Michael Smith Science Challenge 2019 Analysis of Results

Shannon MacFarland, Theresa Liao, and Chris Waltham,

UBC Department of Physics and Astronomy

Translator: Nikita Bernier

Introduction

The Michael Smith Science Challenge is a national bilingual science contest written by students in grade 10/niveau 4 and below. It was first piloted in the province of British Columbia in April of 2002, and since then it has been run annually across Canada. The purpose of the contest is to challenge students' logical and creative thinking with minimal memorization required. The Michael Smith Science Challenge is the only nationwide competition covering all science subjects taught in grade 10/secondaire 4.

This year 117 teachers from 8 provinces and one territory registered for the contest. On the day of the contest, many schools were closed due to snowstorms across the country. A total of 1266 students participated; 53% identified as male, and 47% identified as female.

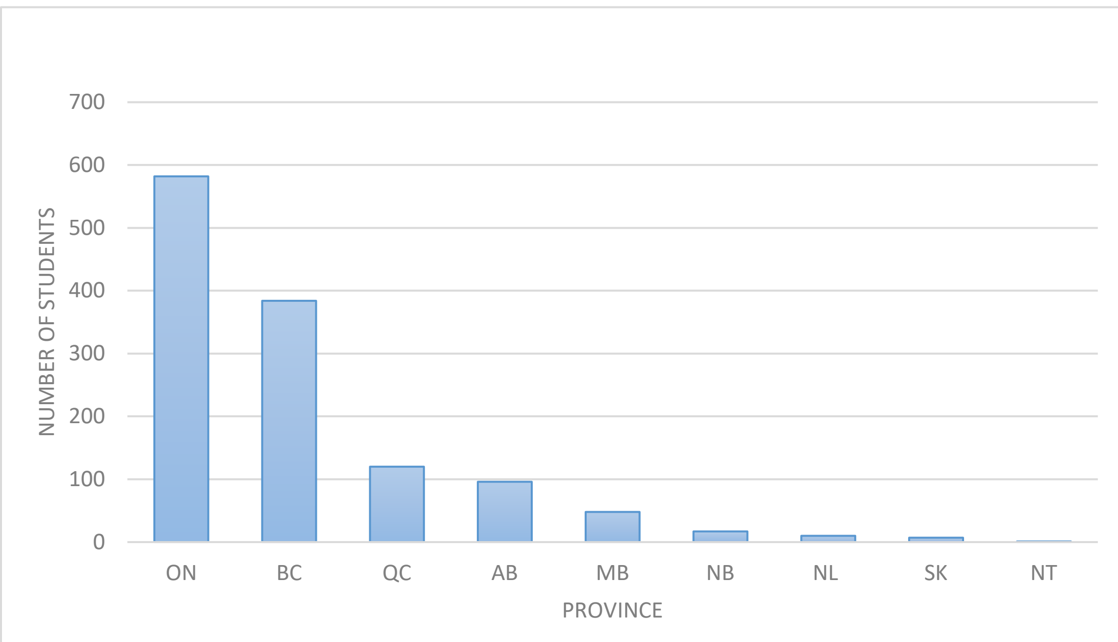


Figure 1: The number of students participating, by province

Aims of the Questions

Question One: Can students read information provided graphically and use that information to solve a problem?

Question Two: Can students apply readily available information or common knowledge (in this case provided for them in the question), together with some simple calculations, to predict the consequences of announcements made in the media?

Question Three: Do students know anything about scientific issues much banded about in the media and apply their school learning to help understand them?

Question Four: Do students understand the general concept of “steady-state”? This concept is as central to human metabolism as it is to such issues as global temperatures and economics (from the personal to the national). If you want things to stay the same, then at some level what goes in has to come out. This question also required some basic understanding of chemistry and human metabolism, i.e. atoms can be neither be created nor destroyed, but molecules can be, in chemical reactions like the “burning” of carbohydrates to fuel our metabolism.

Results

The total mark distribution is shown in Fig. 2. The highest mark was 67/80; the mean was 26/80.

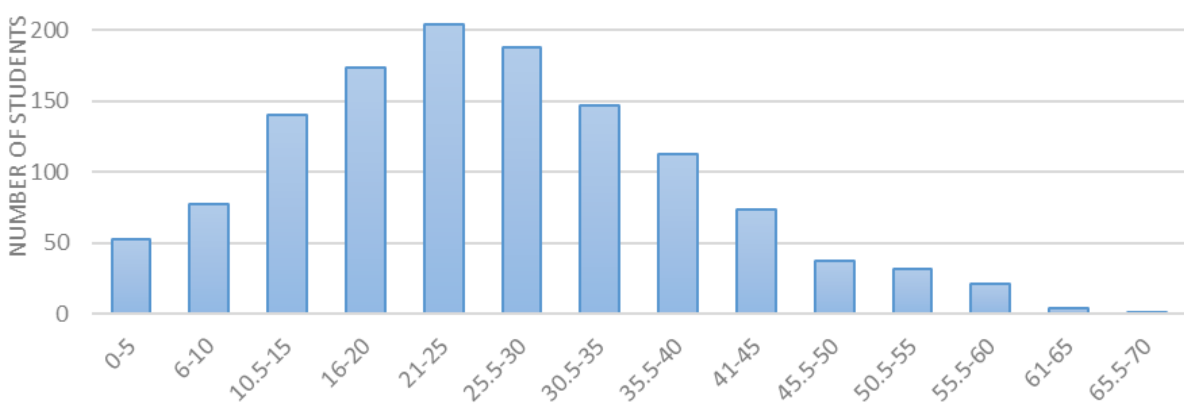
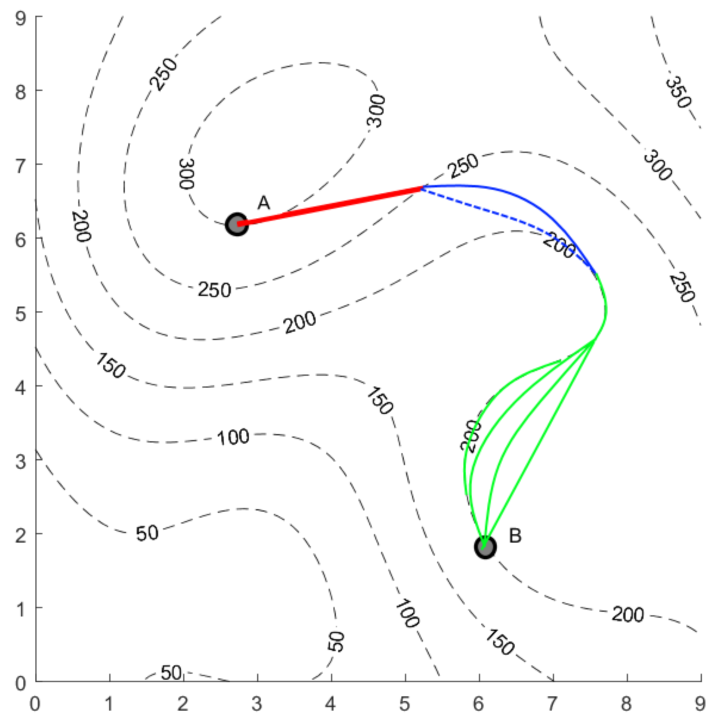


Figure 2: The distribution range of marks (out of 80).

The Contest

1. You are designing a light rail transit system in a new, as yet unbuilt, city. The city is to be built on bare but hilly terrain shown on the contour map below. Your task is to design the shortest track between two planned suburbs, marked with circles A and B, with a grade no larger than 2% (i.e. the elevation must not rise or fall more than 20 metres per km). The track is to be built on the surface; you are not allowed to build bridges, cuttings or tunnels. Draw a line to show where the track should be built.



Contour map of site of planned city. The axes are marked in km, the contours in metres

The maximum gradient of 20 m/km is equivalent to 50 m (the contour spacing) in 2.5 km.

Red section: This section is 2.5 km long, the shortest way to the 250 m contour with a 2% grade.

Blue section: It is impossible to reach the 200 m contour directly in a straight line with a grade under 2%. Therefore this section has to be curved (and as long as the red line), neatly avoiding a sharp corner, which would be difficult for a railed vehicle to negotiate. The dashed line shows the limit of what was acceptable for full marks.

Green section: This is part has a poorly defined gradient, as the hill is plainly not as steep above as below. Taking the gradient below as a reasonable worst case, the straight line most probably has too steep gradient a gradient up and down (~80 m up and down in 3.2 km). Following the contour line is longer but safe, as we know the gradient is zero.

Common Mistakes:

- Tracks which went directly down to the 150 m contour and back up to B, violating the 2% rule
- Correct general shapes but with sharp corners. Light rail would not be able to traverse sharp corners.

The mean score for this question was 5.27/20; 25 students received full marks for this question.

2. In late 2018 the British Columbia (BC) government announced that all cars in the province must be solely electric-powered by the year 2040. If we are to avoid powering these cars with electricity generated by burning fossil fuels, we will need new hydroelectric facilities and windfarms.

   (a) The population of BC is five million and its residents own about three million cars. Assume each car is driven 20,000 km per year, with an average fuel economy of 10 L/100 km, and that the energy content of gasoline is 36 MJ/L. How much extra power will the province need to produce to run all these cars solely on electricity? Note: There are inefficiencies (energy losses) in both running gasoline engines and powering electric motors, so assume for the purposes of comparison that these inefficiencies are the same. Give your answer in the most appropriate units (i.e. W, kW, MW, GW etc.)

Find the total distance driven per year:

$$3 \text{ million cars} \times 20{,}000 \text{ km/year} = 6\times10^{10} \text{ km/year}$$

Find the total volume of gasoline used per year:

$$6\times10^{10} \text{ km/year} \times 10 \text{ L/100 km} = 6\times10^{9} \text{ L/year}$$

Find the total energy used per year (there are multiple ways to reach this step):

$$6\times10^{9} \text{ L/year} \times 36 \text{ MJ/L} = 2.16\times10^{11} \text{ MJ/year}$$

To find the mean power in watts, the total annual energy must be divided by the number of seconds in a year:

$$2.16\times10^{11} \text{ MJ/year} \times \frac{1\ year}{365\ days} \times \frac{1\ day}{24\ hours} \times \frac{1\ hour}{3600\ seconds} = 6849 \text{ MJ/sec} = 6849 \text{ MW}$$

The most appropriate units for this number is GW, final answer 6.849 GW

Common Mistakes:

- Division (instead of multiplication) of the total distance driven per year by the volume of gasoline.
- A majority of students thought the amount of energy in joules was the amount of power in Watts and did not proceed further.
- Some students who tried to convert joules to watts used random conversion rates to do so e.g.: watts = joules/60

   (b) Comment on the magnitude of your answer to (a).

Full marks were awarded for any meaningful numerical comparison at the provincial or household level, e.g. noting that 1 GW is the power output of a large hydro dam or thermal power station.

(Note that the controversial Site-C dam project in BC will have a 1.1 GW output. We did not expect students to provide this particular detailed piece of information.)

Most students only restated their answer to part (a) or gave vague statements such as “This is a large number”

The mean score for this question was 7.43/20; two students received full marks for this question.

3. The 1987 Montreal Protocol called for all developing countries to stop production of ozone-destroying chlorofluorocarbons (CFCs) by 2005. Most industrialized nations had stopped production by 1995. However, there is evidence that CFC production is now increasing.
   Ozone (O3) and atomic oxygen (O) are produced in the upper-atmosphere by the interaction of sunlight with ordinary molecular oxygen (O2), forming the "ozone layer":

$$O_2 + O_2 \rightarrow O + O_3$$

   If CFCs get into the upper-atmosphere, sunlight splits the molecules to form atomic chlorine, Cl. Then this pair of chemical reactions happens, resulting in the breakdown of ozone back into ordinary molecular oxygen:

$$Cl + O_3 \rightarrow ClO + O_2$$

$$ClO + O \rightarrow Cl + O_2$$

(a) Why is even a tiny amount of atomic chlorine so damaging to the ozone layer?

In the two reactions chlorine is a catalyst i.e. it is both a reactant and a product. Students did not need to know the word catalyst, but had to recognize that chlorine broke down ozone in the first equation and in the second equation it was replenished, while ozone was not.

Common Mistakes:

- Many students thought that because a smaller number of chlorine atoms was affecting a larger number of oxygen atoms, the ozone would deplete at a faster rate.
- Some students thought that it was because chlorine is toxic.

(b) Why is the integrity of the ozone layer so important?

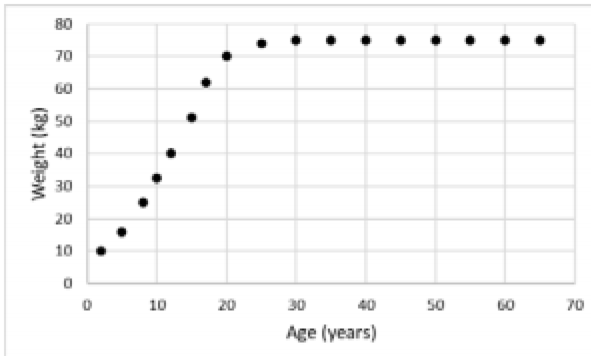
The ozone layer on Earth helps block harmful ultraviolet rays from the sun; if the ozone layer were to breakdown the increase in ultraviolet rays reaching the Earth's surface would lead to increased skin cancer.

Common Mistakes:

- The most common misconception was that the ozone layer helps prevent global warming, when in actuality the ozone layer acts is a minor greenhouse gas.
- The ozone layer protects us from space debris.
- The ozone layer produces oxygen.
- The ozone layer prevents gases and heat from escaping/regulates Earth's temperature.

The mean for this question was 7.37/20; 52 students achieved full marks for this question.

4. Consider these questions about food and nutrition. For (a)-(c) we are looking for statements based on general principles that compare the mass excreted to the mass ingested. In each case, briefly state which principle you are considering.
   Here is a plot of how the weight of person "A" developed with age:



   (a) Health Canada recommends that healthy adults ingest mass X of sodium per day. What can you say about the mass of sodium that person "A" at age 40 should excrete per day? Why?

Sodium atoms cannot be destroyed. Therefore, if a human body is in a steady-state (as indicated by a constant weight), the amount of sodium ingested per day must on average be equal the amount excreted per day.

   (b) Health Canada recommends that healthy teenagers ingest mass Y of calcium per day. What can you say about the mass of calcium that person "A" at age 15 should excrete per day? Why?

Calcium atoms cannot be destroyed either, but at age 15, calcium is being used to build bones, although some calcium may also be excreted. Therefore, on average, the amount of calcium excreted per day should be less than the amount ingested per day.

   (c) Health Canada recommends that healthy adults ingest mass Z of carbohydrates per day. What can you say about the mass of carbohydrates that person "A" at age 40 should excrete per day? Why?

Carbohydrates molecules can be destroyed; they are burned to provide energy for metabolic functions. Some absorbed carbohydrates are excreted (e.g. as dietary fibre). Therefore, on average, the amount of carbohydrates excreted per day should be less than the amount ingested per day.

Common mistakes:

- Students tried to extract numbers from the graph, or invent percentages for how much should be excreted, even though only general statements were requested.
- Instead of comparing the amount ingested to the amount excreted, students compared ingestion for different age groups.

- Many students believe that sodium and carbohydrates are bad for the body, and suggested ingesting *less* than what Health Canada recommended.
- Many confused ingestion and excretion, and made statements like ‘Because teenagers need calcium they should excrete more’, or suggested that people should excrete more than they are ingesting.

(d) A five-year study of a novel food X by experts at University A concludes that X is perfectly safe. At the same time, another five-year study of X by experts at University B concludes that X is dangerous and should not be marketed. Assuming that the two panels of experts are equally distinguished, and you want to know whether you can eat X safely and regularly, what questions should you ask about these studies?

We gave marks if the student’s question related to comparing the two studies, and the students’ questions needed to refer specifically to one aspect of the studies.

Examples of aspects raised in good questions:

- Funding from manufacturer/industry/lobby group?
- Demographics of subjects the same? Age, gender, health?
- Were sample sizes the same?
- Animal or human subjects?
- Definition of safe/dangerous?
- Was range of diet controlled?

Examples of questions we thought too imprecise, irrelevant, or those not comparing the two studies:

- “What were the differences between the studies?”
- Questions relating to the production and ingredients of X, rather than the study itself
- Asking whether trials were conducted at all
- Questions relating to timeframe, which was clearly stated in the question to be the same for both studies.

The mean for this question was 6.02/20; four students received full marks for this question.