# Michael Smith Science Challenge 2016

## Analysis of the Results

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## Introduction

The Michael Smith Science Challenge is a national 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. 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/niveau 4. It is offered in English and French.

This year 167 teachers from 10 provinces registered for the contest. A total of 1781 students participated, 50% identified as female and 50% as male.

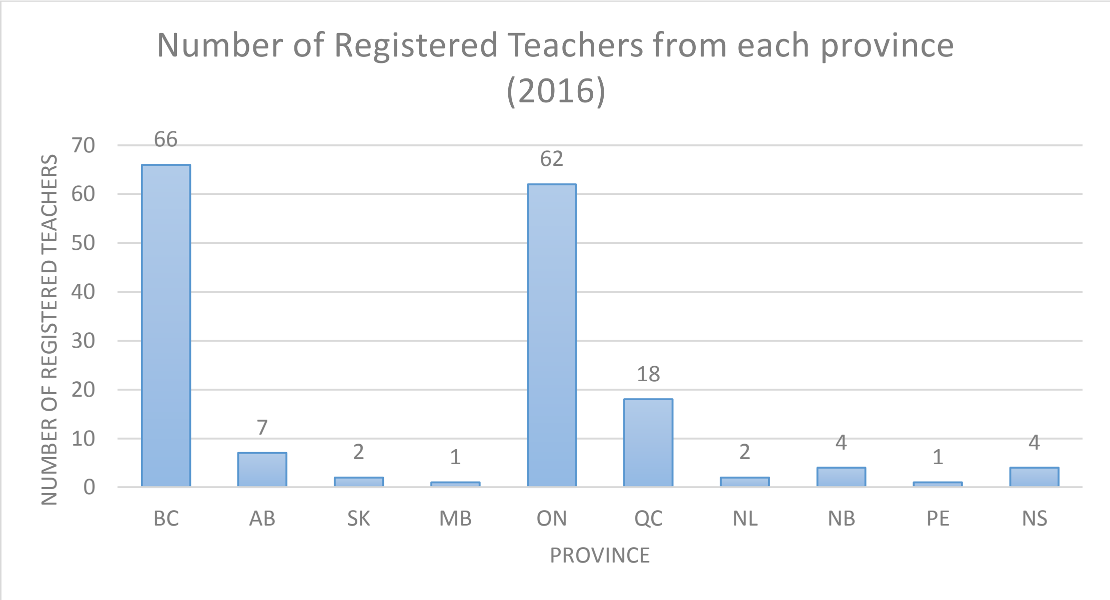



Figure 1: The number of teachers who registered for the challenge in each province.

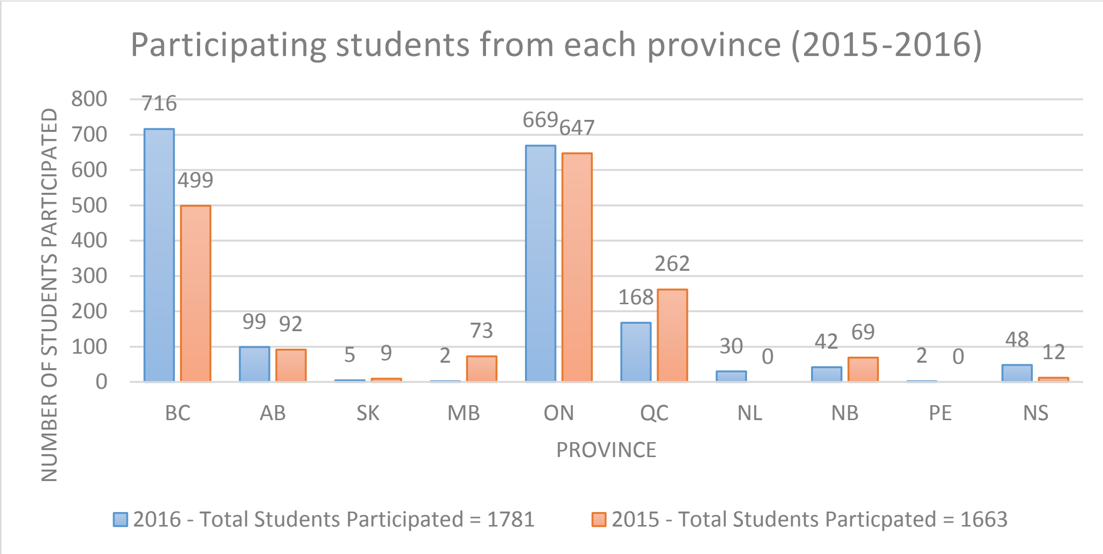
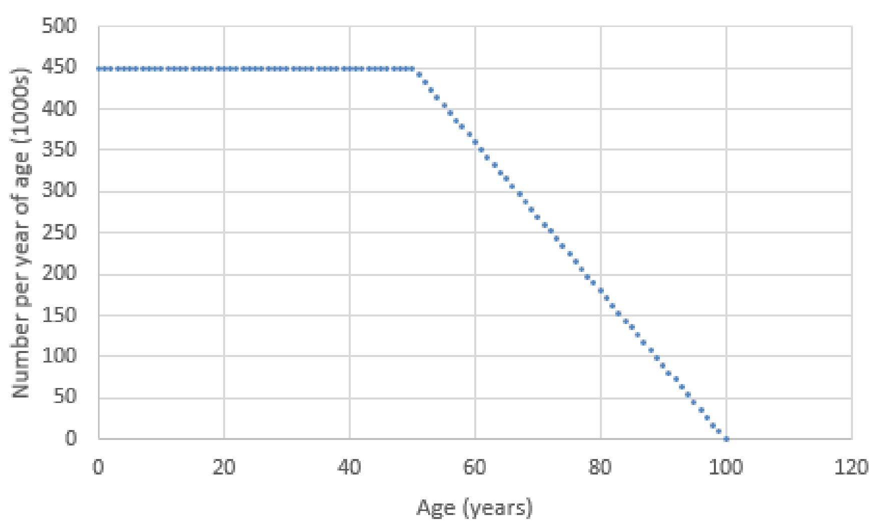



Figure 2: Student participation by province in the 2015 and 2016 Michael Smith Challenges.

# The Contest

## Question 1

The approximate age distribution of the Canadian population is shown in this histogram:

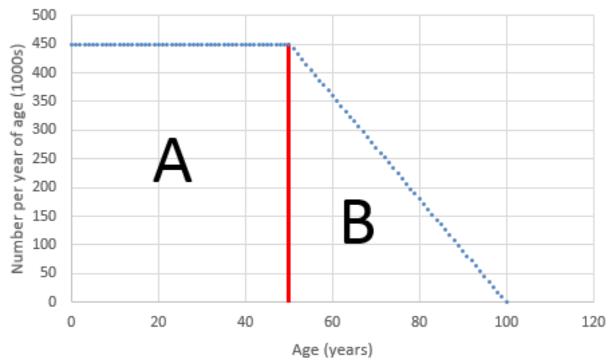



***Mark Distribution:***
***4 marks*** *(part A)*
***4 marks*** *(part B)*
***4 marks*** *(part C)*
***4 marks*** *(part D)*
***4 marks*** *(part E)*
***Top mark:*** *20/20 (92 students)*

For example, there are about 450,000 of us aged 20 (i.e. born between 20 and 21 years ago), but only about 250,000 aged 72.

Using only data shown in this histogram, answer the following questions, briefly describing your reasoning:

(a) What is the total Canadian population?




The total population of Canada can be determined by finding the area of rectangular section A and triangular section B;

$$(50)(450{,}000) + \left(\frac{1}{2}\right)(50)(450{,}000) = 33{,}750{,}000$$

Common Mistakes:

- Approximately ¼ of students gave the answer of 35,000,000, which is the current population according to Wikipedia, although the students probably recalled the number from memory.
- The most common method for trying to determine the total population was described by students as "adding up the dots", i.e. summing the population in each year bin. While this gives hints of understanding that the area of the graph represents the total population, it almost always led to an incorrect answer.

(b) What percentage of the Canadian population is 50 or younger?

The percentage of Canadians 50 or younger as deduced from the histogram is 66.7%. This can be found by dividing the population under section A of the histogram by the total population and converting that to a percentage.

Common Mistakes:

- Approximately 1/5 students answered the question with 2/3, while this is not incorrect, the question asked for a percentage, so only 3 marks were awarded in this case.
- The majority of incorrect answers for this part were due to students getting the incorrect answer for part (a). Marks were not deducted for this if they showed an understanding of how to determine the percentage.

(c) If there was no immigration into or emigration from Canada, how many Canadians would have to be born each year to keep this histogram looking the same for the foreseeable future?

To keep the histogram looking the same 450,000 people must be born each year. This is due to the fact that currently 450,000 people are aged 0-1 on the histogram, so this cannot change.

Common Mistakes:

- Some students simply gave the incorrect order of magnitude due to mistakes when reading the axes of the graph; part marks were awarded for this.

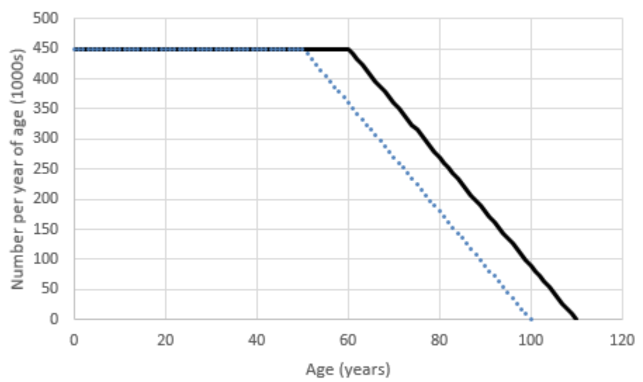
(d) If there was no immigration into or emigration from Canada, how many Canadians would have to die each year to keep this histogram looking the same for the foreseeable future?

This number is the same as the number of Canadians that would have to be born; 450,000. To keep the histogram looking the same, the net change in the population has to be zero, so the number of people being added to the population has to match the number of people being removed. If these two numbers are not equal the population would increase or decreases changing the histogram.

Common Mistakes:

- A quarter of the contestants gave an answer of around 10,000,000 because that is the number of the population over 50 who are beginning to die.
- Half of students did not realize that the answers to parts (c) and (d) should be the same. For incorrect but equal answers (about 20% of responses) for parts (c) and (d) two marks were awarded.

(e) Some medical researchers think they can cure aging. If no-one died from now on, what would the histogram look like in 10 years' time (assuming all else stays the same, and no immigration/emigration)? Draw the new line on the histogram above.




Since nobody at any age is dying, the shape of section B of the histogram does not change, it is simply pushed to the right by ten years as 450,000 babies continue to be born each year.

Common Mistakes:

- While there were a wide variety of answers for this question, the two most common mistakes were (i) simply extending the horizontal line at 450,000 on the y axis all the way out to age 100, and (ii) drawing an upward diagonal line starting at age 100 with a slope of the same magnitude as the downward line from age 50 to 100. Each mistake was made by about 20% of students.

## Question 2

***Mark Distribution:***
***20 marks***
***Top mark:*** *20/20 (92 students)*

We Canadians each waste about 100 kg of food carbohydrates per year. If these carbohydrates are composted anaerobically, half the carbon atoms end up as carbon dioxide ($CO_2$) and half end up as methane ($CH_4$).

The energy needs of a small single-family dwelling is typically 0.3 GJ per day averaged over a year. How long could such a house be supplied with energy from composting 100 kg of carbohydrates?

The approximate ratio of carbon, hydrogen and oxygen atoms in carbohydrates, C:H:O, is 1:2:1.

The enthalpy of combustion of $CH_4$ (i.e. the "energy content") is 55 MJ/kg

The students were given the following information:

| Element | Symbol | Atomic Mass |
|---|---|---|
| Hydrogen | H | 1 |
| Carbon | C | 12 |
| Oxygen | O | 16 |

The decomposition of carbohydrates can be represented by the chemical formula, which can be deduced from the information that half the carbon atoms end up in carbon dioxide and half in methane:

$$2CH_2O \rightarrow CO_2 + CH_4$$

Energy can thus be extracted from composted carbohydrates by collecting and burning the methane.

$$2CH_2O \rightarrow CO_2 + CH_4$$

60 44 16

By adding the atomic masses given, we can use this formula to find that 60 kg of carbohydrates yield 16 kg of methane, and so 100 kg of carbohydrates would yield (100/60)(16) = 26.67 kg of methane (a value of 27 kg was accepted).

To find the energy generated by this mass of methane, we multiply it by the enthalpy of combustion.

$$(26.67\text{ kg})\left(\frac{55\text{ MJ}}{\text{kg}}\right) = 1467\text{ MJ} = 1.467\text{ GJ}$$

If a house need 0.3 GJ/day, then 26.67 kg of methane can supply this for a time period $T$, given by:

$$T = \frac{1.467\text{ GJ}}{0.3\text{ GJ/day}} = 4.89\text{ Days}$$

The energy generated from the methane would last a household approximately 5 days.

Common Mistakes:

- Approximately 2/3 of students split the 100 kg of carbohydrates in half, stating that 50 kg ended up as methane. This led to an answer of 9 days.
- Some students used the atomic fractions of carbohydrates to deduce that there was 25 kg of carbon, 50 kg of hydrogen, and 25 kg of oxygen.

- ¼ of students stated that they could not answer the question because the enthalpy of combustion for $CO_2$ was not provided. One cannot burn $CO_2$, unfortunately.
- Points were awarded for showing understanding of the concepts involved in the question, even if answered incorrectly. For example, if students showed they understood the conversion of GJ to MJ, or if they wrote the correct chemical formula for the decomposition of carbohydrates into methane and carbon dioxide.
- Many students showed that they understood that half of the mass of carbon would go to the methane and all of the mass of hydrogen, but simply calculated the incorrect values for these masses.

## Question 3

***Mark Distribution:***
***6 marks** (part A)*
***4 marks** (part B)*
***10 marks** (part C)*
***Top mark:** 20/20 (32 students)*

In recent weeks the astronomers have been excited about a possible large planet with an orbital radius twenty times that of Neptune. The planet may be a gas giant like Neptune, or a rocky planet like other smaller objects beyond Neptune. The gravitational disturbance of known minor planets indicates that its mass may be ten times that of the Earth.

(a) Why haven't we found it already? Circle any reasonable explanation:

I. Our telescopes cannot see that far.

II. It is too far away for light to reach us; the light dies out on the way.

III. Light from the planet hasn't had time to get to us yet.

IV. It receives too little light from the Sun to reflect enough back for us to see easily.

V. There are too many objects as dim out there and we would have to know precisely where to look to say which one it is; our understanding of that part of the Solar System is not yet that good.

VI. It takes so long to orbit the Sun, moving too slowly across the sky for easy identification as a planet.

For this part of the question two marks were awarded for each correct answer leading to a maximum of six.

Common Mistakes:

- This part was well answered with few students receiving zero marks. A quarter of the contestants picked answers from I-III but not from IV-VI, revealing gaps in their general knowledge of light and the relative magnitude of the solar system in relation to the whole visible universe.

(b) Once identified, how do you think we will first find out whether it is a gas giant or a rocky planet?
Circle any reasonable possibility:

I. We'll send a satellite there to look.

II. If we see rocks on the surface, it is a rocky planet.

III. If it has craters, it has to be a rocky planet.

IV. If it has lots of moons it has to be a gas giant.

V. Gas giants are only made of gas so they are almost invisible compared to rock.

VI. Gas giants are much bigger than rocky planets for the same mass and so will be much brighter.

Response VI is the most likely to be the first indication we receive about the nature of this planet. However, I-IV are possibilities in the more distant future. Hence, one mark was awarded for circling each of I-IV and four marks were awarded for VI. Zero marks were given for (V) even if (VI) was chosen as well, the two being mutually exclusive. A maximum of four marks could be obtained, so if I, II, and VI were circled for example, four marks would be awarded.

Common Mistakes:

- While many students scored highly on this question, it was mainly due to choosing the first four answers. The sixth answer was chosen by about 1/3 of students.
- Only around 5% of students selected V, not realizing that the brightest visible planet in the night sky, apart from our close neighbour Venus, is the much more distant gas giant Jupiter.

(c) If this planet was rocky with the same internal structure as the Earth, what would its diameter be? The Earth's diameter is 13,000 km.

Using the Earth's mass ($M_E$) the formula for a sphere (i.e. recognizing that mass scales as the cube of the diameter), we can set up the following equation (where $d_E$ is the diameter of the Earth and $d_9$ is the diameter of the 9th planet):

$$\frac{d_9^3}{d_E^3} = \frac{M_9}{M_E}$$

$$\frac{d_9^3}{(13{,}000\ \text{km})^3} = \frac{10M_E}{1M_E}$$

Since the units for the mass of the earth (M) cancel out, we can solve this equation for our variable $d_9$. We find that the diameter of the 9th planet would be approximately 28,000 km.

Common Mistakes:

- Approximately 2/3 of students scaled the diameter up by a factor of 10, stating that since the internal structure is the same that means the density profile is the same, and the diameter should scale linearly with mass. While this showed an understanding that scaling was needed, the diameter does not scale linearly with mass. Part marks were awarded for linear scaling.
- Some students stated that they did not know the mass of the earth and therefore could not answer this question.
- ¼ of students grasped the concept of setting up an equation to solve for the variable of the radius, but simply used the incorrect formula for sphere to derive this equation, using R or $R^2$ instead of $R^3$

Note: a recent analysis assuming planet 9 is similar in its interior to Uranus and Neptune gives a much larger diameter of 97,500,000 km.
http://www.bbc.com/news/science-environment-35996813

## Question 4

> ***Mark Distribution:***
> ***20 marks***
> ***Top mark:*** *20/20 (169 students)*

The atomic nucleus consists of positively charged protons and electrically neutral neutrons bound together by a mysterious force ("MF") in a tiny space, the nucleus, much smaller than the atom itself. We can learn something about this force by making some observations:

1. Neutrons and protons do not individually fly out of the nucleus spontaneously.
2. Negatively charged electrons are in stable orbitals around the nucleus, held by electrostatic attraction, and do not stick to the nucleus.
3. Atomic nuclei only exist stably up to the certain size (e.g. $^{209}$Bi), then they fall apart spontaneously (e.g. $^{238}$U).
4. The most common atoms have more or less equal numbers of the protons and neutrons (e.g. $^{12}$C, $^{16}$O).

What can you deduce from the above observations? Here are some possibilities:

(a) The MF is just like the electrostatic force, except that positive charges attract each other
(b) The MF may have nothing to do with electrical charge
(c) The MF must be much weaker than the electrostatic force
(d) The MF must be much stronger than the electrostatic force
(e) The MF is attractive, affecting only the neutrons
(f) The MF is attractive, affecting both protons and neutrons
(g) The MF seems strongest in the presence of both protons and neutrons
(h) The MF must have a short range, much less than the radius of an atom
(i) The MF must have a very long range, much more than the radius of an atom

Pair off as many deductions and observations that you think are correct

| Observation used as evidence | Deduction |
|---|---|
| e.g. (2) | e.g. (a) |
| 1-4 | B |
| 1 | D |
| 1 & 4 | F |
| 4 | G |
| 3 & 2 | H |

Each correct pairing was worth four marks. For example, students selecting 1B, 3B, and 3H received 12 points. However, if a student paired an observation with two mutually exclusive deductions then no marks were awarded even for the correct answer. The mutually exclusive deduction are as follows:

- C & D
- E & F
- H & I

Only the first 6 answers were counted as that was the number of spaces given.

Common Mistakes:

- A pairing of 1 & A was chosen by 1/3 of students implied too broad a generalization; we can only deduce that the MF has some property that is strong enough to overcome the repulsion of the protons' electrostatic force.
- Another common selection was 3 & I, showing a misunderstanding of the size proportions of different parts of the atom. The nucleus takes up a very small fraction of the total volume of an atom, which is mostly occupied by an electron cloud.

## Final Results

The total mark distribution is shown in Fig. 3. The mean was 40.0% and the standard deviation was 14.1%. The mean scores for each question are shown in Fig. 4.

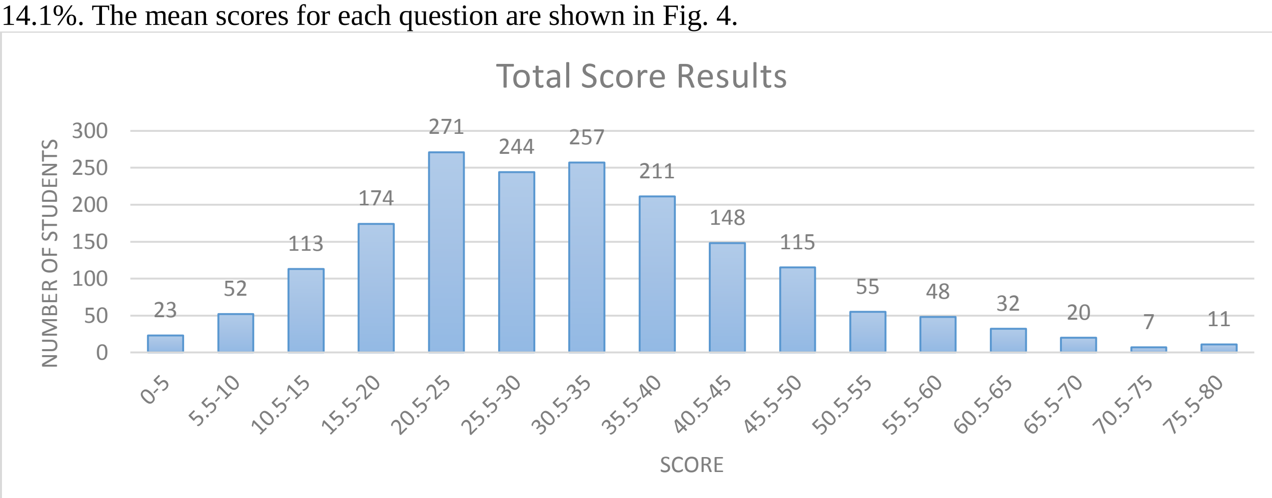
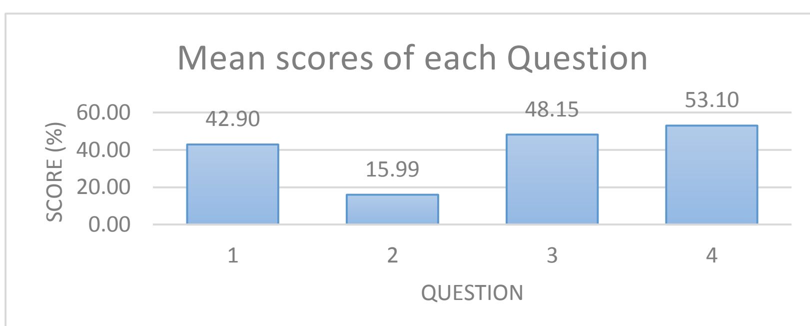



Figure 3: The distribution range of marks. The highest mark achieved was 100% (two students).

Figure 4: The mean scores for each of the four questions as percentages.



## Awards

This year two students tied for first place with a score of 80/80; both received $500. The third placed student received $100. The top-scoring students from each province who did not receive a national prize was awarded $100. In B.C. four students tied for the top place in the province, so four $50 prizes were awarded. Teachers of all prize-winning students received a $50 prize. All prizewinners, students and teachers, received certificates.

Certificates were awarded to those students who scored in the top 10%, 3%, and 1% (i.e. those with marks of 50/80 or more, 62/80 or more, and 71/80 or more, respectively).

## Reference

http://outreach.phas.ubc.ca/exams-and-competitions/michael-smith-challenge/msc-english/