Michael Smith Science Challenge

2009

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Analysis

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Introduction

The Michael Smith Science Challenge is a Canada-wide grade 10 contest organized and run by the University of British Columbia Department of Physics and Astronomy Outreach Program since 2003. Named after the late Michael Smith who was awarded the Nobel Prize in 1993, it was created as a way to prepare interested science students for specialized contests in later years as well as to test student's general knowledge in all aspects of science, rather than a single discipline. The Challenge is written by approximately 800 students annually. It is downloaded off of the Outreach Program's website[1] and then printed and photocopied by each invigilating teacher. This year the contest was written on March 12, a month earlier than last year. An early date was set so that certificates would arrive at schools before end of year ceremonies took place.

Design of the Michael Smith Challenge 2009 Exam

The Michael Smith Challenge was originally a multiple choice examination. This was changed to a short answer format in 2005 after it was discovered that the distribution closely mirrored that of random guessing, except for students who scored high marks (>50%). Questions are usually designed in such a way that they can be answered without the student knowing specialized information beforehand.

The 2008 Challenge was scored out of 30. Upon marking it was discovered that this did not allow a large enough distribution of scores (specifically at the high end) to differentiate students. For example, there were six students tied for third place. To address this issue, each individual question this year was made to have more parts to it and be worth more marks. Thus, the 2009 exam was marked out of 120, with individual questions being worth anywhere from 5 to 20 marks, depending on their complexity.

In addition, one long answer question, Q3, was added and was worth 20 marks. This question, which was perhaps comparable in length to Q4 but not divided into subsections, was very open-ended (although some guidance was given in the question itself) and it was hoped that many different numerical grades would be awarded.

Brief Discussion of Registration

The registration system was unchanged from previous years – it still utilized the web form system.

[1] http://www.physics.ubc.ca/outreach/web/index.php This site contains information on all Outreach programs including the Phenomenal Physics Summer Camps, the Physics Olympiad and the Physics 420 course.

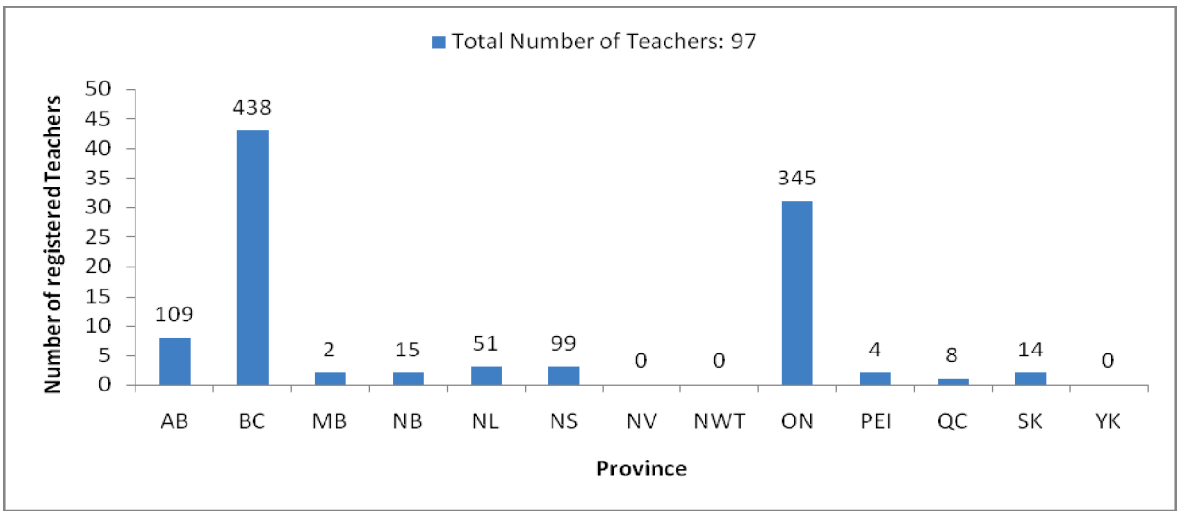


Figure 1: Showing the distribution of teachers registered by province and territory. Teachers registered using the web form available off of our website. Labels indicate the number of students registered by teachers in that province.

Similar to previous years, the province with the most registered teachers was British Columbia, followed by Ontario and Alberta. As can be seen in Figure 1, these provinces also had the most registered students. Ninety of the ninety-seven teachers registered sent in exams (although many sent in fewer exams than the number of students they registered). In total, exams for approximately 4/5 of registered students were received.

This year the page where teachers could download the exam was password protected. Thus, teachers had to register beforehand in order to be able to download the exam (although this did not stop a couple of teachers from registering the day of the contest). Overall, more students were registered to write the exam than in any previous year.

Results of the Michael Smith Challenge Exam

Overall

Province	Number of Writers	Average Score (/120)
AB	101	51.4 ± 18
BC	376	39.2 ± 20
MB	2	56.5 ± 0.7
NB	13	20.9 ± 14
NL	32	47.7 ± 13
NS	68	23.8 ± 15
ON	267	41.6 ± 21
PE	3	32.3 ± 11
QC	7	43.7 ± 10
SK	8	47.8 ± 17
National	876	40.3 ± 20

Table 1: Shows both the distribution of writers across the provinces of Canada as well as the average score of writers in each province. Error values represent one standard deviation from the mean.

As can be seen in Table 1, the three provinces with the largest number of writers were British Columbia, Ontario and Alberta, as has been the case for the past several years. This year had the largest number of students submit an exam in the history of the Challenge. What is notable is that Quebec had only 7 students write the exam (from only one teacher) despite having the second largest population of any province in Canada. Of the provinces with more than 50 writers, the averages of Newfoundland and Alberta are clearly significantly higher than those of British Columbia and Ontario. Whether this is simply due to a smaller sampling size or a better alignment of curricula with the contest is unclear.

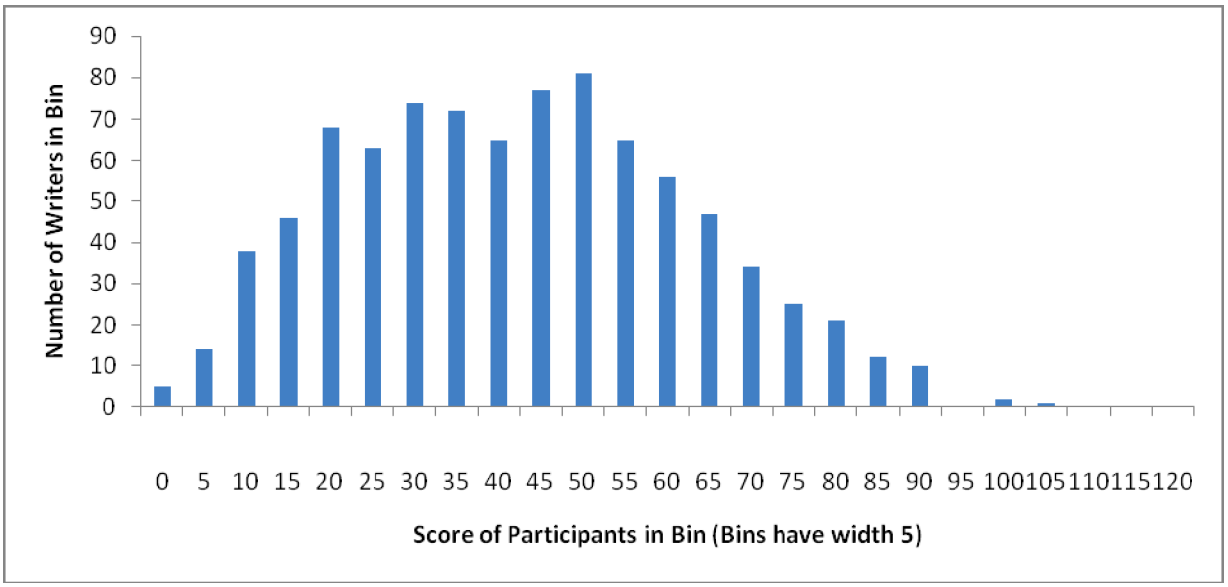


Figure 2: Chart showing the frequency distribution of marks. The maximum score was 101 and the average was 40.3 out of 120. The bin width was 5 with the x-axis labels showing the maximum score in the bin.

The average score was 40.3/120 (standard deviation of 20) out of a sample size of 876 students. Results were much improved from previous years as there were not as many ties at high scores (compare the top 3 marks: in 2008 the top 3 scores were achieved by 8 students, this year only by 5). As can be seen in Figure 2, scores were fairly well distributed (especially the high-end tail). Three students obtained a score of 80% or higher - consistent with previous year's contests.

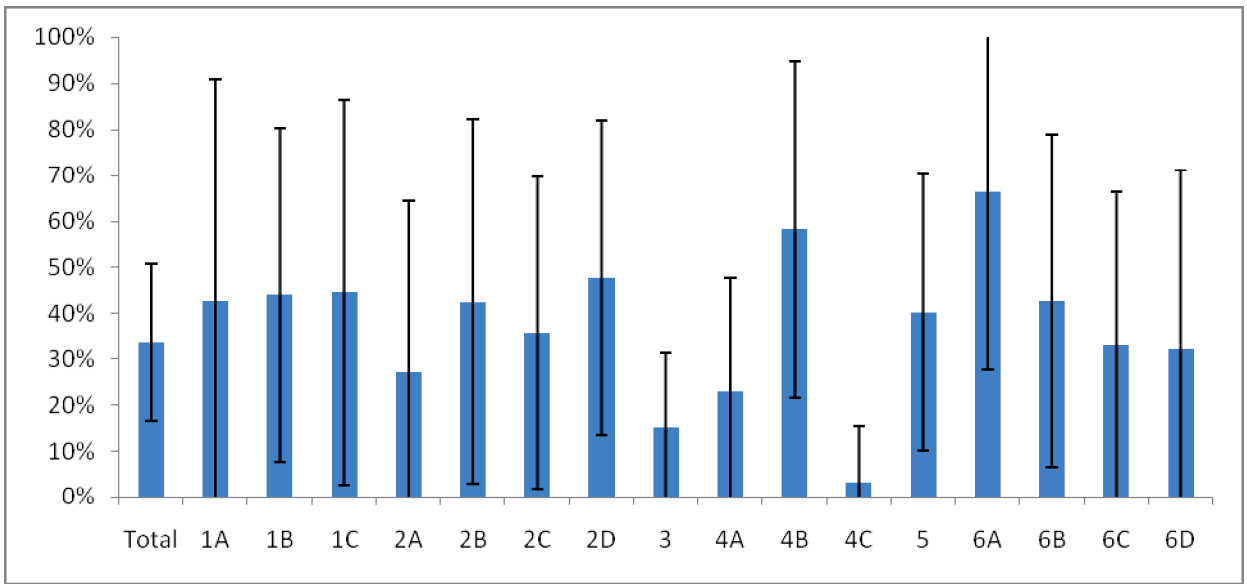


Figure 3: Chart showing the average score on each question. Error bars indicate the standard deviation of the scores. Note that some error bars have been truncated on the graph as they lie above 100% or below 0%.

Looking at each question individually (Figure 3), one can see that for the most part questions were done consistently (eleven out of seventeen questions had averages between 30% and 60%). Notable exceptions were question 3, 4A, 4C and 6A. 6A tasked the students with writing the basic photosynthesis equation which was perhaps widely memorized. 4A and 4C are surprising as the former was a graphing question based on common experience and the latter was basic stoichiometry. Question 3 was the most open ended question that tasked students with interpretation so perhaps the low score is not as unexpected.

Question 1

Question 1A

How many cubic millimetres are there in a cubic metre? Show how you arrived at your answer.

$$\frac{1m}{1000mm} = 1$$

$$1m^3 = 1m^3 \times \left[\frac{1000mm}{1m}\right]^3 = 1 \times 10^9 mm^3$$

Question 1B

What is the surface area, in m^2, of a one-mm cube?

$$Surface\ Area\ of\ Cube = 6 \times Area\ of\ side$$

$$Area\ of\ side = 1mm \times 1mm = 1mm^2$$

$$Surface\ Area = 6 \times 1mm^2 = 6mm^2$$

$$6mm^2 = 6mm^2 \times \left[\frac{1000mm}{1m}\right]^{-2} = 6 \times 10^{-6} m^2$$

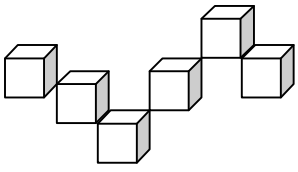
Question 1C

Suppose you have 512 of these one-mm cubes and are free to combine them into any shape you see fit. What is the minimum surface area your shape could have? What is the maximum surface area your shape could have? Leave your answers in mm^2.

$$Minimum\ Area = (8 \times 8)Cube$$

$$Minimum\ Area = 6 \times 64mm^2 = 384mm^2$$

$$Maximum\ Area = 512 \times 6mm^2 = 3072mm^2$$



Example of portion of shape with maximum area.

Marking Scheme:

1A
3 Marks: *Using the ratio [1000mm/1m]* ^{3} *= 1 (or an equivalent form)*
2 Marks: *Correct final answer*

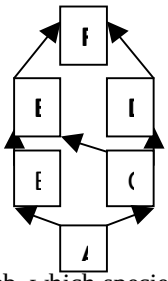
1B
1 Mark: *Multiplying answer by 6*
2 Marks: *Using the ratio [1000mm/1m]* ^{2} *= 1 (or an equivalent form)*
2 Marks: *Correct final answer*

1C
1 Mark: *Min area is a cube*
1 Mark: *Correct answer for min area*
2 Marks: *For knowing that the max area is a shape where no parts of any cube are covered by another*
1 Mark: *Correct answer for max area*

Note: We also accepted the answer of max area = "Line of cubes" because of potential ambiguity of the question

The national averages were 2.1, 2.2, and 2.2 out of 5 for parts a, b, and c respectively. Students from Saskatchewan scored the highest on this question averaging 9.5/15. 38% of students got 1A correct. 25% of students thought that 1000mm=1m implied that $1000mm^3 = 1m^3$. Only 25% of students got 1B correct with most (37%) being unable to convert from mm^2 to m^2. 1C was similar to 1B with 28% achieving 5/5. 19% got the maximum value correct but failed to calculate the minimum value properly. 15% left the question entirely blank. Of those who got the correct answer, 95% assumed a ñline of cubesò as only 11 students realized that connecting the cubes by their edges resulted in zero area being covered. Question 1 was designed to test whether students understood what conversion factors represent (unity) as well as their spatial awareness.

Question 2



Question 2A

In the above closed food web, which species has the most biomass? Why?

Species A is at the lowest trophic level and so it must support all species above it. Since energy transfer through trophic levels is inefficient, A must have the most biomass.

Question 2B

In one sentence, describe the interaction between species E and species D.

Species E and D are in competition for the same food source.

Question 2C

Species B makes a toxin that prevents species D from preying on it. (Species E is unaffected by the toxin). Species B is brightly coloured. Assuming colouration is an indicator of toxicity, which species would benefit most by mimicking the colouration of species B? Why?

Species C would benefit the most by mimicking species Bôs warning colouration as species D may recognize the colour and stop preying on C.

Question 2D

Many years ago, PCBs (a class of chemicals susceptible to bioaccumulation) were introduced into the ecosystem where this community lives. For dinner, you have a choice of eating the same mass of species A, species C, or species F. These three species have equal concentrations of fat per kg body-mass. Which species would have the highest concentration of PCB?

Species F would have the highest concentration of PCB because biomagnification occurs as one goes up a food chain.

Marking Scheme:

2A
1 Mark: *At the lowest trophic level (or equivalent)*
1 Mark: *Has to support all other levels*
1 Mark: *Inefficient energy transfer*
2 Marks: *Correct final answer*

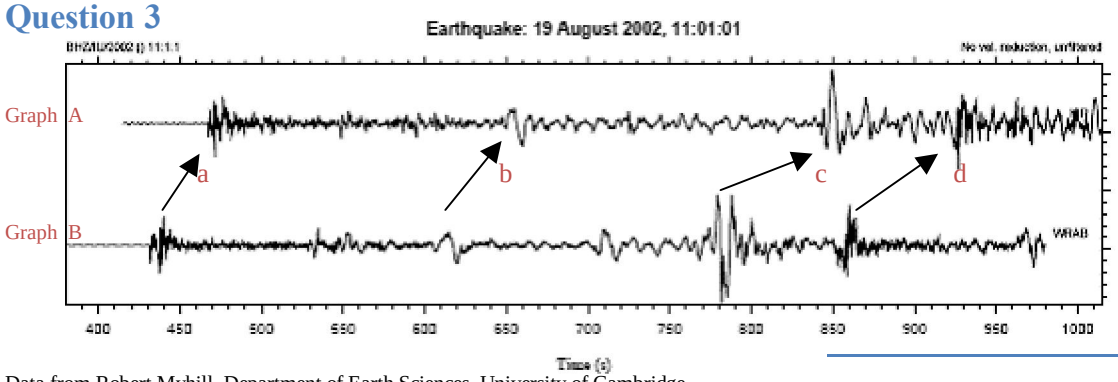
2B
2 Marks: *Mentioning they have same prey*
3 Marks: *Indicating they are competing for the same food source*

2C
2 Marks: *Indicating species D will relate colour to toxin*
1 Mark: *Species D may therefore stop preying on species C*
2 Marks: *Correct final answer*

2D
3 Marks: *Concentration of toxin increases as you go up the food web ("biomagnification" or equivalent form)*
2 Marks: *Correct final answer*

The national averages were 1.4, 2.3, 1.8 and 2.4 out of 5 for parts a, b, c, and d respectively. Students from Manitoba averaged the highest on parts a and c (4.0, 3.0 out of 5) and students from Newfoundland scored the highest on parts b and d (3.0, 3.8 out of 5). Overall, Newfoundland students averaged the highest at 12.0/20. Only 8% of students got 2A correct; the most common mistake was thinking Species A was the top of the food chain (38%). 16% of students said species A but gave an incorrect reason. 2B was done better with 28% getting it correct (common errors were mentioning that they shared the same food source but not indicating competition (21%) or only mentioning that F eats both species (16%)). Again only 8% of students correctly answered 2C with the two most common mistakes being not mentioning that the predator would associate colour with toxin (35%). Fortunately, the writers did better on 2D, with 17% receiving full marks. Common mistakes were giving only partial explanation (29%) or no explanation at all (22%). Apparently, students thought that since there was no ñWhy?ò tacked on they did not need to justify their answers (maximum mark was 2/5 if no explanation was given).

Question 3



Data from Robert Myhill, Department of Earth Sciences, University of Cambridge

The above figure shows traces from two seismographs positioned 500 km apart. The time is measured from that of the earthquake (calculated using data from many such stations). Using these traces, tell us what you can deduce, especially about the speed of the seismic waves. Feel free to draw on the figure.

Graph B was located closer to the epicentre than Graph A because the seismic waves arrive at earlier times.

The peaks labelled a, b, c, and d on the graph are clearly the same waves being recorded at different stations.

One can calculate the average speed of these waves via:

$v_{avg} = \frac{\Delta x}{\Delta t}$, $\Delta x = 500km$ and Δt as found from the above graph

This yields: v_a = 12.5km/s, v_b = 10km/s and $v_c = v_d$ =7.1km/s. These speeds are the maximum possible average velocities because it is never stated that the seismograph stations are aligned with each other and the earthquakeôs epicentre.

Since the waves travel at different speeds they are likely different types of waves.

One can estimate the distance to the epicentre using any of these speeds and $d = v_{avg} \times t$. This yields d_a=5375km, d_b=6050km, d_c=5467km and d_d=6035km for the epicentre-seismograph B distance. One could then give a range of data points.

Marking Scheme:

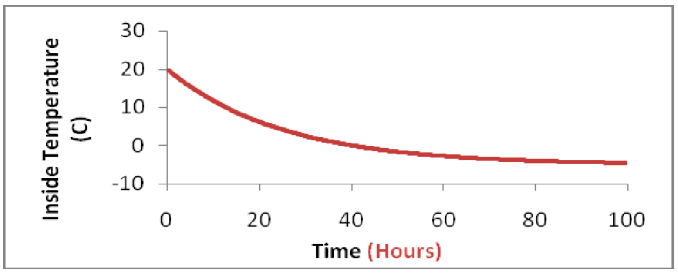
2 Marks: *Station A is closer to epicentre than B*
4 Marks: *Pattern matching the 4 waves*
4 Marks: *Calculating the speed of one of the waves*
1 Mark: *Mentioning that this is the "maximum average speed" (or equivalent statement)*
3 Marks: *Calculating the speed of the other 3 waves*
2 Marks: *Noting that the waves travel at different speeds and so are likely different types of waves*
2 Marks: *Estimating the distance to the epicentre.*
2 Marks: *Calculating more than one epicentre distance and giving a spread of values*

This was the only question on the exam that no writer was awarded full marks. The maximum score was 15/20. The national average was 3.0/20 with Quebec students having the highest average out of the provinces (4.3/20). It should be noted that some information on this question was accidently removed: it was originally given that Station B was 500km closer to the epicentre than Station A. This facet may have confused some students. Based on the answers, it appears that some students may have written less information than they actually knew (i.e. calculating the speed of only one wave). Furthermore, many students only described the graph (i.e. using words such as ñrumbling,ò ñvery slowò etc.) rather than extracting useful information from it. 32% were able to determine that the Earthquake arrived at one station earlier than the other. Despite the specific mention of seismic wave speed in the question, only 25% calculated any sort of speed. Only a couple of students pointed out that this calculated speed was ñthe maximumò or ñthe averageò (or both). 9 students calculated the speed of all three waves; while 17 students calculated the distance to the epicentre, only 1 gave a spread of data. The goal of this question was to see how well students could use patterns to deduce useful information.

Question 4

Question 4A

The supply of natural gas to a gas-heated home is suddenly cut off. The temperature outside is ï 5°C. Sketch on the plot below how the inside temperature of the house changes with time. What are reasonable units for the timescale?



Question 4B

Natural gas is composed mostly of methane (CH_4) and is burnt in order to generate heat. Write a chemical equation describing this combustion. Is this reaction exothermic or endothermic?

$$CH_4 + 2O_2 \rightarrow CO_2 + 2H_2O$$

This reaction is exothermic (releases heat)

Question 4C

The heat of combustion of methane is 55.2 GJ/tonne. Suppose the furnace of a house burns methane at a rate of 10 kW during the winter. How much CO_2 does the furnace produce per day?

1t CH_4/55.2GJ = (1t CH_4/55.2GJ)×(1GJ/1×10^9J) × (10^6g CH_4/1t CH_4) × (1mol CH_4/16g CH_4) × (1mol CO_2/1 mol CH_4) × (44g CO_2/1mol CO_2) = 5×10^{-5}g CO_2/J

10kW = 10000J/s = 864×10^6J/Day

[g CO_2/Day] = (864×10^6J/Day) × (5×10^{-5}g CO_2/J) = 43000g CO_2/Day

Marking Scheme:

4A
1 Mark: *Graph starts around 20°C*
5 Marks: *Graph has a smooth exponential decay*
2 Marks: *Graph is approaching, but not reaching, -5°C*
2 Marks: *Units for timescales is hours*

4B
2 Marks: *Correct reactants*
2 Marks: *Correct reactant coefficients*
2 Marks: *Correct products*
2 Marks: *Correct product coefficients*
2 Marks: *Exothermic*

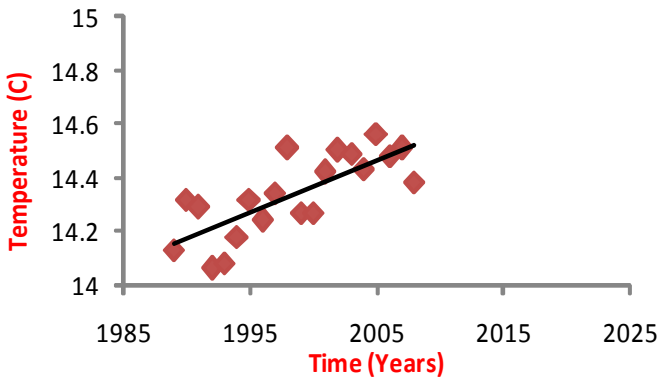
4C
1 Mark: *Converting from GJ to J*
1 Mark: *Converting from tonnes to grams*
2 Marks: *Obtaining correct molar masses for CO_2 and CH_4*
1 Mark: *Correctly using stoichiometric ratio of CO_2:CH_4*
3 Marks: *Correctly converting from kW to J/Day*
2 Marks: *Correct final answer*

The average national scores were 2.3, 5.8, 0.3 out of 10 for parts a, b, and c respectively. The two students from Manitoba had the highest combined average: 17.0/30. In second were Quebec students at 13.3/30. 15% of students drew the correct shape of the graph. 62% thought that the timescale should be in minutes (compared to only 13% saying hours), perhaps because of the ñ60ò on the axis. 20% of students used temperatures outside of 17-23°C (most commonly at 30°C). Question 4B was well done uniformly and had the second highest average out of any question. Question 4C was done particularly poorly: only 10 students obtained the correct answer. 47% of students left 4C blank. 12% of students simply guessed an answer while 19% either multiplied or divided 55.2 and 10 by each other. The poor showing on 4C was very surprising, as a similar question had been asked in the 2007 exam (Q7) where the average score was 2.3/6 and only 25% of students left the question blank. Many students also did not seem to know what a watt was, with several attempting to use the rate of change of power (often 10kW/day).

Question 5

The following table shows the average surface temperatures (T, given in Celsius) of a small rocky planet orbiting around an average-sized star. The measurements were made over the last 20 years. Using these data (and no other consideration), estimate what the mean surface temperature of this planet will be in the year 2025. (Hint: some graph paper is printed below).

Year	T(^{o}C)		Year	T(^{o}C)		Year	T(^{o}C)
1989	14.13		1994	14.18		2004	14.43
1990	14.32		1995	14.32		2005	14.56
1991	14.29		1996	14.24		2006	14.48
1992	14.06		1997	14.34		2007	14.51
1993	14.08		1998	14.51		2008	14.38



Extrapolate line to 14.7-15^{o}C

Marking Scheme:

5 Marks: *Correctly plotting all data points*
1 Mark: *Correctly labelling x- and y-axis*
4 Marks: *Putting a straight line through data*
3 Marks: *For using linear approximation to predict an answer within 14.7-15^{o}C*
*(**1 Mark** if between 14.6-15.1^{o}C)*
2 Marks: *Giving a range for temperature*

The national average was 6.0 marks out of 15. Students from Newfoundland averaged the highest mark: 7.4/15. Three students managed to score all 15 marks. 65% of students managed to correctly plot all data points although 20% left the question blank (one wonders why when it was hinted in the question to plot the data). 47% managed to label both axes correctly with 16% leaving the axes blank. It is interesting that some students decided to put labels without any data (perhaps they have grown accustomed to receiving marks for it). Only 30% of students decided to plot a straight line through the data with 33% putting a squiggly line following the data and 28% putting no line at all. 30% were able to give a reasonable value for temperature with 24% guessing a value, 13% ignoring the upward trend and giving the average temperature, and only 17 writers providing a range of data points. This question was a fairly standard graphing question that we hoped would give students an idea of how one can easily see the general scattered temperature rise. And yes, the rocky planet was Earth for those who asked.

Question 6

We can express the basic mechanism for life in the form of word equations, like:

wordA + wordB +é → word1 +word2 + é

Using some of the following words (and no others):

- argon
- carbon dioxide
- oxygen
- glucose
- hydrocarbon
- water
- ice
- ultra-violet
- sunlight
- kinetic energy
- heat

write a word equation for

Question 6A

Plant Life

Sunlight + Carbon Dioxide + Water → Oxygen + Glucose

Question 6B

Animal Life

Oxygen + Glucose → Carbon Dioxide + Water + Kinetic Energy

Now construct a word equation for a non-living thing, a gasoline-powered (non-hybrid) car.

Question 6C

Accelerating

Hydrocarbon + Oxygen → Carbon Dioxide + Water + Kinetic Energy

Question 6D

Braking

Kinetic Energy → Heat

Marking Scheme:

6A
1 Mark: *Per word*

6B
1 Mark: *Per word*

6C
1 Mark: *Per word*

6D
2 Marks: *Kinetic Energy*
3 Marks: *Heat*

All Questions:
1 Mark: *Subtracted if incorrect reactant used*
1 Mark: *subtracted if incorrect product used*
There were several exceptions to the above scheme, however.

The national averages were 3.3, 2.1, 1.7, and 1.6 for parts a, b, c, and d respectively. Students from Manitoba had the highest average (12.5/20) followed by those from Alberta (12.0/20). 43% of students got 6A correct; on the other hand, only 9% got 6B correct and 6C was even worse with only 8% achieving 5/5. 6D was done slightly better: 13% achieved full marks. 12% of students (13% for 6B) did not use arrows with the most common replacement being the ó=ô sign, possibly due to students not having seen equations with →ôs in them before. 154 students left 6D blank, compared with 80, 43, and 19 for parts c, b, and a. This may indicate that students were running out of time at this point as these questions were eminently guessable. One interesting note was that students did much better describing photosynthesis than cellular respiration, despite the former being a more complicated process. In addition, students were better at identifying both photosynthesis and cellular respiration than accelerating and braking, perhaps because it is more familiar to see biological reactions in this form. Another odd trend was the extensive use of argon in all parts of the question.

Awards

This year, the highest scoring student received a prize of $500. Two students tied in second place and received a $250 prize. Additionally, $100 prizes were given out to the top student from each province who did not win a national prize. Teachers of these award winning students received a $50 prize. Both the students and teachers received a certificate acknowledging their achievements.

For students who scored 68 or more out of 120 a Top 10% certificate was also awarded. Similarly, a Top 25% certificate was given to those who scored greater than or equal to 55 out of 120 but were not in the top 10%.

Results Package to Teachers

Teachers are sent a package by post that contains a list of their students' scores as well as certificates for those students who were in the top 10% or 25% and an official receipt for their payment. Additionally, if the teacher had a student who won either a provincial or national award, the package contains a certificate for that student (who does not receive a top 10% certificate), a cheque for the student's prize money, a certificate acknowledging the teacher and a cheque for the teacher's prize money. A letter is also given notifying the teacher that they can request additional certificates for other teachers who collaborated on the student's education.

Reference

Waltham, C., Kotlicki, A., Bates, G., & Leander, C. (2008). Canada's National Grade 10 Science Contest: The Michael Smith Science Challenge. *Physics Competitions , 10* (2), 16-23.