the support of the administration is vital in case parents or other members of the community fail to appreciate the pedagogical value of a Three Stooges video. *Fuelin' Around* can be purchased at your local video store as part of a Columbia Pictures anthology of Three Stooges episodes. After showing the video, tell your students that you have the "recipe" for the rocket fuel in the video. Perform a demonstration such as the oxidation of glycerin by

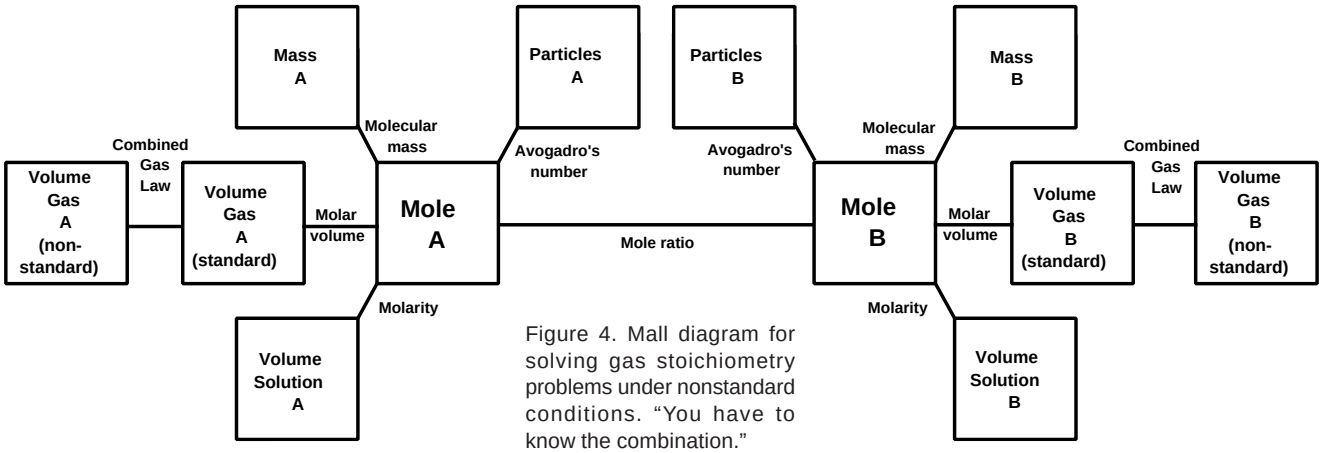

Figure 4. Mall diagram for solving gas stoichiometry problems under nonstandard conditions. "You have to know the combination."

permanganate. This is a delayed reaction, so you will have plenty of time to perform "The Curly Shuffle" while waiting. If you require more instantaneous gratification, try the oxidation of sugar and potassium chlorate.

Additions to the Mall

You can expand Moe's Mall in order to solve mole-mole, mole–mass, mass–mass, and solution stoichiometry exercises by simply adding a mirror image of the mall with a bridge, as in Figure 2. Tell your students that the new mall has been constructed in Canada and that crossing the bridge from one country to another requires an exchange rate (the mole ratio from the balanced chemical equation). Be especially careful when using the mall to solve for solution concentration (in titration exercises, for example). Because they end in one of the molarity hallways, the students will need to start at two stores simultaneously (usually volume of solution A and volume of solution B). The trick is to realize that the setup of the exercise begins with volume of the solution of known concentration on the top, as in the example below.

Example: What is the molarity of an NaOH solution, if 0.0100 L of the NaOH are required to neutralize 0.0120 L of 2.0 M H_2SO_4?

Solution:

$$H_2SO_4(aq) + 2NaOH(aq) \rightarrow Na_2SO_4\,(aq) + 2HOH(l)$$

$$?\ \frac{\text{mol base}}{\text{L base}} = \frac{0.0120\ \text{L acid} \,|\, 2.0\text{mol acid} \,|\, 2\ \text{mol base}}{0.0100\ \text{L base} \,|\, 1\ \text{L acid} \,|\, 1\ \text{mol acid}}$$

Answer: 4.8 M NaOH

Using Moe's Mall for gas stoichiometry exercises under standard conditions requires the addition of the "Balloons for Standard Occasions" store (shown in Figure 3) with the motto "22.4, nothing less, nothing more." Tell your students that this store sells balloons for such occasions as birthdays and anniversaries and that every balloon sold by this store has the same volume: 22.4 liters. Start with molar volume exercises for a single gas and expand to mass–volume and volume–volume exercises involving both sides of the mall. One twist comes into play here. After the students have solved a few volume–volume exercises using the mall, they are ready for a shortcut. At this point, introduce Gay-Lussac's Pogo Stick, which can be used *only* in solving volume–volume exercises under constant (but not necessarily standard) conditions. Gay-Lussac's Pogo Stick allows the learner to leap from the volume of gas A to the mole ratio to the volume of gas B directly, as in the example below.

Example: How many milliliters of carbon dioxide gas are formed when excess methane gas (CH_4) reacts with 0.50 liter of oxygen gas? All gases are measured at the same temperature and pressure.

Solution:

$$CH_4(g) + 2O_2(g) \rightarrow CO_2(g) + 2H_2O(g)$$

$$?\ \text{mL}\ CO_2 = \frac{0.50\ \text{L}\ O_2 \,|\, 1\ \text{L}\ CO_2 \,|\, 1000\ \text{mL}}{|\, 2\ \text{L}\ O_2 \;\; |\, 1\ \text{L}}$$

Answer: 250 mL CO_2

Solving gas stoichiometry exercises under nonstandard conditions involves adding the "Balloons for Non-Standard Occasions" store (shown in Fig. 4) with the motto "You have to know the combination." This store sells balloons for unique occurrences such as natural disasters, acing chemistry, and appearing on the "Ricki Lake Show". However, this store serves a very select clientele—it's locked! In order to shop here, you must know the combination to the lock (the combined gas law). Students can correct gas volumes using the combined gas law as a formula (as we do) or as part of the dimensional analysis framework. Obviously, students should be familiar with the gas laws before tackling these types of exercises.

Conclusion

Thus, Moe's Mall can be used to solve a variety of mole-based exercises using dimensional analysis. Once the learner has acquired this device, she will have developed a scientifically sound schema for the mole concept. When asked to explain why the mole is referred to as the heart of chemistry, a student needs only to refer to all of the places he can go in Moe's Mall. Clearly, the mall cannot eliminate computational errors. Furthermore, students must be familiar with dimensional analysis before attempting to use this device. Moe's Mall is designed to reduce the cognitive load of learning to solve mole-based exercises so that students of varying abilities can focus on developing a deep, flexible understanding of the mole concept.

Acknowledgment

I would like to thank Ward Cates of Lehigh University, without whose wisdom and guidance (and course requirements) Moe's Mall would not exist.