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PART I: INGREDIENTS OF SCIENCE TALENT

1. The challenge

There are many special programs in many parts of the world that seek to identify secondary or tertiary students who are potentially capable of entering the world of pure or applied research in science and mathematics, and to nurture them to become leaders — or at least high caliber practitioners — in these domains. The components of the enterprise of ensuring the growth of the sciences and the development of the best talent in science research in the country can be articulated as:

A. identifying students with aptitude and talent for pure and applied scientific inquiry;
B. helping them actualize their potential for scientific inquiry; and
C. encouraging them to take up research careers in the sciences.

What follows is a systematic exploration of the challenges within the academic aspects of this enterprise, and a set of suggestions resulting from the exploration.

2. What do we mean by ‘science’?

What do we mean by “scientific” and “the sciences” in A-C? For the Joint Entrance Examinations of the Indian Institutes of Technology (IITs), for instance, “the sciences” include only mathematics, physics, and chemistry. The current Kishore Vaigyanik Pratshotan Yojana (KVPY) examinations, in contrast, include biology as well, but not neuroscience, psychology, economics, or linguistics. Such inclusions and exclusions raise questions like the following:

Is mathematics a science? If it is, how do we define “science” such that it includes mathematics?

Whether or not mathematics is a science, what is the rationale for including mathematics and biology while excluding neuroscience, psychology, linguistics, and economics?

These are difficulties of deciding what should be included/excluded from the assessment of science talent. We will not address these questions here, but simply use “science talent” as a cover term for talent not only in science but also in mathematics, the areas of study covered by a “school of science” in a university in India.

3. Inquiry and research

To accomplish the goals outlined in (A)-(C) in section 1, it is crucial that we address the following questions:

1) What is scientific inquiry? How is it related to scientific research?
2) What constitutes aptitude and talent for scientific inquiry?
3) How do we identify it?
4) How do we nurture it?
5) How do we assess it?

We explore question (1) in this section, and question (2) in the next. The subsequent sections of Part I are devoted to question (3). Part II addresses question (5). As for question 4, we discuss it in a separate document, “Nurturing Science Talent,” available at xxx.

Inquiry is the conscious and systematic investigation of questions whose answers are not obvious. Imagine a fifteen-year-old child sitting in a classroom and watching his classmates yawning while the teacher drones on, oblivious to the boredom. What he observes raises questions in his mind: why do human beings yawn? Could it be that yawning allows us to take in more air and increase the oxygen supply? Does this mean that we yawn when the levels of
oxygen in our blood are inadequate? But then, why should people yawn when they are bored? Or when they are sleepy? Also, why do people yawn when they see others yawning?

Let us take another example. A twelve-year old child is drawing lines on paper. She notices that some of the straight lines she has drawn intersect with other straight lines, and some don’t. What would happen if the non-intersecting straight lines were extended infinitely in all directions? Would they then intersect? She remembers the discussion of parallel lines in her geometry lesson, and concludes that any two non-parallel straight lines would intersect if they were extended infinitely in all directions. Can they intersect at more than one point? She has an intuition that they cannot, but how would she prove it?

Then another thought occurs to her. Suppose there are three straight lines. Also suppose that each line intersects with the other two. They can either all intersect at one point, or at three distinct points. Is it possible for them to intersect at only two points? Again, her intuition tells her that there can’t be. But how would she prove it?

Both these children are engaged in independent inquiry. Now, the conscious and systematic investigation of questions and problems is prototypically exemplified in research. What then is the distinction between inquiry and research?

The answer is that research necessarily involves inquiry, but to count as research, inquiry must aim to make a contribution to the existing body of collective knowledge. A ten-year old child can engage in independent inquiry on a question, but we cannot expect the child to have mastered the existing body of collective knowledge on that question to engage in research.

In this sense, inquiry is simulated research. Thus, research and inquiry require the same kind of mental activities; however, they differ in the outcome of the activity and its relevance for the collective pool of knowledge.

4. Components of scientific inquiry

One way to figure out what we should probe into in order to identify young talent for scientific inquiry is to pose the following question to researchers who have made significant contributions to science:

“It is clear that novices in their late teens do not have the kind of in-depth knowledge that you have, and hence are not yet ready for research in the field. So let us factor out the issue of knowledge and knowledge application. Ask yourself: What qualities of mind: allowed you to make the contributions you have made? would allow your students to be better researchers than you are? at least as a potential, would it be reasonable to expect of a scientifically inclined teenager? A synthesis of their answers would provide the profile of a high school student with the potential to become a researcher in the sciences, engineering, and medicine. That potential, I believe, can be summed up as the predispositions to develop a high degree of expertise in four activities that are central to scientific inquiry, namely:

• asking questions,
• looking,
• noticing, and
• thinking.

Given that inquiry is the investigation of questions, it follows that all inquiry begins with questions. We have already seen a few examples. Why do humans yawn? Do animals yawn? Do humans yawn when they are sleeping? The capacity to discover and formulate interesting and significant questions that call for investigation is the very first step in inquiry.

Looking is the activity of consciously directing one’s attention — not only with one’s eyes, but also with one’s other senses, and more importantly, with one’s mind — at what exists both
inside and outside one’s consciousness, to elicit the information relevant to a question or a problem. When a doctor looks at the x-ray of a foot to find out if there is a hairline fracture, she is looking. And a teenager is not looking when he sits with glazed eyes and lets his passive mind be manipulated by ads on a TV screen. Looking presupposes intellectual curiosity, and the readiness to act on it, without which one cannot be a scientist.

Noticing is the mental activity of picking out a significant relation or pattern within a broad area — again, in what exists both inside and outside one’s consciousness. It took a Mendeleev to notice the periodic relation between atomic weight and the chemical properties of elements, and a mathematician like Francis Guthrie, at 21, to discover that four colours are sufficient to colour all maps such that no two countries sharing a border have the same colour. Like the capacity for looking, the capacity for noticing is a fundamental quality for scientific inquiry.

Thinking is a cluster of mental activities directed towards a goal. Designing an experiment to test the hypothesis that obesity is contagious requires thinking, and if it is contagious, inventing a theory that explains how it spreads also requires thinking. Making a recommendation on an article submitted for publication requires thinking, and so do discovering a proof for a mathematical conjecture, and choosing between two competing theories. It is possible to rely solely on mechanical procedures to produce a research paper by following instructions faithfully, without thinking, but only someone who commands a range of thinking abilities can make significant advances in scientific research.

5. Looking, noticing, and thinking

5.1 Modes of looking

A quick glance through the ‘methods’ section in a research paper in a science journal, or through the descriptions of ‘research methodology’ courses in science disciplines, shows that the expression “the scientific method” refers to the modes of looking that are appropriate for the investigation of a given scientific question. Should we use functional Magnetic Resonance Imaging or Positron Emission Tomography? Should we use a chi-square test or a t-test? Should we use a laboratory experiment or a field experiment? It makes sense to use a telescope to look at quasars when investigating celestial phenomena, but not to investigate the behaviour of bacteria. When investigating the neural substrate of mental qualities, researchers surgically remove parts of the brain if the experimental subjects are chimpanzees, but not if they are humans. When studying the social behaviour of animals, we can use surveys and interviews if our subjects are humans, but not if they are gorillas. These are all issues that come under the rubric of research methodology.

For our purposes, the science talent we need to identify is at a stage when students have not yet confronted specialized methods appropriate for a given subject, say, molecular biology as opposed to developmental biology. The broad types of ‘methods’ at this stage are:

- **experimental modes** (e.g., physics) vs. **non-experimental modes** (e.g., astronomy)
- **quantitative** data gathered by **counting** (e.g., the number of people in a city) and **measuring** (e.g., the area of a city) and the **statistical procedures** to process the numerical data vs. **qualitative** data (e.g., case study of a patient suffering from a brain impairment)
- use of **instruments** (e.g., weighing scales, microscopes, spectroscopy) vs. **direct sensory perception** (e.g., field work on ant colonies)
- **verbal evidence** (e.g., surveys, interviews) vs. **non-verbal evidence** (e.g., carbon dating)

There are three important points about such methods that would be useful to bear in mind when identifying science talent:

First, we may view the methods at a broad level as **strategies**, or at a highly specialized level as **procedures, techniques, and tools**. Experimentation is a broad strategy of intervening in
the natural processes of the world to look at the result of the intervention. In contrast, what scientists do to separate DNA strands in the laboratory is to apply a set of reliable techniques developed for that specific purpose. Likewise, statistical inquiry is a broad strategy to make sense of numerical information. In contrast, the chi-square test is a highly specialized tool for a specific purpose. While the mastery of the procedures, techniques, and tools is important for a research scientist working on a specific project, it would be unwise to demand the same degree of specificity from a high school student. Chances are that if those students were trained in the use of the procedures, techniques, and tools, they would mechanically master these “methods” without any understanding of the nature of scientific inquiry, becoming lab technicians instead of scientists. In sum, the assessment of potential for scientific inquiry and research should focus on the general strategies, and not on the specific procedures, techniques, and tools.

Second, even if we focus our attention on the broad strategies of methodology, this strand constitutes only one of the four strands mentioned in the previous section, that of looking. It does not include asking questions, noticing, or thinking.

Third, even within looking, the ‘methods’ sections in research papers and university courses on research methodology do not include the modes of looking that are relevant for theoretical science and mathematics. There are no ‘methods’ sections in Einstein’s papers on relativity, or Euclid’s proof of the infinity of prime numbers. The search for science talent must incorporate ways of probing into those modes of looking that are not represented in traditional methodology courses.

5.2 Modes of noticing

If a woman at a party has different earrings in the left and right ears, chances are that some people would notice this, while others wouldn’t. If the same woman says something that logically contradicts something that she said five minutes earlier, chances are some people would notice the contradiction, while others wouldn’t. Now, the lines of division between those who notice the different earrings and those who don’t, and between those who notice the logical contradiction and those who don’t, are unlikely to coincide. Noticing, as mentioned earlier, requires a certain kind of mindset that, in a mass of details, pays attention to and highlights something specific within the individual’s world of interest.

Nobel Laureate Albert von Szent-Gyorgyl once said, “Discovery consists of seeing what everybody else has seen, and thinking what nobody else has thought.” What he said about thinking is perhaps even more apt for noticing. All human beings have observed the phenomenon of yawning — that when one person in a group yawns, the others also tend to yawn; but how many of us have made a mental note of the interestingness of this fact, to use it as a springboard for research questions? Most of us have noticed that the pupils of human eyes can be different in colour: black, brown, blue, green, grey, and so on. But how many of us are intrigued by the fact that an individual with eyes of different colours (say, one blue and the other green) are extremely rare? Like eye colour, we all know that human hair comes in different colours: black, brown, blond, yellow, or grey. Many of us may also have noticed that blond hair typically goes with blue eyes. But how many of us have noticed, or been intrigued by, the rarity of people with black hair and blue eyes, or with blond hair and jet black eyes?

As far as scientific inquiry is concerned, noticing is the discovery of an interesting pattern that is likely to be real, a conjecture that is likely to be true. If we ask a group of high school students to take a piece of paper, fold it, and open the fold, all of them would see that the crease is a straight line. In contrast, if we ask them to fold it again, unfold it, and repeat the process a number of times, not many would be able to identify the generalizations that they can observe in the multiple creases. And if you ask them to fold a fresh piece of paper a number of times without unfolding, and unfold it at the end of the foldings, still fewer would be able to see what distinguishes the first set of creases from the second set. Discovering mathematical patterns calls for a mind that is tuned into patterns in
numbers, shapes, and other abstract entities.

Some of the types of patterns that we tend to notice repeatedly in scientific inquiry are:

- **Linear correlations**: x increases as y increases (direct proportionality) or x decreases as y increases (inverse proportionality); e.g., correlation between the temperature and volume of a given body of gas under constant pressure; correlation between the diameter and circumference of a circle. Correlations can also be in terms of categories rather than numbers: for instance, organisms that give birth to babies do not have feathers, every adult human being has a heart, and so on.

- **Cycles**: x increases up to a point as y increases, after which it reverses and begins to decrease, and then reverses again, and so on. The swinging of a pendulum is a well-known example of a cycle. Cycles involving categories include seasons (autumn-winter-spring-summer-... and day-and-night).

- **Asymmetries**: Given a set of logical possibilities, only a proper subset is attested; e.g., human beings have black hair, brown hair, red hair, yellow hair, and gray hair, but not (natural) purple hair, green hair, or blue hair.

- **Anomalies**: Given what we know/assume, we expect x, but we observe not-x; e.g., given Newton’s laws of motion and theory of gravity, we would expect all the stars and galaxies to move towards one another because of gravitational attraction, and collapse together as a single mass. Why hasn’t this happened?

### 5.3 Modes of thinking

Thinking in formal and empirical sciences includes, but is not restricted to:

1. figuring out strategies to test ideas, predictions, hypotheses, and conjectures;
2. inventing axiomatic systems (mathematical theories) and explanations (scientific theories);
3. deducing the logical consequences of theories (i.e., deriving predictions and theorems);
4. making inferences (which includes making calculations), solving problems;
5. testing predictions and conjectures;
6. doubting and questioning one’s own and other people’s beliefs and practices, including established ones; and
7. critically evaluating claims of knowledge and practice.

The document, “Nurturing Science Talent,” referred to earlier, elucidates and illustrates these ingredients.

### 5.4 Formal and empirical sciences

The words ‘science’ and ‘scientist’ conjure up images of quantum mechanics, molecular biology, Einstein, and Darwin. They don’t conjure up images of Euclidean geometry, graph theory, Euler, or Poincaré. The reason is quite straightforward: if we define science as inquiry that seeks to understand the nature of the world we live in, then pure mathematics, pure computer science, and formal logic are not sciences, they are inquiries that seek to understand the nature of possible worlds, not the particular world we live in. Mathematics does not tell us whether, in our universe, the sum of the angles of a triangle is two right angles; all that it tells us is that in any universe that obeys Euclidean postulates, the sum of the angles of a triangle is two right angles. In a Riemannian universe, the sum of the angles of a triangle is more than two right angles.

Needless to say, we can use the word “science” to include not only the investigation of the world we live in, but also of all the logically possible worlds. If so, physics, chemistry, and biology would be empirical sciences while mathematics would be a formal science. To see the distinction between formal and empirical sciences clearly, let us formulate a mathematics
curriculum for secondary schools in terms of the abilities that we want successful candidates to have at the end of the program:

**Applied Mathematics**

1) Given a scenario as a problem, children should be able to  
   a) come up with a mathematical model of the scenario, and  
   b) identify the pieces of mathematical knowledge (theorems, equations, formulae, operations) that are relevant for calculating a solution from that model.

2) Children should be able to make calculations with adequate speed and accuracy.

**Pure Mathematics**

3) Given some examples, children should be able to ‘see’ patterns/generalizations they illustrate, and articulate them as plausible conjectures.

4) Given a conjecture, with some examples, children should be able to test the conjecture on the basis of more examples, to establish it as legitimate.

5) Given a conjecture, children should be able to discover a proof, and articulate it to establish it as a theorem (true conjecture).

6) Given a conjecture/theorem, children should be able to come up with examples that illustrate it.

7) Given a conjecture/theorem, children should able to generalize it further.

These goals do not include strategies that are central to empirical sciences: “data” collection, explanation of what can be gathered through sense perception, theory testing, and choosing between competing theories.

6. **Why focus on abilities?**

Why is it important to assess the potential for scientific inquiry rather than the accomplishment of scientific knowledge? Because we are concerned with the potential of novices, not the accomplishment of experts. If students have:

- considerable talent for inquiry,
- high capacity for independent learning, and
- strong motivation,

they would acquire the required scientific knowledge on their own in the course of their undergraduate and graduate programs. But those who have acquired a high degree of scientific knowledge through intense cramming and coaching need not necessarily be good at or interested in research.

Even after shifting our attention from knowledge and mechanical application to broader and more fluid mental abilities, separating aptitude from actual accomplishment is not going to be easy. Examination performance can only measure actualized potential. Such accomplishment is a function of not only the potential but also the kind of exposure and instruction that a candidate has received. That in turn is a function of the candidate’s socio-economic status and availability of resources (including mentors and role models). However, using questions that test thinking and inquiry rather than knowledge alone stand a better chance of identifying genuine talent.

7. **Deciding what to assess**

The core capabilities that go into research in mathematics, we believe, can be summarized as (A)-(H) below:

Research in *Applied Mathematics* calls for the ability to:

A. “translate” real life phenomena as mathematical models; and

B. calculate/deduce the logical consequences (predictions) of the model on the basis of
existing mathematical knowledge (theorems, equations, formulae, operations).

Research in *Pure Mathematics* calls for the ability to:

C. invent/create mathematical objects/procedures, and define them clearly and precisely;
D. invent/create axioms/postulates that govern these objects/procedures;
E. discover patterns/generalizations on the objects/procedures and articulate them as plausible conjectures;
F. identify counterexamples that refute given conjectures, to evaluate their plausibility;
G. discover proofs for plausible conjectures and articulate them to establish them as theorems; and
H. evaluate proofs, and identify flaws of reasoning, if any.

Likewise, the core capabilities that go into research in science can be summed up as in (J)-(U) below:

Research in *Observational Science (including experimental science)* calls for the ability to:

J. discover patterns/generalizations in the observed phenomena and articulate them as plausible correlational hypotheses;
K. speculate on plausible causal factors for the observed effects;
L. design methodological strategies (experimentation, measurement, invent instruments, etc.) to gather evidence/data to test correlational or causal hypotheses;
M. implement those designs (conduct experiments, make measurements, record/document observations…);
N. process the data; and
O. evaluate the credibility of a hypothesis on the basis of the evidence gathered.

Research in *Theoretical Science* calls for the ability to:

P. identify what calls for an explanation in the outcomes of observational science;
Q. invent theories (models, laws, frameworks) to propose explanations for observed patterns/generalizations;
R. critically evaluate theories by deducing the predictions arising from them and testing the predictions;
S. choose between alternative/competing theories;
T. justify the postulation of theories and the choice between alternative/competing theories; and
U. critically evaluate the evidence and argumentation in support of/against theories.

Which of these abilities we can realistically test among secondary and tertiary students depends partly on their intellectual maturity and partly on our ingenuity to find adequately simple problems that probe into the relevant abilities. Some of the abilities may not lend themselves to testing in an examination. Of these, some can be assessed in an interview. There will still be some abilities that cannot be assessed at the point of entry into a program.
PART II: SAMPLE QUESTIONS

8. Non-MCQs

We begin our sample questions with the non-MCQ format. These questions are feasible if the number of candidates is relatively small, but when faced with tens of thousands of candidates, we need to resort to computer gradable questions of the type illustrated in sections 9 and 10. In such cases, the computer gradable exams can be used for short-listing the candidates, and the kinds of questions given in this section can be used for interviews to select from the short-listed candidates.

At the beginning of each question, we have spelt out the abilities (from among A-U) that it tests.

**Question 1**

[These tasks test the students’ ability to construct realistic mathematical models of observed phenomena, and arrive at conclusions based on the model, at varying degrees of difficulty (abilities A, B).] ¹

**Task a:** A goat is tied with a 10-meter rope to the corner of a closed rectangular shed that is 6 meters long and 4 meters wide. The shed is on a field of grass, with the goat on the grass. What is the area of the land that the goat would be able to graze on?

**Answer:** ………………………

**Task b:** A goat is tied with a 10-meter rope to the corner of a closed rectangular shed that is two meters long and one meter wide. The shed is on a field of grass, with the goat on the grass. What is the area of the land that the goat would be able to graze on?

**Answer:** ………………………

**Task c:** A goat is tied with a 10-meter rope to the corner of a closed triangular shed whose sides are 5 meters each. The shed is on a field of grass, with the goat on the grass. What is the area of the land that the goat would be able to graze on?

**Answer:** ………………………

**Question 2**

In contrast to questions (1a–c), the question “What is the area of a circle whose radius is 10 meters?” is restricted to testing the students’ ability to make mechanical calculations based on memorized formulae. Such questions do not involve mathematical modeling. The following questions do involve modeling, but since they are standard types, no thinking or special imagination is required in coming up with a model.

A goat is tied with a 10-meter rope that is attached to a stump on the ground. What is the area of the land that the goat would be able to graze on?

A goat is in an enclosed circular meadow whose diameter is 10 meters, and there is a closed circular shed of 3 meters inside the meadow. What is the area of the land that the goat would be able to graze on?

In contrast, the following question demands a moderate level of difficulty in modeling, but not sufficient to distinguish the talented from the ordinary:

A goat is tied with a 10-meter rope to the corner of a closed rectangular shed that is 60 meters long and 40 meters wide. What is the area of the land that the goat would be able to graze on?

If we provide a model for a few sample problems, and extensive practice in applying that model to a large number of standard problems, then give another standard problem, all that the learner has to do is mechanically apply that model to the given problem and proceed to make a mechanical calculation. Standard problem solving skills are acquisable through repeated supervised practice (i.e., through mere training) and mechanically reproducible without being guided by thought.

¹ In contrast to questions (1a–c), the question “What is the area of a circle whose radius is 10 meters?” is restricted to testing the students’ ability to make mechanical calculations based on memorized formulae. Such questions do not involve mathematical modeling. The following questions do involve modeling, but since they are standard types, no thinking or special imagination is required in coming up with a model.
Unlike the tasks in (1), those below belong to the realm of pure mathematics. They test the students’ ability to discover patterns, formulate them as conjectures, and prove these conjectures, again at varying degrees of difficulty (abilities E and G).

**Task a:** If you take a sheet of paper and draw a number of horizontal and vertical straight lines from one edge to the other such that the lines intersect at right angles, you will get a number of polygons (shapes bounded by straight lines). Colour each polygon in such a way that no two adjacent shapes have the same colour. (Two polygons are adjacent if they share a line segment as a boundary.) What is the minimum number of colours that you need to colour every shape?

**Answer:** ......................

**Task b:** If you take a sheet of paper and draw a number of straight lines randomly from one edge of the paper to another, you will get a number of polygons (shapes bounded by straight lines). Colour each polygon in such a way that no two adjacent shapes have the same colour. (Two polygons are adjacent if they share a line segment as a boundary.) What is the minimum number of colours that you need to colour every shape?

**Answer:** ......................

**Task c:** If you take a sheet of paper and draw a number of straight lines randomly from one edge of the paper to another, you will get a number of polygons (shapes bounded by straight lines). Colour each polygon in such a way that no two adjacent shapes have the same colour. (Two polygons are adjacent if they share a line segment as a boundary.) Now consider the following conjecture:

No more than two colours are needed to colour the polygons as required.

Would any of the following diagrams prove that this conjecture is true, or that it is false?

![Diagram](image)

**Answer:** ......................

If your answer is yes, say which one(s):

**Answer:** ......................

**Question 3**

[Like tasks (2 a-c), the following tasks test the students’ ability to discover and prove conjectures (abilities E and G), except that this time the patterns are those of numbers, not shapes.]

**Task a:** Consider the sum of three consecutive numbers:

\[
1+2+3 = 6 \quad 2+3+4 = 9 \quad \ldots \quad 7+8+9 = 24 \quad \ldots \quad 13+14+15 = 42 \quad \ldots
\]

In terms of their divisibility (e.g. 6 is divisible by 2; 15 is divisible by 5; 100 is divisible by 25; \ldots), what property is shared by the sum of any three consecutive numbers?

**Answer:** ..............................
**Task b:** Consider the sum of three consecutive numbers:

\[1+2+3 = 6 \quad 2+3+4 = 9 \quad 7+8+9 = 24 \quad 13+14+15 = 42 \quad \ldots\]

In terms of their divisibility (e.g., 6 is divisible by 2; 15 is divisible by 5; \ldots), what property is shared by the sum of any three consecutive numbers?

*Answer:* ……………………………………

If you want to prove that your answer is correct, which of the items given below would you use?

- A 3 is a prime number
- B \((a+b)^2\)
- C \((a-b)^2\)
- D \(n + (n+1) + (n+2)\)
- E 3 is an odd number
- F triangular numbers
- G 3 is an odd number
- H factorization

*Answer:* ……………………………………

**Task c:** Consider the sum of consecutive numbers:

- Two numbers: \(1+2 = 3 \quad 2+3 = 5 \quad 7+8 = 15 \quad 14+15 = 29 \quad \ldots\)
- Three numbers: \(1+2+3 = 6 \quad 2+3+4 = 9 \quad 7+8+9 = 24 \quad 13+14+15 = 42 \quad \ldots\)
- Five numbers: \(1+2+3+4+5 = 15 \quad 7+8+9+10+11 = 45 \quad \ldots\)
- Twelve number: \(1+2+3+4+5+6+7+8+9+10+11+12 = 78 \quad \ldots\)

In terms of their divisibility (e.g., 6 is divisible by 2; 15 is divisible by 5; 100 is divisible by 25; \ldots), can you identify the general pattern(s) that applies to the sum of consecutive numbers?

*Answer:* …………………………………………………………………………

**Question 4**

[These tasks test the students’ ability to detect counterexamples to a conjecture (ability F).]

**Task a:** Examine the numbers divisible by 11 (e.g., 11, 22, 33, 44, 55\ldots) and check if the following conjecture is true:

The digits in a number divisible by 11 are identical.

*Answer:* …………………

Write down a number divisible by 11 that supports your answer. [A more challenging version of the task: “Write down a number that supports your answer.”]

*Answer:* …………………

**Task b:** Examine the numbers divisible by 11 (e.g., 110, 121, 132, \ldots 176, 187, 198, \ldots) and check if the following conjecture is true:

The last digit in a number divisible by 11 is less than the previous digit.

*Answer:* …………………

Write down a number divisible by 11 that supports your answer. [A more challenging version of the task: “Write down a number that supports your answer.”]

*Answer:* …………………
Question 5
[This task tests the students’ ability to invent proofs (ability G).]

**Task:** Consider a rectangle ABCD, and a point E on BC such that AED forms a triangle.

If you were asked to prove that the area of ABCD is twice the area of AED, which of the following diagrams would you use?

<table>
<thead>
<tr>
<th>I</th>
<th>II</th>
<th>III</th>
<th>IV</th>
<th>V</th>
<th>VI</th>
<th>VII</th>
</tr>
</thead>
</table>

**Answer:** …………………

Question 6
[This question tests the students’ understanding of the distinction between causes and correlations, as well as the role of control in experiment design (ability O).]

In a famous study conducted by researchers at the University of Southern Gelostia, a randomly selected sample of 10 million subjects from all over the world were given an aptitude test in mathematics. When their scores were compared with their body weight, it was discovered that there was a strong correlation between the body weight and the scores: the greater the body weight, the higher the scores in the math test. Once these results were announced in public, parents who were eager for their children to do well in mathematics started over-feeding them to make them gain weight and thereby improve their math performance.

**Task 1:** Is the conclusion that increased body weight improves math performance justified by the results of the experiment?

**Answer:** …………………

**Task 2:** What is/are the reason(s) for your answer?

**Answer:** …………………

For your answer, make your choice(s) from the list of statements in (i)-(x) below. To get full marks, it may be necessary to choose more than one option. But the choice of inappropriate options would result in penalties (i.e., marks would be deducted).

i) Inadequate sample size.
ii) It is not true that increasing body weight results in better math performance.
iii) Research design has probably not controlled for age.
iv) Weight increases blood flow to the brain.
v) Conclusions of scientific research cannot be false.
vi) University of Southern Gelosti is an internationally reputed research centre.
vii) As babies grow older, their body weight increases until they become adults.
viii) Fatty foods increase body weight.
ix) There is no connection between body weight and brain activity.
x) Unlike performance in math, obesity is genetic.
**Question 7**  
[This question tests the students’ ability to identify counterexamples to observational generalizations (abilities L and O).]

Imagine a Martian scientist Rpunsel Jenglicz visiting Earth and discovering that Earthlings exhibit a phenomenon that they call ‘language’. Martians communicate with one another directly by projecting messages through brain waves, so Jenglicz concludes that language must be something that Earthlings use for communication. She also discovers that Earthlings communicate either through speech or through writing. She examines the writing system in English and formulates the following laws governing the use of capital and small letters:

- a. The first letter of every sentence is capital.
- b. The first letter of every name is capital.
- c. All other letters are small.

**Task 1:** Are the laws formulated by Jenglicz correct?

**Answer:** …………………

**Task 2:** Provide evidence to support your answer:

**Answer:** ………………………………………………………………………………………………

**Question 8**  
[This question tests the students’ ability to connect theories to the generalizations/correlations that it correctly predicts, and work through the evidence that supports the theories under scrutiny (abilities T, U).]

In the nineteenth century, John Dalton proposed the atomic theory of matter, which says that

- All elements are made of tiny particles called atoms.
- All atoms of a given element are identical.
- The atoms of a given element are different from those of any other element.
- The atoms of different elements can be distinguished from one another by their respective relative atomic weights.
- Atoms of one element can combine with atoms of other elements to form chemical compounds.
- A given compound always has the same relative numbers of types of atoms.
- Atoms cannot be created, divided into smaller particles, nor destroyed in the chemical process; a chemical reaction simply changes the way atoms are grouped together.

**Task:** Consider the generalizations in (i)-(vii) below. Which of these generalizations can be used to argue that Dalton’s theory is correct?

i) Law of definite proportions (A chemical compound always contains exactly the same proportion of elements by mass.)

ii) Valence (When the atoms of two elements combine to form a compound, the ratio of the numbers of atoms of each compound remains the same.)

iii) Atomic structure (An atom consists of a nucleus and one or more electrons.)

iv) Boyle’s law (If the temperature is kept constant, the pressure of a body of gas is inversely proportional to its volume.)

v) Chemical reaction (A chemical reaction is a process that leads to the transformation of one set of chemical substances to another.)
vi) Law of multiple proportions (When chemical elements combine, they do so in a ratio of small whole numbers.)

vii) Law of combining volumes (The ratio between the volumes of gases that participate in a chemical reaction and those of the resulting ones can be expressed in simple whole numbers.)

Answer: ………………………………………

Question 9

[This question tests the students’ ability to critically evaluate definitions, as a simpler variant of the ability to critically evaluate theories (ability R).]

As you probably know, the standard definition of species is that it is a group of organisms capable of interbreeding (i.e., capable of sexual reproduction with one another) producing fertile offspring of both sexes. Now consider the following statements.

a. Dogs and wolves belong to the same species.
b. Dogs and wolves belong to different species.
c. Dogs and wolves belong to different species and they can interbreed producing fertile offspring of both sexes.
d. Many plants reproduce asexually.
e. Both bacteria and amoeba reproduce through a kind of cell division called binary fission.
f. Interbreeding producing fertile offspring of both sexes has been found to be possible between the following pairs:
   - groups A and B;
   - groups B and C;
   - groups C and D;
   - groups D and A;
   but not between the following pairs:
   - groups A and C;
   - groups B and D.
g. Interbreeding between horses and donkeys produces mules, which are infertile.
h. Interbreeding between horses and donkeys produces fertile mules.
i. The offspring of mating between two species are very often, but not always, sterile.

**Task:** Which of the above, if true, would demonstrate that the standard definition of species needs to be revised? (Your answer may specify a single item from the above list, or more than one item, or you may say, “none of them”.)

Answer: ………………………………………………………………………………………………………
**Question 10**

[This question tests the students' ability to deduce and check the predictions of theoretical models (ability R).]

Stated without the specifics of numbers, Newton’s law of gravitation says that every body in the universe attracts every other body, with a force that is directly proportional to their masses and inversely proportional to the distance between them. The consequence of such a force is expressed in his laws of motion. Now consider the following possibilities:

a. The sun has been getting colder; it will finally turn into a huge cold rock with no light.

b. The sun has been getting hotter and hotter; it will finally explode.

c. Planets have been revolving around the sun for billions of years.

d. Pluto is not a planet.

e. Stars and galaxies of the universe have been moving away from one another.

f. Stars and galaxies of the universe have been moving towards one another and will form a single mass at some point of time.

g. The distances between stars and galaxies have remained the same for several billion years.

h. Seasons are caused by the elliptical orbit of the earth around the sun.

**TASK:** Given Newton’s theory of gravitation and motion, which of the above would you not expect to find? (Your answer may specify a single item from the above list, or more than one item, or you may say, “none of them”.)

**Answer:** ………………………………………………………………………………………

**Question 11**

[This question tests the students’ ability to judge the legitimacy of conclusions that can be drawn from a given body of evidence (ability O).]

18th century French scientist Antoine Lavoisier heated a piece of tin in a tightly sealed flask. The tin began to melt, and grayish ash appeared on its surface. The heating continued for a day and a half, until no more ash formed. Then he allowed the flask to cool. When he inverted it and unsealed it under water, he noticed that the water rose one fifth of the way into the flask.

Now consider the following conclusions:

a. Zinc oxide is grayish in colour.

b. Water reacts with zinc.

c. Air is not an element.

d. Tin needs air to oxidize.

e. The production of stannous oxide takes a day and a half.

f. Some component of air is used up in the burning of tin.

g. The density of water is higher than that of air.

**TASK:** Which of the above can be accepted as legitimate conclusions of Lavoisier’s experiment? (Your answer may specify a single item from the above list, or more than one item, or you may say, “none of them”.)

**Answer:** ………………………………………………………………………………………
**Question 12**

[This question tests the students’ ability to judge experiment design (ability L).]

Miko and her 12-year old brother Jomo bought hot chilly pepper seeds, and planted some under a tree in their backyard. When the chillies were ready to eat, Miko was disappointed because they were not hot. Why were the chillies not hot? Jomo's hypothesis was that the plants were not watered enough. Miko disagreed. Her hypothesis was that the plants didn't get enough sun. They decided to conduct an experiment to find out who was right. They took some chilly seeds, and randomly divided the lot into four groups, I-IV. Group I seeds were planted where they would get plenty of sunlight and were watered regularly. Group II seeds had received plenty of sunlight but not much water. Group III seeds had plenty of water but didn’t receive much sunlight. And Group IV seeds didn’t receive either much sunlight or much water.

Consider the potential outcomes of this experiment, and the conclusions that one can draw from each of these outcomes.

<table>
<thead>
<tr>
<th>Outcomes</th>
<th>Conclusions</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 All the four groups produced hot chillies.</td>
<td>A For chillies to be hot, the plant needs plenty of both sunlight and water.</td>
</tr>
<tr>
<td>2 Group IV didn’t produce hot chillies; groups I-III did.</td>
<td>B For chillies to be hot, the plant doesn’t need a lot of either sunlight or water.</td>
</tr>
<tr>
<td>3 Group I produced hot chillies; groups II-IV didn’t.</td>
<td>C For chillies to be hot, the plant needs plenty of sunlight; the quantity of water doesn’t matter.</td>
</tr>
<tr>
<td>4 Groups I and II produced hot chillies; groups III and IV didn’t.</td>
<td>D For chillies to be hot, the plant needs plenty of water; the quantity of sunlight doesn’t matter.</td>
</tr>
<tr>
<td>5 Groups I and III produced hot chillies; groups II and IV didn’t.</td>
<td>E For chillies to be hot, the plant needs either plenty of water or plenty of sunlight, but not necessarily both.</td>
</tr>
<tr>
<td>6 None of the groups produced hot chillies.</td>
<td>F For chillies to be hot, the plant needs something other than water and sunlight.</td>
</tr>
</tbody>
</table>

**TASK:** For each of the outcomes in the left column in the table above, specify the conclusion(s) on the right that legitimately follow(s) from it. (Against each number given below, indicate the corresponding letter(s) for the conclusion(s). Your answer may specify a single letter, or more than one letter, or you may say “none”.)

**Answer:** (1) ……… (2) ……… (3) ……… (4) ……… (5) ……… (6) ………
Question 13

[This question tests the students’ ability to distinguish between causes and correlations, as part of the more general ability to judge the legitimacy of conclusions that can be drawn from a given body of statistical evidence (ability O).]

When the University of Zigornia examined their student records over the last ten years, they discovered an important correlation: the lower the rates of attendance of the students, the lower the grades they obtained in the final assessment. The group of students whose mean rate of attendance was below 20% flunked their courses, while the group whose mean rate of attendance was above 80% or above obtained grades ranging between A and B.

Consider the following conclusions that one can draw from this data.

a. Poor attendance in classes is one of the causes for poor performance in the final assessment.
b. The cause for poor performance in the final assessment is poor attendance in classes.
c. Poor attendance in classes is not a causal factor in a student’s performance in the final assessment.
d. Students who do well in the final assessment are motivated to attend classes.
e. Class attendance and performance in the final assessment are correlated.
f. Either poor attendance causes poor performance in the final assessment, or they are both different effects of some other causal factor.
g. Universities should make class attendance compulsory to improve student performance.

TASK: Which of the above can be accepted as legitimate conclusions of the research findings reported above? (Your answer may specify a single item from the above list, or more than one item, or you can say “none of them”).

Answer: …………………………………………………………………………………………………………………

Question 14

[This question tests the students’ ability to distinguish unrelated occurrences of two events from events that involve the cause-effect relation, as part of the more general ability to judge the legitimacy of conclusions that can be drawn from a given body of evidence (ability O).]

Read A and B to answer the question given below.

A. The foreign prisoner shackled in heavy iron chains was dragged to the public gallows of the castle, where the gleeful crowd was chanting, “Hang him! Hang him!” He stood upright below the gallows, his head held high, and shouted, “You fools! Goddess Lia will strike you down with lightning and thunder!” A split second later, there was a blinding flash of lightning, followed almost instantly by a deafening peel of thunder. The shocked


crowd was totally silent, until someone whispered, “Goddess Lia protects him!” Almost in unison, they fell on their knees, chanting, “Son of Lia, forgive us!”

B. A report that came out in 2010 says that the number of births in Singapore declined by 1.8% from 32,423 in 2008 to 31,842 in 2009, and asserts that the cause of the decline is the global recession in late 2008.

**TASK:** Identify the error of thinking and reasoning that is common to the conclusion that Goddess Lia protects the prisoner (item A) and that the cause of the decline in birth rate is the global recession in late 2008 (item B).

**Answer:** …………………………………………………………………………………………………

**Question 15**

[This question tests the students’ ability to evaluate the data presented as evidence against a theory, determine whether it poses a problem for the theory, and if it doesn’t, propose a defense (abilities S and T).]

As early as the third century B.C.E, Greek astronomer Aristarchus of Samos had proposed that

a) the patterns that we observe in the apparent movement of the stars and planets in the sky can be explained by assuming that the earth spins on an axis (which would explain the daily east-west cycle of the sun and the nightly cycle of the stars) and

b) along with the other planets, the earth revolves around the sun (which would explain the yearly north-south cycle of the sun as well as the retrograde motion of planets).

This theory, however, was rejected by the main-stream community of Greek scientists on the basis of the following arguments:

i. If the earth rotates on an axis, then an object that is thrown straight up in the air from one location would land in another location, because by the time the object comes down, the earth would have moved away. This is not observed, and hence it couldn’t be the case that the earth rotates.

ii. We observe that unsupported objects fall to the earth. If, as Aristarchus’ theory claims, the center is the sun and not the earth, objects should fall towards the sun, not the earth. Hence, it is not true that the sun is the center. The center is the earth.

**TASK:** Do you think these objections present a problem for the heliocentric theory? If you do, present a solution. If you don’t, say how you would defend Aristarchus against the objections.


The questions given in the previous section call for human judgment in the grading of their answers. The need for human graders create insurmountable difficulties when the number of candidates is huge, as is the case with the entrance examinations for IITs in India. Hence, it is necessary to design computer gradable examinations, Multiple Choice Questions (MCQs) being the best option.

The run-of-the-mill MCQs are useful for the assessment of the recall of isolated information that we treat as regurgitation and of routinized mechanical application, but not for the assessment of deep understanding, thoughtful or creative application, informed judgment, critical thinking, or inquiry abilities.

It is indeed possible to use MCQs to rest thinking abilities, reasoning and inquiry. We begin with two questions in the standard MCQ format (questions 16 and 17), and proceed, in section 10, to illustrate what we call “Enhanced MCQs” which are superior to the standard MCQ.
**QUESTION 16** [Tests the ability to select the mode of reasoning appropriate for the justification of a given research claim/conclusion.]

A strict and intellectually hygienic formulation of conclusions in some (not all) modes of reasoning demand the use of expressions like *it is most likely that, in the absence of contrary evidence, and in the absence of an alternative conclusion* as qualifications that signal various degrees of uncertainty.

**Task:** For each of instances of reasoning in given below, choose the most appropriate form of conclusion.

a. In the 1860’s, a monk called Gregor Mendel cross-bred pea plants with red flowers with those with white flowers. When the parent plants were both pure red, the offspring (pure red) produced red flowers, and when both were white the offspring (pure white) produced white flowers. But when one of the parents was white and the other red, the offspring produced red flowers (mixed red).

When Mendel crossed two mixed red pea plants, the result was 75% mixed red and 25% mixed white. But when two of the resulting mixed white pea plants were crossed, the result was always white, never red.

We can explain these results by assuming – as Mendel did – that in sexual reproduction, (i) each parent contributes a gene corresponding to a property, in this case redness or whiteness of flowers, (ii) genes can be dominant or recessive, (iii) given a conflict between a dominant gene and a recessive gene, the dominant one wins, and (iv) the gene for redness in flowers is dominant and that for whiteness is recessive.

Therefore, we conclude:

| i) | that the theory of dominant and recessive genes is true. |
| ii) | that it is most likely that the theory of dominant and recessive genes is true. |
| iii) | in the absence of contrary evidence, that the theory of dominant and recessive genes is true. |
| iv) | in the absence of an alternative explanation, that the theory of dominant and recessive genes is true. |
| v) | in the absence of contrary evidence or an alternative explanation, that the theory of dominant and recessive genes is true. |
| vi) | none of the above |

b. When we bring a magnet close to an iron needle, we observe that the needle moves towards the magnet. Suppose we mark the two ends a magnet as A and B, and those of another magnet as C and D. When we bring two magnets close to each other, we observe the following. A and C move towards each other, and so do B and D. In contrast, A and D move away from each other, and so do B and C.

Another interesting phenomenon we observe is that if we suspend a magnetic needle in such a way that its ends are free to point in any horizontal direction, one of the ends always ends up pointing to the north, the other pointing to the south.

We can explain these results by assuming that (i) magnets attract iron (ii) every magnet has a south pole and a north pole, (iii) similar poles repel each other, and opposite poles attract each other, (iv) the earth is a magnet, with its magnetic north pole located very near the geographical north pole and its magnetic south pole located very near the geographical south pole.

Therefore, we conclude:

| i) | that the above theory of magnetism is true. |
| ii) | that it is most likely that the above theory of magnetism is true. |
| iii) | in the absence of contrary evidence, that the above theory of magnetism is true. |
| iv) | in the absence of an alternative explanation, that the above theory of magnetism is true. |
| v) | in the absence of contrary evidence or an alternative explanation, that the above theory of magnetism is true. |
| vi) | none of the above |
**QUESTION 17** [Tests the ability to identify the counterexamples/counterevidence to a theory, as one of the ingredients of critical evaluation (subjecting a theory to critical thinking). It involves:

- deriving the logical consequences that follow from the propositions of the theory (= predictions in scientific inquiry) and
- checking whether or not these consequences agree with the grounds (=observations in scientific inquiry)]

**Section 1**

As you know, the heliocentric hypothesis holds that

A. The earth rotates on its axis and revolves around the sun, and

B. The planes of rotation and revolution of the earth are nearly but not exactly the same: the axis of rotation is slightly tilted, at an angle perpendicular to the plane of revolution.

Consider B’ as an alternative to B:

B’. The plane of the rotation of the earth is perpendicular to the plane of the revolution of the earth: the axis of rotation is along the plane of revolution.

What is the evidence to show that B’ makes a grossly incorrect prediction?

- i) Planets exhibit retrograde motion.  
- ii) From the point of view of an observer on earth, the positions of stars change along a circular path, completing a cycle in 24 hours.  
- iii) The north pole and the south pole have snow all the year round.  
- iv) The axis of earth’s rotation is not actually along the plane of its revolution.  
- v) The fact that there are solar and lunar eclipses.  
- vi) None of the above.

**Section 2**

Miko and Jomo were looking for an explanation for the yearly cycle of summer and winter. Miko said that the explanation lies in the hypothesis that the planes of rotation and revolution of the earth are nearly but not exactly the same: the axis of rotation is slightly tilted, at an angle perpendicular to the plane of revolution of the earth around the sun. Jomo disagreed, holding that the explanation lies in the hypothesis that the revolution of the earth is in an elliptical rather than a circular orbit.

Which of the phenomena below can be used as evidence to settle their dispute?

- i) In addition to summer and winter, most places also exhibit autumn and spring.  
- ii) Foucault’s pendulum experiment.  
- iii) The north pole and the south pole have snow all the year round.  
- iv) At the equator, there is very little change in the yearly cycle of climates.  
- v) Unlike rainy seasons, there is only one winter a year.  
- vi) None of the above.
10. Enhanced MCQs.

The standard format of MCQs can be considerably improved, making them approximate open ended questions, if we adopt the following general principles:

- MCQs should be used only in open book examinations. (This means there cannot be any questions that students can anticipate and come prepared with, and whose answers are readily available in textbooks, readings, or class notes.)

- The questions should be designed in such a way that at least half the time should be allocated to thinking. (This means that we can’t have, say, a hundred questions in an MCQ paper for a two-hour exam.)

- The questions should require students to consider something that they haven’t reflected on prior to the exam (e.g., by presenting a body of new information) to ensure that they engage in thinking before answering the question.

- We should maximize the use of open-ended questions (that is, questions in which there is only one correct answer such that for each question a student gets either full marks or zero, but nothing in between.)

It is possible to create a format of Enhanced MCQs (EMCQs) in harmony with these principles. Central to the format are:

- the use of more than 15 options for each question (instead of the standard five options), and
- the choice of more than one option (such that for many questions, full marks require selecting two or more options) but without specifying how many options need to be selected, and
- penalties for the choice of inappropriate options.

What follows is a discussion of the substantive design features of MCQs and EMCQs.

Needless to say, even EMCQs can’t test everything that we want to test. For instance, some of the learning outcomes that can be tested in terms of one paragraph answers or two page answers are not testable through EMCQs. So this is only a plea to explore the possibility of replacing at least some conventional MCQs and some open ended answers with EMCQs.

The general features of EMCQs are:

a. As in the case of the previous questions, every question requires students to process and think through a complex body of new information.

b. As in the case of the previous questions, the design of the task allocates about three fourths of the time for reading and thinking.

c. Fifteen options, instead of four or five. The wider range of options simulates open-ended questions to some extent.

d. Students can choose more than one option. For some questions, students can get full marks only if they choose three or more options. Different options receive different marks.

e. Marks are deducted for irrelevant options and incorrect options. This means that if students choose all the fifteen options (or a large set of options to play it safe), they end up getting zero, even if they have included the “correct” options in set they have chosen. Students have to think very carefully before they answer.

Needless to say, what matters is not the format but the substantive aspect of the question design. However, features (c) – (e) format lend the format to the design of probing questions.

Given below are a few examples:
**QUESTIONS 18**

[This question tests the students’ ability to deduce the predictions of a theory (ability R).]

The sun-centered theory of the solar system that we currently accept holds that:

I. the earth rotates on its axis and revolves around the sun.

II. the axis of rotation is slightly tilted at an angle perpendicular to the plane of revolution.

III. the rotation of the earth is in a 24-hour cycle and its revolution a 365-day cycle.

Suppose we replace I with I*, and propose an alternative sun-centred theory consisting of I*-III instead:

I*. the earth revolves around the sun, but does not rotate on an axis.

II. the axis of rotation is slightly tilted at an angle perpendicular to the plane of revolution.

III. the rotation of the earth is in a 24-hour cycle and its revolution a 365-day cycle.

**TASK:** Which of the scenarios given below would you expect to observe if theory I*-III were true?

You may choose more than one option in answer to the questions. To get full marks, it may be necessary to choose more than one option. But the choice of inappropriate options would result in penalties (i.e., marks would be deducted).

<table>
<thead>
<tr>
<th></th>
<th>Throughout the year, it will be night on one side of the earth, and daylight on the other side.</th>
</tr>
</thead>
<tbody>
<tr>
<td>ii</td>
<td>The duration of the year and the day will be the same.</td>
</tr>
<tr>
<td>iii</td>
<td>The snow in the North Pole and the South Pole will melt once a year.</td>
</tr>
<tr>
<td>iv</td>
<td>At the equator, there won’t be any change in the yearly cycle of climates.</td>
</tr>
<tr>
<td>v</td>
<td>England won’t have a cold season when it is warm in Australia, and vice versa.</td>
</tr>
<tr>
<td>vi</td>
<td>The location of sunrise and sunset will not show a yearly cycle in the north-south direction.</td>
</tr>
<tr>
<td>vii</td>
<td>The earth’s orbit around the sun won’t be elliptical.</td>
</tr>
<tr>
<td>viii</td>
<td>The location of Polaris (the ‘pole star’) will exhibit displacement along a circular path.</td>
</tr>
<tr>
<td>ix</td>
<td>There won’t be any solar eclipses.</td>
</tr>
<tr>
<td>x</td>
<td>There won’t be any lunar eclipses.</td>
</tr>
</tbody>
</table>

Another possibility for this question would be to replace II with II* (instead of replacing I with I*), keeping (i-x) unchanged:

I. the earth rotates on its axis and revolves around the sun.

II* the axis of rotation is exactly perpendicular to the plane of revolution.

III. the rotation of the earth is in a 24-hour cycle and its revolution a 365-day cycle.

There are also several other alternatives.
Question 19
[This question tests the students’ ability to critically evaluate quantitative evidence for/against a claim/hypothesis (ability O).]

Professor Linus Clay of Indiago University asked five top experts in mathematics education to design tests to assess the mathematical abilities of children aged 10 to 15. He administered the tests to a sample of 5,000 boys and 5,000 girls. In every test for each age group (10-11, 12-13, and 14-15) he observed the following distribution:

Prof Hamilton of Dristan University replicated the study among adults, and found the same results.

**TASK 1:** There are 15 statements given below. Which of these statements express **conclusions** you would draw from the distribution above? Put a tick against your choice(s) under column A.

**TASK 2:** Which of these statements would you **speculate** as probable causes of the distribution? Put a tick against your choice(s) under column B.

You may choose more than one option in answer to the questions. To get full marks, it may be necessary to choose more than one option. But the choice of inappropriate options would result in penalties (i.e., marks would be deducted).

<table>
<thead>
<tr>
<th></th>
<th>A</th>
<th>B</th>
</tr>
</thead>
<tbody>
<tr>
<td>i</td>
<td>Males do better in math than females.</td>
<td></td>
</tr>
<tr>
<td>ii</td>
<td>Males do worse in math than females.</td>
<td></td>
</tr>
<tr>
<td>iii</td>
<td>Males do better and worse in math than females.</td>
<td></td>
</tr>
<tr>
<td>iv</td>
<td>Males have greater aptitude for math than females.</td>
<td></td>
</tr>
<tr>
<td>v</td>
<td>Males have lower aptitude for math than females.</td>
<td></td>
</tr>
<tr>
<td>vi</td>
<td>Males have greater and lower aptitude for math than females.</td>
<td></td>
</tr>
<tr>
<td>vii</td>
<td>Males exhibit greater variability in math tests than females.</td>
<td></td>
</tr>
<tr>
<td>viii</td>
<td>Males exhibit higher standard deviation in math tests than females.</td>
<td></td>
</tr>
<tr>
<td>ix</td>
<td>Males have greater variability in aptitude for math than females.</td>
<td></td>
</tr>
<tr>
<td>x</td>
<td>In the higher range, males do better in math than females.</td>
<td></td>
</tr>
<tr>
<td>xi</td>
<td>In the higher range, males have greater aptitude for math than females.</td>
<td></td>
</tr>
<tr>
<td>xii</td>
<td>In the lower range, males do worse in math than females.</td>
<td></td>
</tr>
<tr>
<td>xiii</td>
<td>Females are discouraged from displaying high aptitude for math.</td>
<td></td>
</tr>
<tr>
<td>xiv</td>
<td>Females who are extremely intelligent do not pursue math.</td>
<td></td>
</tr>
<tr>
<td>xv</td>
<td>Females are more intuitive than males.</td>
<td></td>
</tr>
</tbody>
</table>
**Question 20**

[This question tests the students’ ability to deduce the predictions of theoretical models, and the ability to choose between competing theoretical alternatives (abilities R and S).]

Column I below has a set of claims about the heart and the brain. Column II has a set of observations, some of which may be relevant for one or more of the claims in Column I. Some of these observations are results of experiments designed to test specific claims. Figure out which observation is relevant to which claim. If an observation is relevant to a claim, decide whether it supports it, or refutes it.

**TASK 1:** In the space provided alongside each observation, specify the letter corresponding to the claim for which the observation is relevant.

**TASK 2:** In the next column, say whether the observation supports the claim (S), refutes it (R), or is insufficient to either support or refute it (I).

<table>
<thead>
<tr>
<th>I. Claims</th>
<th>II. Observations</th>
<th>Claim</th>
<th>S/R/I</th>
</tr>
</thead>
<tbody>
<tr>
<td>A. Blood circulates through the body.</td>
<td>1. When we have strong emotions, our heart starts beating faster.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>B. The heart pumps blood to various parts of the body.</td>
<td>2. In a famous vivisection experiment that Galen carried out with a pig, severing the nerves from the brain to the larynx (the “voice box” in the throat) resulted in the pig losing its capacity to produce any sound.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>C. (i) Arteries carry blood from the heart to the rest of the body, and (ii) veins carry the blood back to the heart.</td>
<td>3. Harvey measured the amount of blood ejected from the heart at each pulse, and given the number of heart beats per minute, he could then calculate the amount of blood that leaves the heart in a given time period. He discovered that more blood leaves the heart in a short span of time than the amount that the whole body contains.</td>
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<td>D. The brain is the centre of thought.</td>
<td>4. When Harvey opened up a live snake and squeezed its vena cava (the vein connected directly to the heart), its heart became “whiter in colour” and smaller in size, and started beating slower. When he squeezed the aorta (the artery connected directly to the heart), the portion of the artery between the heart and the point of constriction began to swell. The heart became “distended, turned purple to livid in colour,” and looked as if it was about to burst.</td>
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<td>E. The lungs purify blood and infuse it with oxygen.</td>
<td>5. If you tie a bandage lightly around your arm (enough to constrict the veins but not the arteries), little points of swelling will stand out at the valves in the veins below the bandage. (Try this experiment.)</td>
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<td>F. The heart is the centre of emotions.</td>
<td>6. If you tie a bandage very tightly around your arm (such that both the arteries and the veins are constricted), the pulse on your wrist will become weak, and there will be a throbbing between the bandage and the shoulder. (Try this experiment.)</td>
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<td>G. The liver is the centre of emotions.</td>
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