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.

A total of 1438 exams were received this year, from 8 provinces and 133 teachers.

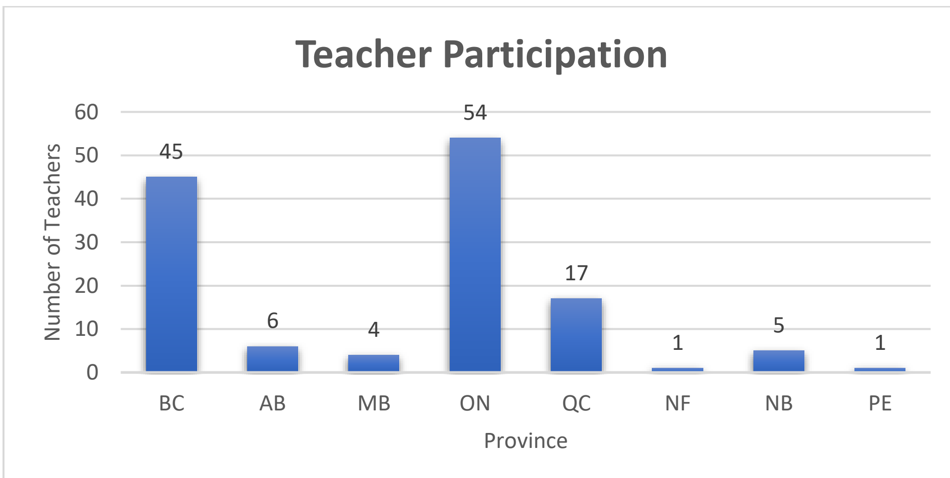


Figure 1: Teacher Demographics

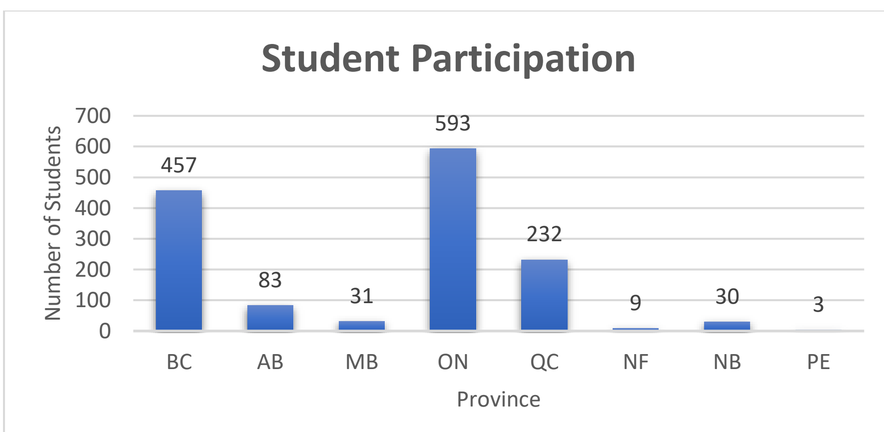


Figure 2: Student Demographics

Results

With reference to the scores out of 80, the mean was 24.5, the mode was 27 and the median was 24. 10% of students scored 41 or above (shown in green).

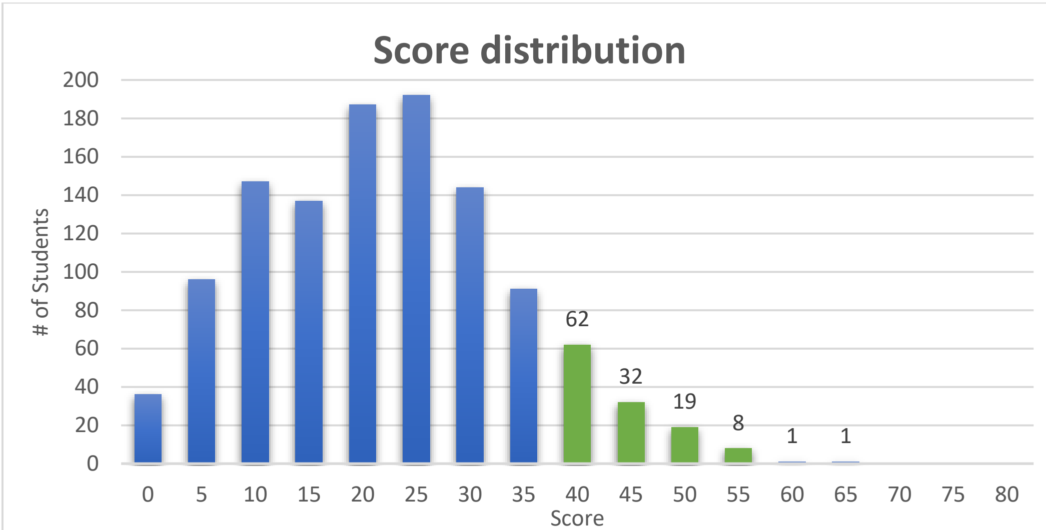


Figure 3: Score distribution for the entire exam.

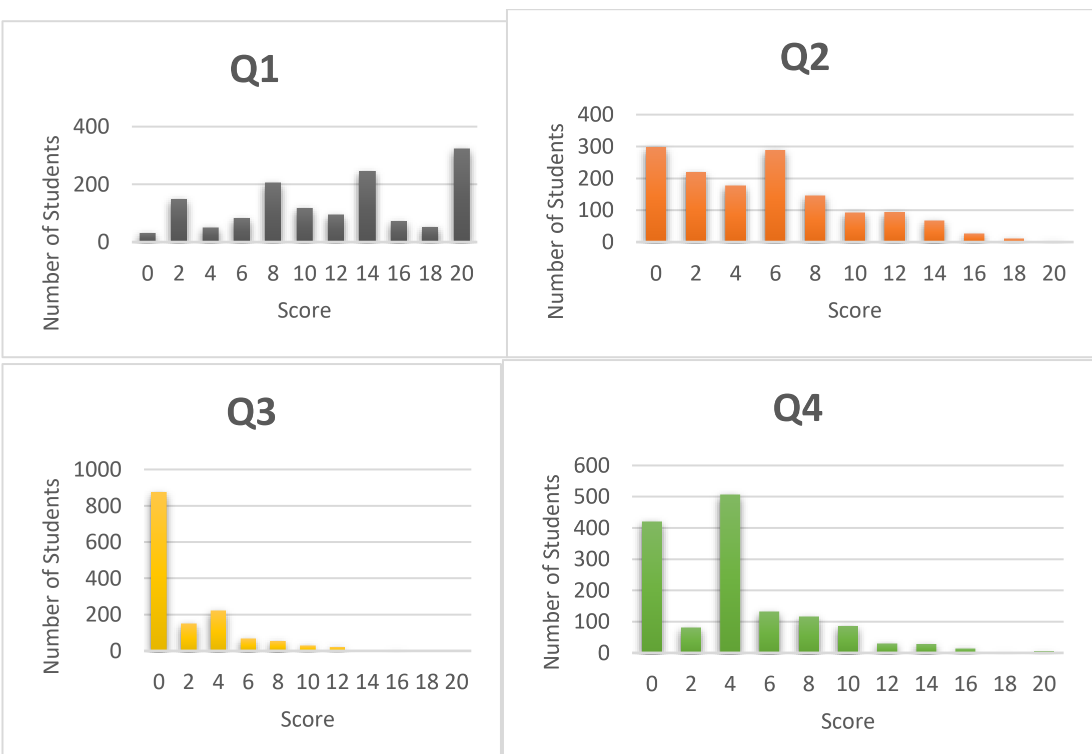


Figure 4: Score breakdown for each question. Notice how Q3 has the only score distribution without a significant peak above 0.

Question 1:

In January 2020, two people made an "Earth Sandwich", where they each placed a piece of bread on opposite sides of the Earth. One person was from place A (37° S, 175° E) and the other from place B (37° N, 5° W). We propose that the next Earth Sandwich will have one of its slices in Vancouver BC (49° N, 123° W).

Mark Distribution

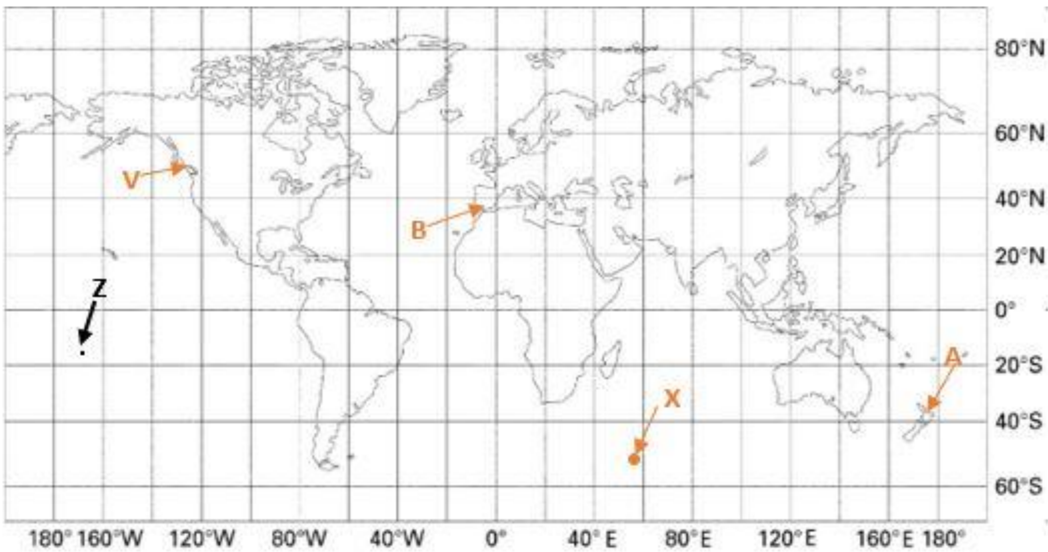
(a) 3 marks

(b) 12 marks

(c) 5 marks

Mean: 12.3/20

Top Mark: 20/20 (324 students)



a) On the map, clearly mark places A and B, and mark Vancouver with a "V". Use an arrowhead and dot to mark the positions, like position "Z" on the map.

Goal of the Question:

To see if students could correctly transition between different representations of the same data point.

Scoring:

Full marks were awarded to students who correctly labeled A, B and V as shown on the above map. Otherwise, 1 mark was given for each location marked correctly. To qualify as correct, the marked location must have been within the 20°×20° grid, as these were the only things that could be used to find the location.

Common Mistakes:

This question was generally well-done. The only recurring mistake was reversing the cardinal directions (North-South or East-West).

b) Give the coordinates of and mark on the map with an "X", the location that the slice opposite Vancouver should be placed. Give your answer in the box provided.

(49° S, 57° E)

Goal of the Question:

Test for the ability to recognize a linear relationship between two points, apply it to another point, and re-use the plotting skills from part (a).

Scoring:

Full marks were awarded if both coordinates were correct, with their corresponding locations accurately marked on the map (same marking criteria as part (a)). Otherwise, part marks were awarded for a correct coordinate (49° S **or** 57° E), as well as marking the coordinate on the map.

The most common score for part (b) was 6/12, as many students correctly identified the latitude opposite Vancouver (49° S) and accurately marked it on the map.

Common Mistakes:

- Reversing the direction of the longitude from East to West, even though this is clearly wrong based on the provided example.
- Placing the antipode of Vancouver in the northern hemisphere (49°N, __°_)

c) For an earth sandwich starting somewhere in South America (x° S, y° W), give a formula in terms of x and y for the coordinate of the other slice. Give your answer in the box provided.

(x° N, 180 – y ° E)

Goal of the Question:

To exercise the ability to generalize the results from part (b). The results from this question were expected to closely follow those of part (b), as they are in a sense the same question.

Scoring:

Full marks were awarded if the formulas for both coordinates were correct. Part marks were given if one of the coordinates was correct. Marks were given only for strictly correct formulas, as they could be checked with the provided points.

Surprisingly, 28% of participants scored full marks on part (c), but not on part (b). This suggests that students are not checking their answer to part (b) with the formula derived in part (c).

Conversely, 10% of students scored full marks on part (b) but failed to generalize on part (c). This is likely due to a reliance on intuition instead of equations, leading to unjustified answers.

Common Mistakes:

- Reversing the sign of the longitude expression (e.g. y – 180 ° E).
- Thinking that longitude ranged from [170° W, 170° E] (e.g. 170 – y ° E). The origin of this misconception is unknown, and surprising given that the full range [180° W, 180° E] is shown on the map.

Neither of these responses were awarded any marks, as the provided coordinates could be used to check to formulas.

Mark Distribution

(a) 6 marks

(b) 6 marks

(c) 4 marks

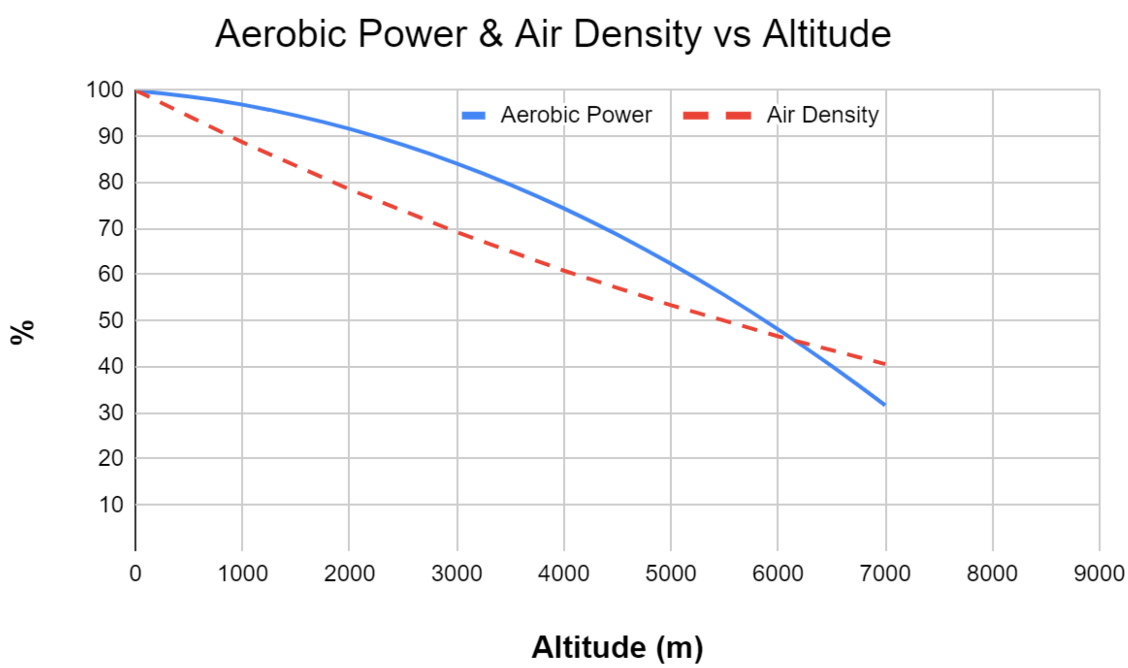
(d) 4 marks

Mean Score: 5.8/20

Top Score: 20/20 (3 students)

Question 2:

The chart below shows the effects of altitude on air density and the aerobic performance of non-acclimatized athletes. Both datasets are scaled such that 100% corresponds to their respective values at sea level (0 m). Write your answers within the boxes below.



a) Briefly state the main reason why aerobic performance changes with altitude.

As altitude increases, air density decreases so the density of available oxygen decreases. Less oxygen leads to a decrease in performance.

Goal of the Question:

This question was meant to test whether students could use one parameter to explain the behaviour of another. Aerobic power depends on oxygen density, which depends on air density, which depends on altitude - the student should qualitatively explain this nested relationship.

Scoring:

Full marks were awarded for the following logic:

Increasing altitude → decreasing air density → less oxygen → decrease in performance

Part marks were given for less specific variations of this argument, if they followed a similar structure:
Increasing altitude → decreasing air density → decrease in performance

Common Mistakes:

- Confusing aerobic performance with overall performance, and arguing that the decrease in air density/air drag increases aerobic performance

Top Student's Response:

> "As air density declines with altitude, as shown above, less oxygen enters the lungs per breath, reducing aerobic performance."

b) The 1968 Summer Olympics were held in Mexico City at an altitude of 2240m. At these games, a surprising number of world record times were set in high-speed track & field events. Why?

Decreases in air density reduce drag on the athlete, allowing for faster times. The accompanying reduction in aerobic power is outweighed by this decrease in drag.

Goal of the Question:

This question was meant to test whether students could use two parameters to explain behavior of another. Overall performance is dependent on aerobic power, and air density – the student was to explain how changes in both parameters affect the overall result.

Scoring:

Full marks for the following logic:

Decreased air density → decreased drag → increase in performance

Decreased air density → decreased aerobic power → decrease in performance

Increase in performance > decrease in performance

Common Mistakes:

- Neglecting the decrease in aerobic power and attributing the performance gain solely to lowered drag (If this were true, the optimal altitude would be above the atmosphere ~ 10,000 m, where air density reaches zero and aerobic power is zero!)
- Arguing that Mexico City is at a low enough altitude, so aerobic performance is sufficiently high for world-record times

Both errors are due to students focusing on only one of two parameters in the problem, which leads to an underdetermined problem.

c) Estimate the optimal altitude for setting track and field world records. Briefly state why you chose that value.

The aerobic power to air density ratio is highest at **3000m**, so this is the optimal altitude.

Goal of the Question:

This is another question with a focus on describing the behavior of a system with two inputs. To optimize performance, both air density and aerobic power must be considered.

Scoring:

Full marks were given for responses within 2500m -3500m, only if they acknowledged that this altitude provides the max ***ratio*** of aerobic power to air density. Part marks were given for answers within this range that were lacking justification.

Common Mistakes:

- Choosing sea level (0m), as this is the altitude that maximizes aerobic power
- Re-stating the altitude of Mexico City

No students chose altitudes where air density would be very low (altitudes above 7500 m), likely because they intuitively know that aerobic performance would suffer greatly. This contrasts the fact that in part (b), many students attributed world record performances to lowered air density. Had they used the same logic here, they would have arrived at answers upwards of 10,000 m, which is obviously nonoptimal. This suggests that many students improved their logic from (b) to (c), without changing their response to (b).

d) Estimate how high one can climb without supplemental oxygen. Briefly state why you chose that value.

The aerobic power graph looks like it will hit 0% at **8000m**, so this should be the highest one could possibly climb.

Goal of the Question:

This question was aimed to test the ability to extrapolate information from a graph. Aerobic power was the value to focus on, as climbing mountains is a slow-speed activity that doesn't enjoy benefits from lowered air-drag. After determining what the limiting factor is, the problem is simply finding an x-intercept.

Scoring:

Full marks were given for responses within 8000 m – 10,000 m, if they mentioned that aerobic power would reach zero at this point.

Common mistakes:

- Choosing 7000 m, as this is where the provided data ends. This has no physical meaning.
- Choosing 6100 m, as this is where Aerobic Power fraction = Air Density fraction. This has no physical meaning.
- Picking an arbitrary aerobic power and using the corresponding altitude as a response.

These responses indicate an inability to interpret a word-problem. Most students responded with an elevation corresponding to some obvious feature on the graph, although very few knew to find the x-intercept of the aerobic power line.

3. The Antarctic continent has an area 1/25 of that of the Earth's oceans; the mean thickness of the ice sheet covering it is 2 km. Icebergs float with 90% of their volume beneath the water level.

(a) If it all melts, make an estimate of the rise in global sea level. Use only the information given above and show your work.

Mark Distribution

(a) 4 marks

(b) 16 marks

Mean Score: 1.9/20

Top Score: 20/20 (1 student)

$$\Delta h = \frac{\Delta Volume}{Area} = (2km)\left(\frac{A}{25}\right)\left(\frac{0.9}{A}\right) = \mathbf{72m}$$

Goal of the Question:

This question was meant to test whether students can analyze a simple problem quantitatively. It is not obvious how to operate on the numbers given, making it unlikely to arrive at the correct answer by luck. The last statement "Icebergs float with 90% of their volume beneath the water level" was chosen instead of simply stating the density of ice.

Scoring:

Full marks were given to students who performed the calculation shown above. 1 mark was deducted for errors in magnitude.

Common mistakes:

- Ignoring the last statement and proceeding with calculations. This is neglecting the density difference between ice and ocean water, and it resulted in many students arriving at an answer of $\Delta h = \frac{(2km)(A)}{25A} = 80m.$
- Misinterpreting the statement that "Icebergs float with 90% of their volume beneath the water level" to mean that only 10% of the iceberg contributes to sea level rise. Students who did this mostly responded $\Delta h = \frac{(2km)(A)}{25A}(0.1) = 8m$
- Responding with a relative increase [%], and not an absolute increase [m] in sea level.
- Answering in units of volume and not length, after multiplying an area by a length. This suggests that the students were simply multiplying numbers without thinking about their significance.

(b) Write down up to four additional pieces of information that you would need to improve your estimate in (a). State their relevance to sea level rise. Please keep your writing inside the boxes.

New information	Relevance to sea level rise
Evaporation/Ground absorption	What percentage of water is lost in the process?
Ocean Salinity	Saltwater has a higher density than fresh water
Temperature change of ocean	The melted ice will have a small cooling effect, increasing density
Density of Ice at Depth	The ice at the bottom of the sheet is presumably more compact than that at the top. How much so?

Goal of the Question:

In part (a), the student was asked to make a prediction from a small amount of information. Part (b) was to see if the student recognized the limitations of their earlier calculation. Contrasting part (a), the emphasis of this was to analyze a complex problem qualitatively.

Scoring:

There are many possible responses to such a qualitative question, and the scoring reflected this. 4 possible responses are shown in the table above, and these were the most common answers that scored marks.

Common mistakes:

- Asking for more information about the dimensions of the Ocean or the Ice Sheet (depth, area or volume). Students with this response also generally answered part (a) with a relative [%] increase, as they thought more information was needed.
- Asking for more precise information, or better measurements. This is not new information and would not change the steps of the calculation.
- Asking for information on other ice masses melting (e.g. Arctic icebergs, Greenland ice sheet etc.). This is not relevant, as the question is regarding Antarctic ice solely.

4.

Mark Distribution

(a) 6 marks

(b) 14

Mean Score: 4.4/20

Top Score: 20/20 (5 students)

(a) The chemical formula for wood is approximately $(CH_2O)_n$, where n is a large integer. Write balanced chemical equations for the following processes.

(i) Formation of wood:

$nCO_2 + nH_2O \rightarrow (CH_2O)_n + nO_2$

(ii) Combustion of wood:

$(CH_2O)_n + nO_2 \rightarrow nCO_2 + nH_2O$

Goal of the Question:

To see if students recognize basic chemical equations that represent real world phenomena. When wood burns, it is essentially "undoing" the photosynthesis reaction that created it in the first place – the correct answer to this question shows this clearly.

Scoring:

Full marks were awarded for the answers shown above. Part marks were given for equations that did not balance the "n" in the formula for wood, only if they contained the correct reactants and products.

Common mistakes:

- Writing the formation of wood as the product of its elements (e.g. $2H + C + O \rightarrow CH_2O$)

In general, the combustion equation was done much better than the formation equation.

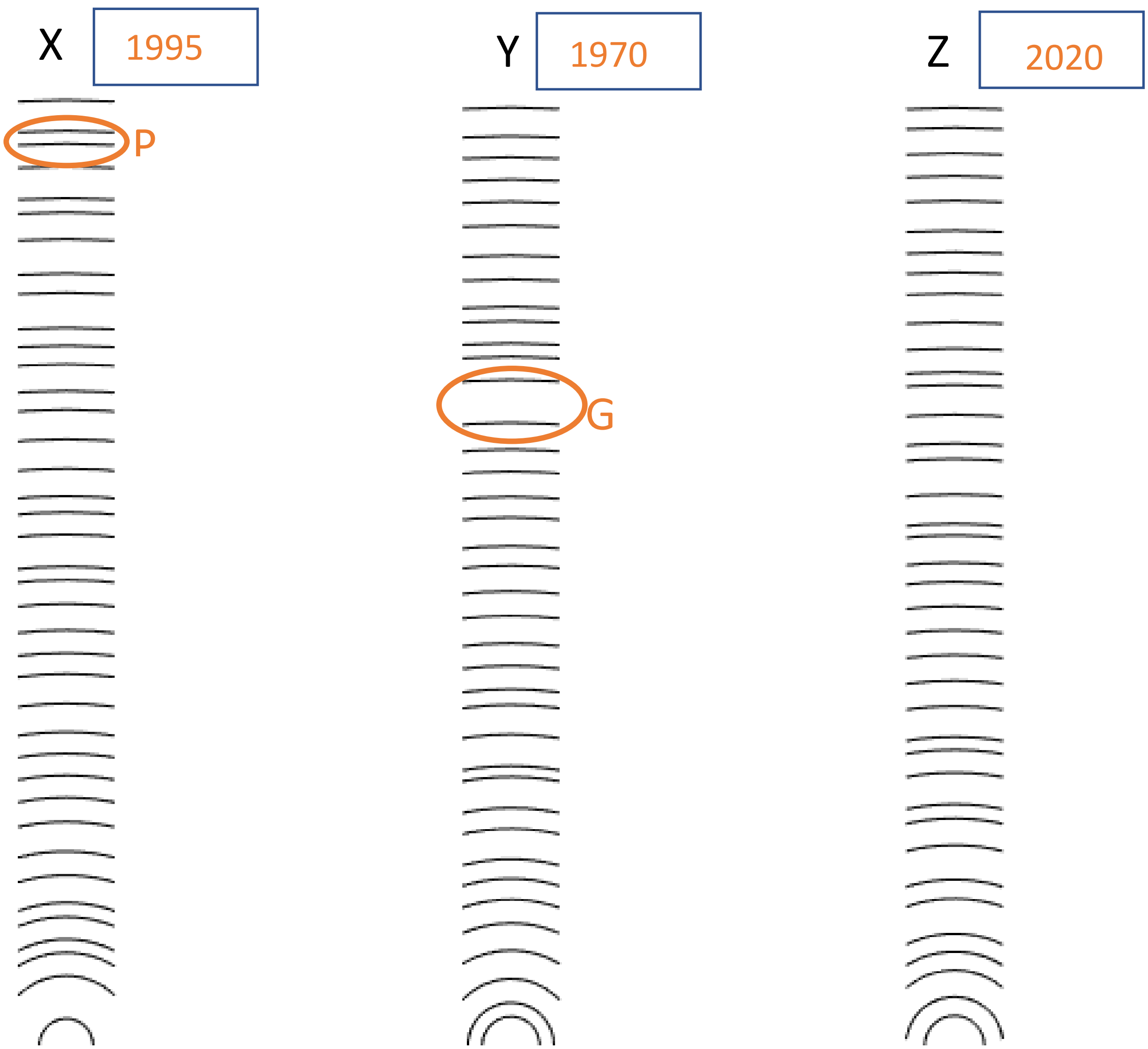
(b) Dendrochronology is the use of tree ring spacing to date wood. Distinctive ring patterns arise as a result of sequences of good and bad growing years. On the next page (p.8) are diagrams of complete cores taken from three trees (X, Y, Z) of about the same age, grown in the same forest but cut down in different years. The ring data have been corrected for all trees' natural tendency to grow faster when young than when they are old, i.e. if every year was the same as every other, all ring spacing would appear in the diagram to be the same. One tree has just been cut down (in 2020). Look at the tree rings and answer the following questions, marking your answers on the diagrams on the following page (p.8).

Note: these diagrams are repeated on p.2 of this exam; tear off and tear or cut up p.2 to allow comparisons to be made between the ring cores.

(i) Circle and mark with a "G" one 12-month period that was particularly good for growth

(ii) Circle and mark with a "P" one 12-month period that was particularly poor for growth

(iii) Mark in the boxes the year each tree was cut down



If you wish, make a brief comment on your answer in this box

Match up similar growth patterns between each tree

Goal of the Question:

This was meant to be entirely self-contained. As such, it was particularly thought-provoking. In order to correctly determine the dates of the trees, students were expected to use both provided diagrams to directly compare patterns between the 3 trees.

Scoring:

For parts (i) & (ii), full marks were given if the student identified years of similar growth as the ones circled below.

For part (iii), full marks were awarded only to those who arrived at the answer shown below. There were multiple other combinations that presented themselves as viable, but imperfect solutions. Part marks were given for these answers.

Common mistakes:

- Thinking that small ring spacing means a good growth year, when the converse is true
- Counting the rings in each tree, and using the difference in their ages to get an answer
- Answering 2020 for all three trees, in the hopes of getting one correct. This answer earned zero marks.

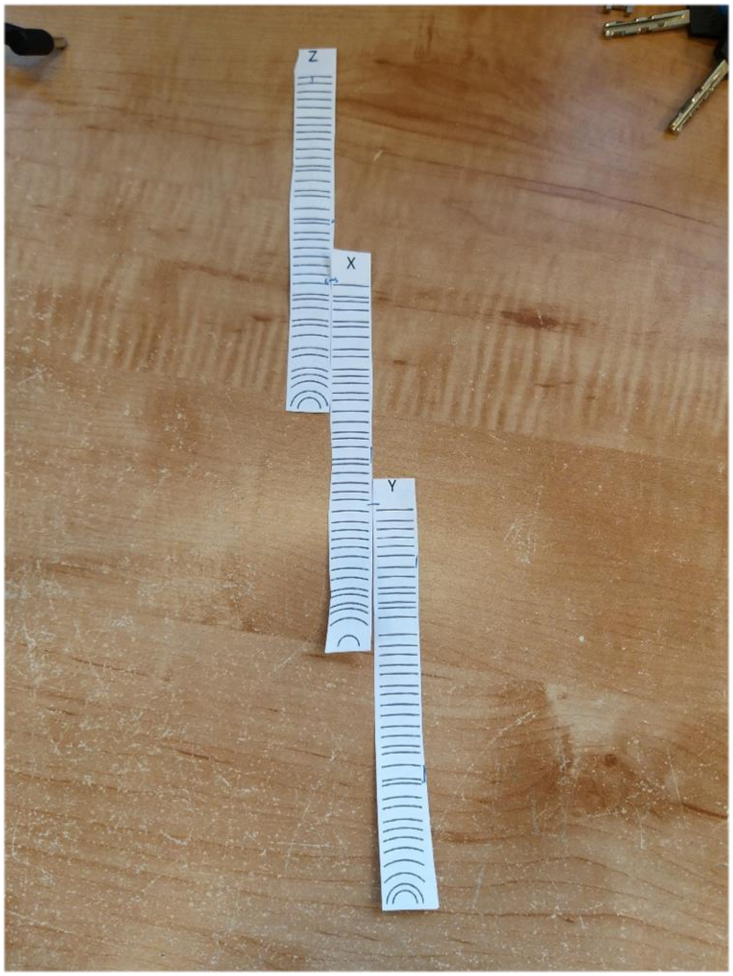


Figure 5: The optimal approach to dating the trees. Students were expected to employ a similar strategy using P.2 of the exam.