STUDENTS AS TEACHERS:

HOW SCIENCE TEACHERS CAN COLLABORATE WITH THEIR STUDENTS USING PEER INSTRUCTION

KEVIN CLOSE, NICOLE BOWERS, ROHIT MEHTA, PUNYA MISHRA & J. BRYAN HENDERSON

This article explores peer instruction in the science classroom. The authors use research in science education to illustrate, practically, how teachers can work with their students to increase learning using peer instruction.

'Learning is least useful when it is private and hidden. It is most powerful when it becomes public and communal.'
— Lee Shulman

'The facts of science and, à fortiori, its laws are the artificial work of the scientist; science therefore can teach us nothing of the truth; it can only serve us as rule of action.' — Henri Poincaré

Teachers often forget that science is social and rhetorical in nature. Group consensus and peer review, not political discourse, define scientific facts. Therefore, scientific instruction should embrace the push-and-pull and back-and-forth of scientific dialogue and argumentation. When instructors speak of the scientific method in school, they focus on generating hypotheses and conducting experiments, but often fail to present the whole process as what it really is — a way of crafting a convincing argument. In other words, science is a way of harnessing facts, logic, and evidence in order to convince others that a particular idea is likely to be correct.

With this in mind, we present a way to introduce meaningful scientific discussion in the classroom using the most valuable classroom resource — the students themselves. This technique, called **Peer Instruction**, wrests control from the teacher and gives it to students. According to a recent paper by Dr. Trisha Vickrey, a Professor of Chemistry at the Brevard College, North Carolina, United States, and four of her co-authors, it is one form of research-based instructional reform that has been widely adopted by instructors in science, technology, engineering, and math[1].

Peer Instruction allows students time to talk, debate, and teach each other during instruction. Students can serve as tutors, models, and sounding boards for their peers. In fact, research shows that much learning occurs during these peer-to-peer interactions. According to John A.C. Hattie, a renowned professor of education, *"If you want to increase student academic achievement, give each student a friend."* Social interaction, he asserts, drives students to become their own teachers. It is this social interaction that Peer Instruction seeks to provoke.

Additionally, Peer Instruction replicates something that is fundamental in the scientific process — convincing others of the '**truth value**' of one's approach. This is a process of argumentation — or systematically marshalling data and logic to explain one's point of view. This rhetorical turn is crucial, forcing students to not only come up with the right answer, but also to explain how and why and convince others of the same. A student with a different explanation would approach their partner's statements with a questioning attitude — and, also, an open-mindedness to being wrong. What is interesting is that such conversations do not necessarily mean that the student with the right answer necessarily believes their own logic. A situation could arise where a student with an incorrect understanding manages to convince their partner (who may have had the right explanation) of its correctness. In fact, this situation may reveal weaknesses in the understanding of even those students who are able to come up with the right answer. Essentially, Peer Instruction stresses conceptual understanding and the logic of the argument, over merely getting the correct answer.

What does the research say?

Eric Mazur, a Professor of Physics at Harvard, was interested in the practice of interactive voting. According to Drs. Eugene Judson and Daiyo Sawada of Arizona State University and the University of Alberta respectively, this practice has been used in science classrooms since the 1960s but has become popular on some campuses since the mid-1990s[2]. A teacher using interactive voting solicits student responses to a question through a class vote or poll, often with flashcards or 'clicker' systems. In some cases, the question may be intended to increase student curiosity; while in others, it may be designed to check for student understanding. Mazur discovered that in certain circumstances, students learned more if they discussed their answers with their peers after voting[3]. He coined the phrase Peer Instruction to describe this observation, and outlined a specific model for implementing it:

1. Pose a question
2. Give students time to think
3. Have students record their individual answers
4. Have students convince their neighbors (peer discussion)
5. Have students record their revised answers
6. Calculate the results
7. Explain the correct answer

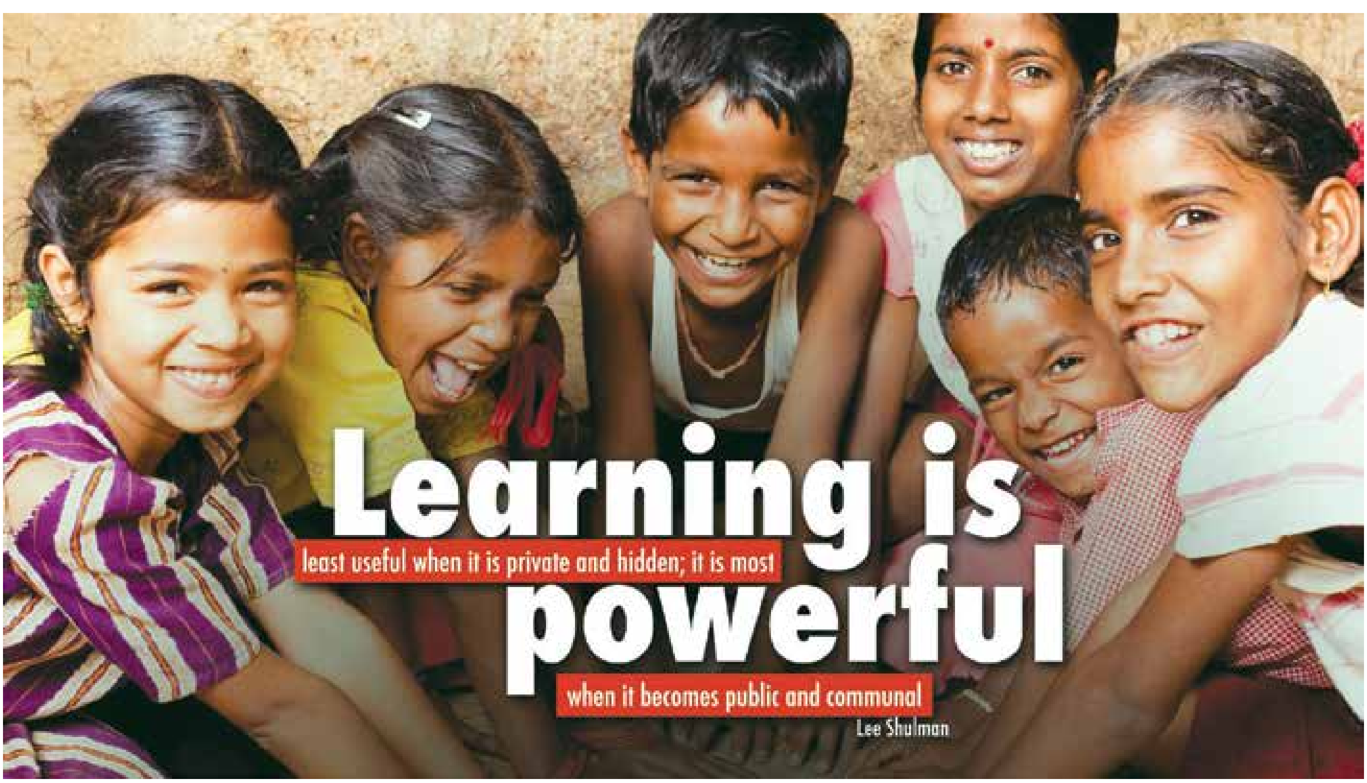

Fig. 1. Learning is least useful when it is private and hidden. It is most powerful when it becomes public and communal.

Credits: Quote by Lee Shulman. Illustration by Punya Mishra. License CC-BY-NC.

Mazur's findings and his model for Peer Instruction inspired a generation of follow-up research. A ten-year study by Mazur and Catherine Crouch, his colleague at Harvard University, looked for differences in performance of students in an introductory Physics course taught by traditional lecture method versus those that used some element of Peer Instruction. They measured student performance by giving students conceptual Physics tests before and after class. Through this study, Mazur and Crouch showed that students who took the course with Peer Instruction consistently and significantly outperformed those who took a course without it. Often, learning gains of students in classes using Peer Instruction were twice as high as those in classes without it. Other studies showed that Peer Instruction improved learning in classes on geoscience, computer science, and calculus[4, 5]. This suggested that Peer Instruction may be suitable as a general teaching strategy, not confined to Physics.

Though Peer Instruction appears straightforward, each step contains subtle considerations for effective implementation. The following sections will unpack each step and give examples of best practices.

How can teachers support Peer Instruction in their classrooms?

Guide 1: Choose the right question

Teachers know that questions differ in their degree of challenge. Questions that fit well with Peer Instruction represent a conceptual challenge for the students. A test question like, "Name the phases of mitosis in order," provides students with the opportunity to recall information. A test question like, "How does alternation of generations represent an effective evolutionary turn for the survival of some plant species?" requires students to think through several concepts and link them together.

Recall questions do not require Peer Instruction; simply providing the correct answer allows students to understand how their own answer was incorrect. Providing the correct answer for a conceptually challenging question does not allow students to understand how their answer was not correct. For such questions, merely providing answers without explanation honors the answer above the explanation. Without access to and practice with explanation of phenomena, students cannot truly develop an in-depth understanding of either scientific concepts or the central nature of argumentation in science.

Regarding the central nature of argumentation in science, Peer Instruction strengthens the conceptual fluency of students with correct answers. Such students may or may not fully understand all of the concepts behind the correct answer. Peer Instruction provides these students with a chance to talk through their thinking, particularly when a peer asks questions. As a result, it helps them think through

Fig. 2. A diagram of the seven steps in the peer-instruction process.

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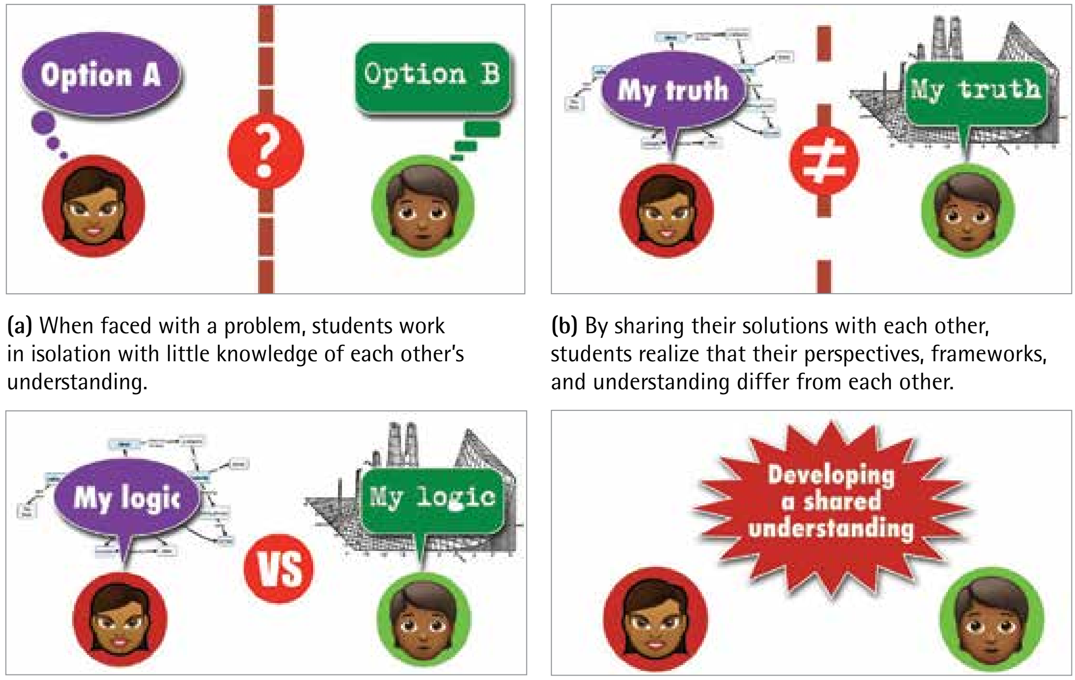
their response **and** articulate it so that another student can understand it. Challenging questions require a deeper level of understanding, and Peer Instruction allows students to work through that deeper level of understanding together, regardless of their initial answer. Essentially, Peer Instruction emphasizes **understanding** over merely getting the right answer, while allowing students to participate in the authentic practice of argumentation in science.

Fig. 3. How peer instruction works. Credits: Illustrations by Punya Mishra. License CC-BY-NC.



(a) When faced with a problem, students work in isolation with little knowledge of each other's understanding.

(b) By sharing their solutions with each other, students realize that their perspectives, frameworks, and understanding differ from each other.

(c) In attempting to convince each other of the correctness of their solution, students have to explain their logic and perspective on attacking the problem at hand.

(d) Through explaining their logic, the students have a higher probability of developing a correct shared understanding of the problem.

How to Implement: Think of Peer Instruction as a perfectly timed learning opportunity for your students. Will any old question do? Clearly, factual questions with answers that can be looked up do not work well. The trick, research shows, is to choose questions that focus on concepts, not on facts[6]. Also choose questions that incite curiosity – questions that may divide the class. Often, questions based on common misconceptions (e.g., *"in a frictionless world, which falls faster: a bowling ball or a tennis ball?"*) drive rich peer discussion.

Guide 2: Elicit individual responses

It seems counter-intuitive that individual responses are necessary for a technique called Peer Instruction, but research shows that Peer Instruction does not work without this crucial step. It is important for students to think initially through the question because it lights the fire of curiosity in the student. They make a decision and commit to it. When students do not engage in this step, peer discussion lacks robust peer critique. In these cases, less confident students often just go along with more confident students without deep discussion. Individual responses allow students time to engage with the question thoughtfully once without the influence of a peer. This initial commitment produces a deeper discussion between peers.

How to Implement: Ask the question and allow students to share their individual answers in class. Introduce white boards, flash cards, paddles with 'yes' or 'no' written on each side, (or, if you have access, technology like iClickers or free online tools like Braincandy.org) for them to brainstorm and note their answers. Give them time and space to form an individual response and commit to it. This creates more engagement in the peer discussion to follow. Students report that taking the initial responsibility to answer the question individually forces them to think more deeply about the question and the answer.

Guide 3: Peer discussion

Implementing peer discussion may be the single most important part of the whole Peer Instruction process. However, not every question posed to the class requires peer discussion. Research shows that when a question is too easy (over 70% of students get the correct answer on the first vote), teachers should just skip peer discussion because learning gains are negligible. If the question is too hard (under 35% of students get the correct answer on the first vote), teachers should provide more explanation or hints before discussion.

Additionally, teachers should prompt students to discuss not only their answers, but the **reasons behind their answers**. This is key because the focus of learning should be on conceptual understanding rather than getting the right answer. Research shows that when teachers prompt 'reason-centered' discussions instead of 'answer-centered' discussions, learning gains increase.

How to Implement: Observe students carefully during the first round of voting to see if the question is too easy or too difficult for peer discussion. If the question lies in the sweet spot between the two, then encourage students to turn to their neighbor and explain why they chose their individual answer. Give the students time to discuss; trust that they are acting as their own teachers.

Guide 4: Explaining the answer

Peer Instruction is incomplete without a final explanation by the teacher after voting, discussing, and re-voting. Studies indicate that combining peer discussion with instructor explanation outperforms other similar pedagogical approaches. Presumably, this is because students are now primed and motivated to hear the instructor's explanation. Which of their answers was correct — the first one (i.e., their individual answer), or the new one co-created with a peer? After the first steps of the Peer Instruction cycle, students are ready to hear their instructor's point of view.

How to Implement: Once student re-votes are collected, identify and explain the correct answer. Try to draw on some of the popular answers, explaining why a certain answer reflects a common misconception or why a certain answer is correct.

Conclusion

Peer Instruction empowers students to create their own ideas, defend their own thoughts and in the process bring clarity to their own thinking, and construct meaning with their peers. It motivates students, incites curiosity, and allows students to experience the collaborative aspect of finding answers. Peer Instruction works in a variety of disciplines and with students at different levels of engagement. And, if implemented correctly, it seems to improve not just factual knowledge but also conceptual knowledge. Peer Instruction belongs in the tool-box of every educator precisely because it is empowering and effective.

References

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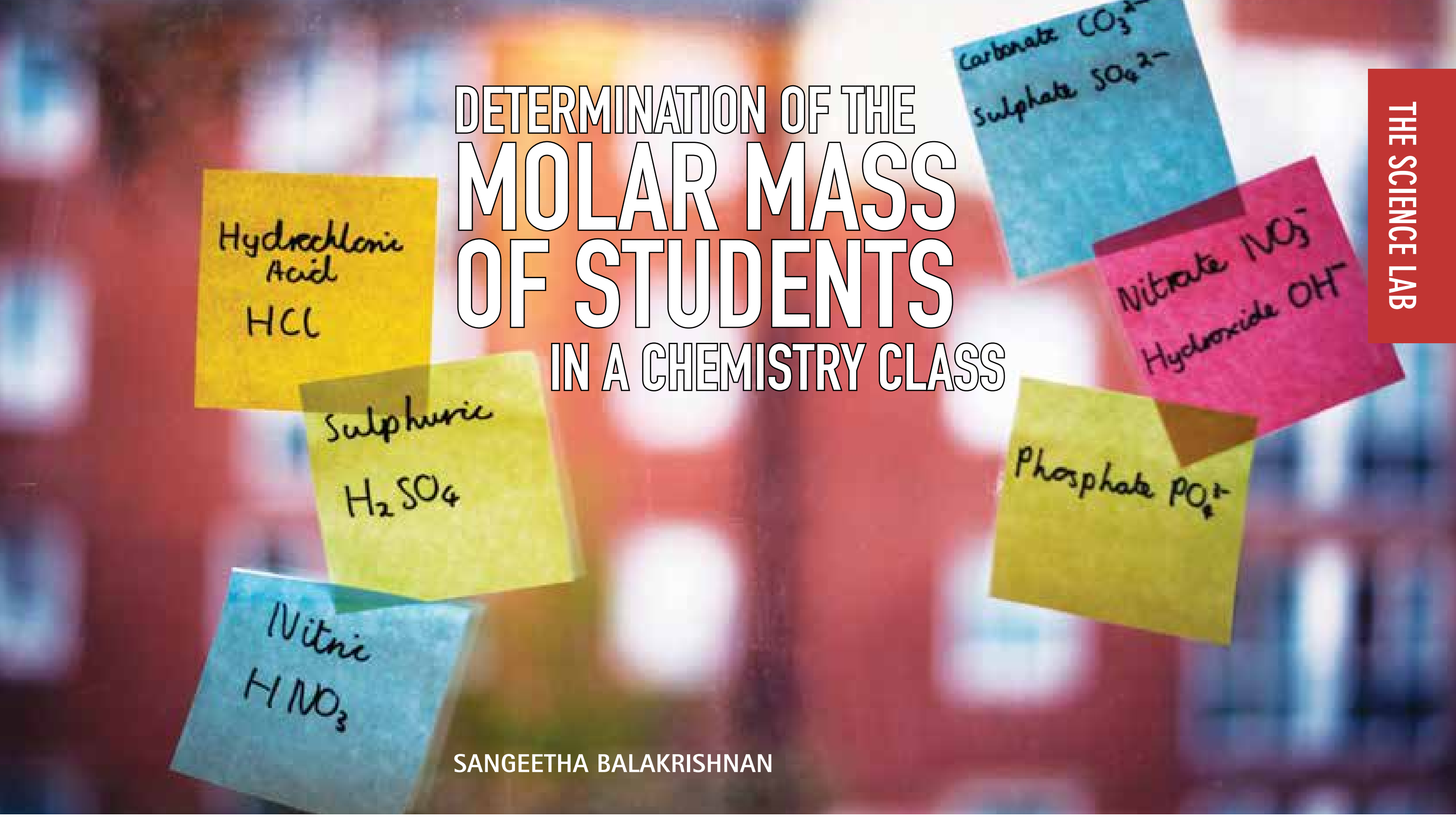


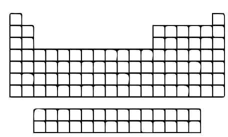
DETERMINATION OF THE MOLAR MASS OF STUDENTS IN A CHEMISTRY CLASS

SANGEETHA BALAKRISHNAN

A not-quite-procedure for not-really-an-experiment for chemistry educators

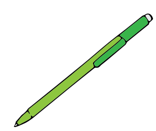
Aim: To determine the molar mass of students in a chemistry class[1].

Things required:



Periodic Table

Paper



Pen

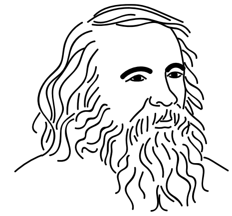
Non-things required: A group of chemistry students.

Principle: Ineffably fun. And funnily ineffable.

Setting: Best done impromptu. Especially when you begin to detect signs of boredom in the class.

Procedure

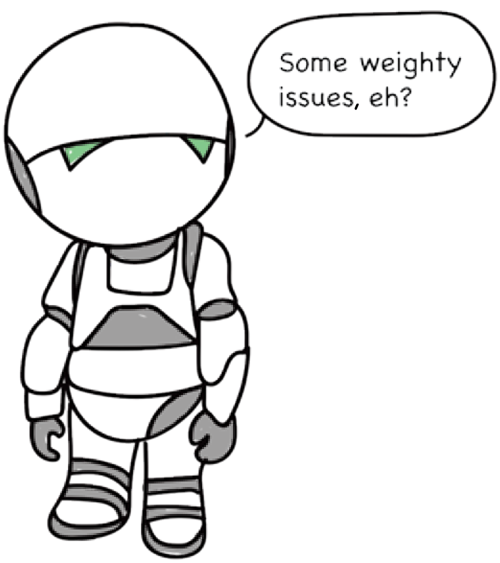

Antoine Lavoisier


Johann Wolfgang Döbereiner

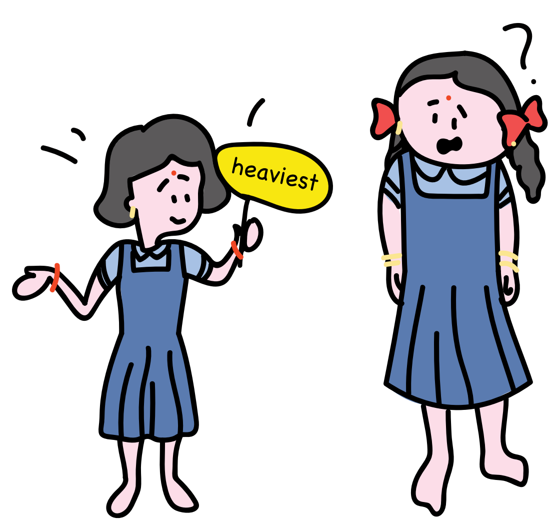

John Newlands


Dimitri Mendeleev

1. Pose the following question or some variant of it (semantics is your friend) to the students: *"So, shall we continue with this topic, or do you want to play a game?"* Chances are exceedingly high that upon posing the question, you'll go unimpeded to the next step[2].
2. Tell the students that they'll now be playing a game called '**Who is the heaviest of all?**' involving the periodic table. Make sure your enthusiasm is infectious.
3. This step is titled: A **very, very** short introduction to the periodic table. Lavoisier, Doebereiner, Newlands, Mendeleev and the four newly discovered elements – that's more or less your timeline here. You are, in essence, covering 300 plus years of work on the periodic table in a minute. Foray into the philosophy of the periodic table. This part of the step may be omitted depending on factors best known to you. Time for testing waters: 4 seconds. Time for your entire monologue: 56 seconds (because: foray[3]).
4. This step shall never be omitted. Talk to the students about some of the ways in which the periodic table has been used outside of curricular instruction. Do not forget to mention the **Periodic Table Table**[4].

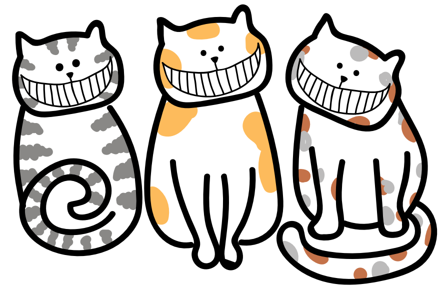


5. This is the **procedure per se** of the procedure. Write your first name on the black /green /white board in the classroom. Make the letters big and bold. Circle symbols of elements in your name. Write down the atomic masses of those elements on the board. Add them up. The resultant number is your molar mass in atomic mass units (amu). Put a big, bold polygon around it.
6. Task for the students: ask students to calculate their molar mass as per the **procedure per se** of the procedure. Instruct students to choose the heavier combination of elements in their first name. For example, if **Marvin the Paranoid Android** were your student, among the following two elemental combinations available to him in his first name, Marvin would go with the first one:
    a. Ar (argon), V (vanadium), I (iodine) and N (nitrogen). This combination affords a molar mass of 231.8006 amu.
    b. Ar (argon), V (vanadium) and In (indium) which affords a molar mass of 205.7075 amu.
7. Announce a small prize for the 'Heaviest student of all'.
8. Announce another small prize for students with Nh (nihonium), Mc (moscovium), Ts (tennessine) and Og (oganesson) in their first names.
9. Ask students to carry out the task, and shout out their mass if they beat yours written on the board.
10. Brace yourself for gleeful outbursts from the students[5].
11. Record every new 'top chemical molar mass' on the board with the student's name.
12. Look for the 'winner' as per 7.



13. Separately, look for 'winners' as per 8.

14. Grin. Put an entire clowder of Cheshire cats to shame.



Result

Happy students. They think the Periodic Table was never more fun.

A happier teacher. You think the Periodic Table was never more fun[6].

Precautions

Colleagues might pop their heads into your classroom wondering if you and your students have smuggled nitrous oxide from the lab into the class.

On detection of such quizzical looks, smile beatifically.

Notes:

1. Exercise done in class with inspiration drawn from Journal of Chemical Education 2015, 92 (10), 1757-1758.
2. Personal experience and anecdotal evidence.
3. Foray (n): a short period of time being involved in an activity that is different from and outside the range of the usual set of activities. Source: http://dictionary.cambridge.org/dictionary/english/foray. Also, it is assumed that a foray lasts less than a minute.
4. http://theodoregray.com/periodicTable/
5. Being in the midst of this will be a heartening experience.
6. Each class is unique, and the teacher is the best judge of when and how to introduce any activity therein. The author used this activity to break the monotony of lecturing. However, it can easily be used as an add-on activity for school students when introducing the Periodic Table to them; or better yet, when teaching molar masses. It is hoped that since this activity engages students on a personal level, it will help them grasp the underlying chemical concepts better.
7. Credits for the image used in the background of the article title: Chemistry Test. Thebarrowboy, Flickr. URL: https://www.flickr.com/photos/thebarrowboy/6283758878. License: CC-BY.

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