Criteria for inclusion in the “Spatial Thinking” category

Overarching comments: Item must be spatial AND must require thinking (not just looking up or recall.) There are three broad categories described below: Spatial Concepts, Spatial Representations, and Spatial Skills. One exam item can have multiple codes. Criteria for exclusion from the spatial thinking category follow Criteria for inclusion.

Spatial concepts (SC)

A Regents item is categorized as “spatial” if any of the following concepts are needed to correctly answer the question, or to understand the phenomena that the question is asking about—at a 9th grade level of understanding.

- **Position (SC-Po).** Thinking about the position of something (in space, in the earth, on the earth’s surface) is needed to answer the question. Position can be expressed by a drawing/graph/map/diagram, as latitude & longitude, “high/low”, or as a verbal description or label (e.g. “Earth’s equatorial region”, “depth below surface”). If students have to think about position to answer the question, that would be spatial even if there are no spatial terms in the question (e.g. edge versus interior of a tectonic plate.)

- **Configuration (SC-Cn).** Configuration refers to the relative position of two or more objects, attributes or phenomena. Configuration can be expressed by a drawing, or a map, or by words such as “behind”, “within”, or “between” (topological terms).
  
  Example: Jan ’11, Q33: The map below shows the names and ages of different bedrock formations in North America. The bedrock ages are shown in billions of years. [map] The ages shown on the map suggest that the (1) oldest bedrock is located in the Churchill formation, (2) the youngest bedrock is located in the Wyoming formation, (3) younger bedrock has been added to the east and west coasts of the continent, (4) age of bedrock increases from west to east across the continent. Correct answer (3) involves direction (east and west) and also configuration (youngest along east and west coasts with older in between). Option (4) asks you to test for a gradient.

- **Distance (SC-Ds).** Distance refers to how far apart things are in or on the earth. Distance doesn’t imply either motion or direction. Distance can be expressed as: words such as “distance,” “altitude” (aka distance from ground), “depth” (aka distance below sea surface or earth’s surface), “elevation” (aka distance from sealevel) or by a map scale.
Example: Jan 'll, Q2. The theory that the universe is expanding is supported by the (1) blue shift of light from distant galaxies, (2) red shift of light from distant galaxies, (3) nuclear fusion occurring in the Sun, (4) radioactive decay occurring in the Sun. This could be answered by pure memorization. But there is value added in thinking about this spatially. Expanding universe theory says distant galaxies (distance) are moving away from us (direction). Therefore the wavelength of their lightwaves is being lengthened (size); longer wavelengths means shifted towards the red end of the visible spectrum. Even if keyword “distant” in “distant galaxies” were missing, this would still be spatial.

• **Direction (SC-Dr).** Direction can refer to either a static position (e.g. northern New York state), or to a dynamic direction of motion (e.g. northward flowing stream). Direction can be expressed in words (North/South/East/West, up/down, upward/downward, towards/away, diverging/converging, clockwise/counterclockwise, inward/outward, onshore/offshore) or by an arrow or label on a diagram, or by motion from one place or region to another place or region. Also code SC-DR if thinking about direction is required to arrive at the answer, even if not mentioned in the question.
  - Example: Aug '09, Q 80: [topographic map] Towards which compass direction is Snapper Creek flowing?
  - Example: June '09: Q61: [diagram showing moon or biting the Earth with sun's rays coming in from the side] Which letters represent the two positions of the Moon when the least difference between the levels of high and low ocean tides occur on Earth? (requires thinking about the direction of gravitation pull.)

• **Motion (SC-Mo).** Motion through space or in space. The path and direction of the motion may or may not be specified. Can be expressed as arrows or words:
  - rotation, revolution,” ”, “universe is expanding,”
  - move/motion/movement, velocity
  - “transport,” “runoff,” “[sediment] is carried,” “blowing,” “flowing,” “discharge of water”, [water] current
  - “transferred” [referring to energy]
    - Aug '08 Q6: When Earth cools, most of the Energy transferred from Earth’s surface to space is transferred by the process of (1) conduction, (2) reflection, (3) refraction (4) radiation. Coded as motion (Mo), Position (Po).
  - subduct, displaced, overturned
  - Example: Jun '09, Q5: The arrows in the diagram below represent the movement of water in the water cycle [diagram showing a sketch of a landscape with arrows for water cycle elements] Which arrow represents the process of transpiration? This is coded as SC-Mo + SC-Dr rather than SC-Tr because no discrete path is shown or implied.

• **Speed (SC-Sp).** Speed is distance/time and therefore can sometimes be spatial (but usually not). Speed does not include direction (i.e. it is scalar).
  - Example: Aug '09, Q 69. [diagram showing sun with earth’s orbit around it] Approximately how many days does it take Earth to move from position A to position C in its orbit? Rationale: need to know that earth’s speed is one revolution per year, and interpret the diagram to infer that one half year has elapsed between A and C, and come up the correct answer between 182 and 187 days.
- **Trajectory (SC-Tr).** Trajectory refers to motion along a path. If there is no path specified, code as “motion.” Path can be straight or curved. Trajectory can be expressed in words (e.g. orbit, path across the sky, path of a storm system), or as arrows or lines on a map or diagram. In almost all cases, an item coded as SC-Tr will also be SC-Mo.

- **Angle (SC-An).** Angle can be expressed in degrees, in words (”gentle slope/steep slope”, “horizontal/vertical”, “directly overhead”), or by a diagram. Note that “altitude” can be either an angle (“altitude of Polaris”) or a distance (distance from the ground or from sea level).

- **Size (SC-Sz).** Count as spatial if the size has significance, i.e. the size either influences geo processes or is influenced by geo processes, and that influence bears on what is being asked.

- **Volume (SC-Vl).** Can be expressed as a change in volume (e.g. “expands/contracts”) or distance.
  - Note that *density* is a ratio that involves volume (mass/volume) and thus can be spatial if students have to think substantially about volume. But usually density is just presented as a property of matter with no spatial aspect (e.g. what is the density of basalt?).

- **Area (SC-Ar).** Similar to “volume” except 2D rather than 3D; refers to an amount of space, as would be measured in square meters, square kilometers, etc. Does not refer to a region (e.g. “New York metro area”) for purposes of this coding.
  - Example: June ’11 Q14: Thin layers of volcanic ash act as excellent time markers in the correlation of bedrock because volcanic ash (1) is easily eroded and lasts only a short time on Earth’s surface, (2) stays in the atmosphere for millions of years (3) is deposited over millions of year (4) fall to Earth over a large area in a short period of time.

- **Shape/morphology (SC-Sh).** Shape can be shown by a diagram, photograph. Count as spatial if the shape is central to the question being asked.
  - Example: Aug ’09, Q 42. Base your answers to questions 42 through 44 on the cross section below, which shows the bedrock of a portion of the Helderberg Escarpment, located in Thacher State Park near Albany, NY. [diagram of flatlying strata, with stairstep edge]. Which formations appear to be the most resistant to weathering? Answer requires identifying that the stairstep shape is caused by varying resistances of rock layers, with most resistant layers forming near-vertical portions. Note that what is distinctive is the stairstep morphology, not gradient alone.

- **Texture (SC-Tx).** Code if texture causes or influences an Earth process, or is caused by an earth process. Do not code if texture is purely descriptive or part of an illustration not used in answering the question.
  - Example, texture causes an Earth process: Jan ’11, Q6. Which type of land surface will most likely absorb the greatest amount of incoming solar radiation? (1) rough, dark-colored surface, (2) rough, light-colored surface, (3) smooth, dark-colored surface, (4) smooth, light-
colored surface. Rough versus smooth is a texture that influences an Earth process (light reflection) and an Earth attribute (albedo), because of the difference in the trajectories of light rays hitting a rough surface vs a smooth surface.

- *Example, texture is caused by an Earth process*: Jan ’11, Q14. Sediments found in glacial moraines are best described as (1) sorted and layered, (2) sorted and not layered, (3) unsorted and layered, (4) unsorted and not layered.

- **Gradient (SC-Gr)**. Question requires thinking about a situation in which an earth attribute changes through space. Can be expressed in words, numbers or diagrams.
  - *Qualitative Example*: Aug ’09, Q11. In which two temperature zones of the atmosphere does the temperature increase with increasing altitude? (1) troposphere and stratosphere (2) troposphere and mesosphere, (3) stratosphere and thermosphere, (4) mesosphere and thermosphere. Refer to ref tables p. 14, shows temperature changes (gradients) with altitude. (note this question is also *position*, and *spatial representation*.)
  - *Quantitative example*: Aug ’09, Q81. [topographic map] Calculate the gradient between points X and Y. Units must be included in your answer.

- **Global interconnection (SC-GI)**. Student has to think about how processes in one part of the globe are impacting or can impact processes or observable attributes in other parts of the globe.
  - *Example*: Aug ’10 Q11: “For weeks after a series of major volcanic eruptions, Earth’s surface air temperatures are often…. [answer] cooler because ash and dust decrease atmospheric transparency.” In this example, students have to think about how a process in one place (volcano) can have an impact over a wider area.

- **Cycle (SC-Cy)**.
  - *Material cycles*: e.g. the rock cycle, the water cycle.
    - Note that these cycles are spatial but also conceptual. (Spatial aspects: rock gets eroded from mountains, transported down and coastward by rivers, carried further down to into the Earth’s interior during metamorphism, etc.)
  - *Temporal Cycle*: something varies over time with a regular period (the attribute that varies needs to be spatial, otherwise it’s only temporal thinking, not spatial thinking)
    - E.g. tides,
    - *Example*: [Diagram of moon/sun/earth] Q: An observer at location A noticed that the apparent size of the Moon varied slightly from month to month when the Moon was at position M4 in its orbit. Which statement best explains this variation in the apparent size of the Moon? A: The Moon’s distance from Earth varies in a cyclic manner.
**Spatial Representations**

Classify as spatial if the student has to interpret processes or structures from a spatial representation, including:

- **Map (SR-Mp).** Representation uses two dimensions of the paper to depict two spatial dimensions of earth, both horizontal.
  - If question involves substantial use of maps in Reference tables or exam booklet or answer booklet, categorize it as spatial even if there is not an explicit spatial term/concept explicit in the question.
    - Example: Jan ’11 Q17. In which New York State landscape region have fossilized footprints of Coelophysis dinosaurs been found in the surface bedrock? (1) Allegheny Plateau, (2) Tug Hill Plateau, (3) Hudson-Mohawk Lowlands, (4) Newark Lowlands. This could be memorized. More likely route to answer is to look up in timeline when dinosaurs were, then look on geological map to see where Mesozoic rx are, then look on landscape map to see what landscape region that is.
  - If they have to use two or more maps (e.g. combine information from multiple maps; transfer information from one map to another), that would count as “substantial.”
  - If they just have to mindlessly look something up on a single provided map, and there is no thinking about spatial processes or structures at all, that would be non-spatial. (see example under “exclusion” criteria.)

- **Cross-section/Profile (SR-Pf).** Representation is a slice perpendicular to the earth’s surface
  - Typical SR-Pf uses two dimensions of the paper to depict to two spatial dimensions, both proportional to earth dimensions, one horizontal and one vertical.
  - Alternative, also classified as SR-Pf, is a slice into the center of the earth, like the Inferred Properties of Earth’s Interior diagram on p 10 of the ESRT.

- **Block diagram (SR-Bd).** Representation uses space on the paper to depict three spatial dimensions of earth.
  - {does not include topographic contour maps}
  - {does not include a 3-D representation of a laboratory apparatus, like a stream table or settling tube.}

- **Photograph (SR-Ph).** A photograph could be a spatial representation if size or another spatial concept can be observed in the photo and is probed by the question.
  - Example: Aug ’08, Q 20. The photograph below shows a large boulder of metamorphic rock in a field in the Allegheny Plateau region of New York State. [photo] The boulder was most likely moved to this location by (1) glacial ice, (2) prevailing wind, (3) streamflow, (4) volcanic action. The size of the boulder (judged relative to trees in the photo) is diagnostic to determine that only a glacier could move the rock. (Note: a separate spatial line of reasoning is to find Allegheny Plateau on landforms map, cross-check on geological map to see that this region is all Devonian sedimentary rocks, and infer that the metamorphic boulder had to be an erratic.)
• **Graph of Y versus Distance (SR-Gd):** Graph which has Earth-distance as the independent variable (e.g. Y versus altitude, Y versus latitude, Y versus distance onshore/offshore). The dependent variable, Y, can be any earth attribute (e.g. temperature, seismic wave travel time, density, grain size). These graphs usually involve thinking about gradients.
  
  o *Example:* June 09 Q 52: requires use of altitude versus air temperature graph from Reference tables.
  
  o *Note:* if BOTH X and Y (both dimensions on the paper) are spatial distance measures, then you probably have a map (Mp) or a profile (Pf) rather than a Gd.

• **Solar System Representation (SR-SS).**
  
  o Includes a view of celestial bodies (sun, moon, Earth, other planets) from a vantage point in space
  
  o *Example:* Jan ’11, Q28. diagram shows position of the Sun, the Moon, and the Earth during a solar eclipse....

• **Other representations in which dimensions of the paper represent dimensions of the Earth system (SR-O).**
  
  o *Example:* Aug ’10 Q61: [diagram in which relative diameter sizes of circles are proportional to sizes of planets] "Circle only the terrestrial planets"
Spatial skills:

- **Perspective taking (SS-PT).** The student needs to exercise perspective-taking to answer the question. Perspective-taking requires envisioning how something would look from a viewpoint other than that currently occupied by the student.
  - *Example:* Jan ’11, Q1. If an observer on Earth views Polaris on the horizon, the observer is located at the (1) equator (0°); (2) North Pole (90°N); (3) Tropic of Cancer (23.5°N); (4) Tropic of Capricorn (23.5°S)

- **Visual penetrative ability (SS-VPA).** The student needs to exercise visual penetrative ability to answer the question. Visual penetrative ability involves envisioning or imagining the inside of a volume when only the exterior is shown.¹

- **Mental animation (SS-MA).** Student needs to exercise or would benefit from exercising mental animation,² i.e. envisioning that objects are moving or deforming and how they are moving or deforming.³
  - *Example:* Aug ’09 Q2. A camera was placed in an open field and pointed towards the northern sky. The lens of the camera was left open for a certain amount of time. The result is shown in the photograph below. The angle of the arc through which two of the stars appeared to move during this time is show. [photo with many concentric arcs, each spanning 90° of sky] How many hours was the lens left open to produce the photograph? (1) 12, (2) 2, (3) 6, (4) 4.
  - *Example:* Jan ’08. The water table usually rises when there is: (1) a decrease in the amount of infiltration, (2) a decrease in the amount of surface area covered by vegetation, (3) an increase in the amount of precipitation, (4) an increase in the slope of the land. [Rationale: spatial, because the question benefits from a mental image of water falling onto the ground, infiltrating, and causing the water table to rise. This example sits at the fuzzy borderline between mental animation and mental manipulation; is the water a continuous material being deformed (MM) or individual objects/drops moving relative to each other (MA)?] ⁴

  *Possible modification:* should Mental Manipulation and Mental Animation be combined?


² The term “mental animation” was taken from: Hegarty, M. (1992). Mental animation: Inferring motion from static displays of mechanical systems. *Journal of Experimental Psychology, 18*(5), 1084-1102. Mental rotation would be a subset of mental animation as I am currently viewing this term; there are not enough occurrences of mental rotation in the ES Regents to justify a separate category.

³ 4may2011: We used to have a separate category of “mental manipulation” defined as “the ability to mentally manipulate an image into another arrangement.” This definition comes from Titus & Horsman (2009). Similar to what was called “spatial orientation” by Ekstrom et al, (1976). Usage by Titus & Horsman leans heavily towards deforming and un-deforming bodies of rock. We merged mental manipulation and mental animation, because for something like moving water they are indistinguishable.
• **Sequencing (SS-S).** student needs to use spatial information to unravel the temporal sequence in which events occurred.
  
  o  **Possible modification:** focus of this category so far has been on unraveling geological relationships from cross-sections or maps. Perhaps this category should be expanded to "diachronic thinking" (sensu Dodick⁴), which could include other kinds of tasks in which students think about the relationship between time and space.

• **Describe (SS-D):** Student needs to *describe* a spatial relationship or use spatial terms to describe an earth phenomenon.
  
  o  **Example:** Jan '11, Q65. Base your answers to questions 64 and 65 on the graph below, which shows the distance from the Sun and the period of revolution for four planets in our solar system labeled A, B, C, and D. [graph] State the relationship between the distance from the Sun and the period of revolution for these four planets. Answer: the farther from the Sun, the greater the period of revolution. Rationale for coding: Relationship stated is a function of distance.

  o  **Example:** Aug '09, Q 51. Describe the change that takes place in the gravitational attraction between Earth and the Sun as Earth moves from perihelion to aphelion and back to perihelion during one year [accompanied by diagram showing Sun, Foci, perihelion and aphelion]. Rationale for coding: answer requires describing a phenomenon as a function of distance between objects.

  o  **Example:** Jan '08, Q 70. Base the answers to questions 66 through 70 on the weather map in your answer booklet... Describe the pattern of the surface winds around the center of the low-pressure system. Answer: “inward” or “towards the center” or “counterclockwise.”

• **Representational Correspondence (SS-RC):** Student must transfer information from one spatial representation to another, or combine information from multiple spatial representations, or distinguish between (compare and contrast) similar representations. Term and idea come from Liben (1997)⁵.
  
  o  Note that "describe" could be considered as a form of representational correspondence (visual to verbal representation), but it is sufficiently distinct that we are giving it its own category.

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**Criteria for Exclusion from the “Spatial” category**

**Classify as Non-Spatial if:**

- There is a spatial concept (e.g. distance, size, etc.) in one of the distractors only, and thinking about this spatial concept does not contribute to answering the question.
  - *Example:* Jan '11, Q8. Which weather variable is measured by a barometer? (1) dewpoint, (2) wind speed, (3) air pressure, (4) visibility. Speed is a component of trajectory, and pressure is a ratio of force/area, but this is a straight memorization question that just requires remembering the definition of barometer. Thinking about speed as distance/time and pressure as force/area do not contribute at all to answering this question.

- There is a spatial attribute mentioned, but its spatialness is completely beside the point, not useable at all in solving the problem.
  - *Example:* Jan '11, Q26. Which pie graph correctly shows the percentage of elements by volume in Earth’s troposphere? [pie graphs] *Rationale:* This is a pure reference table question; understanding of volume is of no use in answering question.
  - *Example:* Aug '09, Q1. An observer recorded the times of three successive high tides at one Earth location as 7:12 am, 7:38 pm, 8:04 am. What was the time of the next high tide? (1) 8:12 pm, (2) 8:30 pm, (3) 8:38 pm, (4) 9:04 pm. *Rationale:* “Location” is a spatial concept, but here the word is just used to clarify the question; the fact that tides differ from location to location isn’t used to answer the question. “High/low” can be a variant of the spatial concept of position, but here it is merely a time marker on the tidal cycle, and the required thinking is temporal rather than spatial.
  - *Example:* Aug '09, Q12. Which type of electromagnetic radiation has the longest wavelength? (1) ultraviolet, (2) gamma rays, (3) visible light, (4) radio waves. This is purely a look up question from ref tables, thinking about relative lengths of waves is not needed and does not help.

- The dimensions of the paper are used to express a non-spatial attribute of the Earth.
  - *Example:* Jan '11, Q26. Which pie graph correctly shows the percentage of elements by volume in Earth’s troposphere? [pie graphs] *Rationale:* Composition of the troposphere is a non-spatial attribute of the Earth. Pie graphs spatialize a non-spatial attribute, which isn’t enough to count as spatial in the conditions of this project.

- There is a map or other spatial representation involved, but the use of the spatial representation is a trivial look up with no spatial significance.
  - *Example:* Jan '11, Q54. [Generalized bedrock map of Iceland] According to the map, during which geologic era did the surface bedrock at location D form? Locate D on map, and find age of bedrock from map key (700,000 to 3,100,000 years old), then look on the timeline to determine that time is Cenozoic era. Purely a look up question, location of D has no significance.
  - *Counter example:* Aug '09, Q13. Which cold ocean current affects the climate of the northeastern coast of North America? (1) Gulf Stream, (2) Canaries, (3) Labrador, (4) North
Atlantic. This requires slightly more spatial thinking than the question above, and so was classified as spatial. Additional spatial elements: find Surface Ocean Currents map on Ref tables p. 4. *direction* (knowing which was northeastern coast), *proximity* (knowing that current would need to be proximal to affect climate), *trajectory* (knowing that the cold current would be coming down from the north).

- There is a deep and advantageous way to think about the question spatially, but it is not typically taught that way to Regents ES students.
  - *Example:* Aug ’09, Q18. The basaltic bedrock of the oceanic crust is classified as (1) felsic, with a density of 2.7 g/cc, (2) felsic, with a density of 3.0 g/cc, (3) mafic, with a density of 2.7 g/cc, (4) mafic, with a density of 3.0 g/cc. [Rationale: Density is mass/volume, and one could have a deep conversation about isostasy, but 8/9th graders don't go there.]