Evaluating Elementary Pre-service Sience Teachers' Alternative Conceptions about Earth and Space Using Diagnostic Multiple-Choice Items

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Abstract: - The present qualitative research, a crucial investigation, focuses on the alternative conceptions (ACs) of one hundred and twenty (N = 120) elementary pre-service teachers (PSTs) from Quebec in Canada regarding Moon-Earth-Temperatures, Shadow-Sun-Earth, and Earthe-Cloud-Lightning. A multiple-choice questionnaire (MCQ) was meticulously constructed and administered. The results, with profound implications for science education, reveal that most of their ACs regarding these phenomena are erroneous compared to those accepted by the scientific community, underscoring a significant gap in understanding. These findings directly and significantly impact science education, highlighting the urgent need for targeted interventions to correct these misconceptions. Their ACs were: 1. The Sun is a warm light source; 2. The Moon is closer to the Sun than the Earth; 3. The distance between the Earth and the Sun and the Moon explains the difference in temperature between them; 4. The Moon's temperature is much higher than that on Earth because the Moon is much smaller than Earth's; and 5. The positive charges accumulated at the top of the cloud collide with the negative charges located at the bottom of the cloud. These electrical charges are attracted to the Earth, which has already been charged; 6. When hot temperatures meet cold temperatures, atmospheric pressure causes lightning to form; 7. Lightning forms when the cloud is sufficiently charged with a magnetic field. The results confirm the findings astronomy and physics education researchers highlighted worldwide and, in some cases, provide possible explanations for previously reported ACs.

Key-Words: - Qualitative study; multiple-choice questionnaire; elementary pre-service teachers; alternative conceptions; Moon-Earth-Temperature; Shadow-Sun-Earth.

Received: April 19, 2024. Revised: December 22, 2024. Accepted: January 24, 2024. Published: June 2, 2025.

1 Introduction

A review of the international literature on students' (from elementary school to university) and pre-service and practitioner teachers' alternative conceptions (ACs) (i.e., misconceptions or incorrect scientific understandings) of Astronomy and Earth Science education. This review, based on a diverse range of research methodologies, brings to light the most usually encountered concepts studied. These include the seasons and the day-night cycles [1-4]; the phases of the Moon [5-7]; solar and lunar eclipses and formation of shadow and penumbra [8-12]; the Earth's shape, weight, gravity, and free fall [13-20]; distance, space, time, and velocity [21-24]; earthquakes, earth structure, geologic resources, glaciers, plate tectonics, rivers, rocks and minerals, soils, volcanoes, and weathering and erosion [25-28]; rectilinear and circular motion [29-31], and Heat and Temperature [32-34]. This thorough review provides a comprehensive understanding of the most common misconceptions in Astronomy and Earth Science education.

Understanding these phenomena and their underlying scientific concepts is crucial for effective teaching and learning in Astronomy and Earth Science education. This review identified many ACs that persist even after teaching spread over several years, underscoring the importance of understanding ACs. It's crucial to note that these are not just misconceptions, but incorrect beliefs that need correction.

The most common ACs demonstrated in these researches are: 'The seasons caused by the change in the distance of the Earth to the Sun'; 'The seasons occur as a result of the Sun's orbit around the Earth'; 'Clouds obscure the unseen part of the moon'; 'Earth's shadow blocks our view of the moon'; 'we always see the same side of the Moon from the Earth implies that the Moon does not rotate on its axis, which is a common but incorrect belief'; 'There is no gravity in space (Weight disappears in the absence of air)'; 'A lunar eclipse occurs when the sun covers the moon'; 'During a solar eclipse, the Earth faces the sun and covers the moon'; and 'a lunar eclipse occurs when the Moon blocks sunlight.'; 'The gravitational acceleration exerted on a free-falling body increases throughout its falls'; 'The notions of mass and weight are synonymous'; 'Most things that are in our environment we must push or pulled them to overcome gravitation'; 'heat is substance quantity that flows like the smoke'; and 'temperature is a measure of heat'; These ACs are crucial for developing effective teaching strategies and correcting these misconceptions. Addressing these misconceptions in the Physics and Eart Science curriculum is paramount as it will enhance students' understanding and appreciation of the subject.

It is crucial to emphasize that the ACs mentioned above are not isolated incidents. They are prevalent among elementary school students, high school students, university students, pre-service teachers, and practicing teachers.

Despite years of study in physics and Earth science education, ACs persist, demanding immediate and urgent attention and action. Numerous studies highlight four factors that explain this complex tenacity: **1.** Everyday experience [5], [21], [35-36]: For instance, the experiments we conduct in our daily lives with the concept of gravity lead us to establish the following generalizations which are false relative to scientific relations: 'objects fall at the same rate regardless of their mass,' ' the Earth is flat,' and 'the Sun revolves around the Earth.'; Felicita [5] highlights, as does the work of Vosniadou [35], the crucial importance of reconciling everyday experience explanations with the currently accepted scientific view: "A common problem is one of reconciling everyday experiences, such as observing the rising and setting sun, with abstract models, which attempt to explain why this occurs." (p. 26); **2.** Life-world knowledge [37-38]: Life-world knowledge, the familiar understanding of the world gained through personal experiences and observations, is something we all possess. For example, we know from our life-world knowledge that 'exercise can help in losing weight' and that 'in summer, the sun sets late.' These are everyday experiences that we can easily relate to and understand, providing a sense of reassurance and confidence in our knowledge; **3.** Curriculum materials as science textbooks [39-42]: For example, Newton stated the law of universal gravitation while observing a free apple, and Archimedes stated the principle of floatability while taking his bath; **4.** Scientific errors teachers make when teaching subjects are a significant challenge.

Addressing these misconceptions is complex because they persist in traditional teaching [43-47]. These findings underscore the urgent need for further research. We must develop learning and teaching strategies that consider students' ACs and aim to foster conceptual change. To this end, the urgency and importance of preparing teachers to consider their students' misconceptions is crucial [48-49]. As Rasul et al. [48] point out, "Research indicates that teachers, like students, also have misconceptions and can be a source of transferring them to their students. Consequently, pre-service and in-service teachers need to be trained in exploring and overcoming misconceptions of students."

Despite the considerable research on students' and teachers' ACs synthesized higher, there is still a significant gap in our understanding. More about students' and teachers' ACs related to the Earth's interactions with the Moon and the Solar need to be known. This research is part of a lineage of studies that recognize the pressing need for further investigation. The present research, therefore, aims to investigate the following questions:

a. Do elementary pre-service teachers (PSTs) consider Earth's rotation on its axis to explain the shadow changes throughout the day?

b. Do elementary PSTs know that Life on Earth, unlike the Moon, is possible because of the atmospheric layer?

c. Do elementary PSTs know that the difference between Earth's and Moon's temperature is related to their atmosphere?

d. Do elementary PSTs know that lightning between the lower base of a cloud and the ground of the Earth cannot occur if the air is not ionized?

Below, we will specify the multiple-choice questionnaire (MCQ) developed to identify the ACs of PSTs and analyze the data collected during the experiment. This MCQ was designed to assess the understanding of elementary PSTs on key concepts related to Earth and Space.

The data collected from this questionnaire will be crucial for understanding the PSTs' ACs of Earth and Space.

2 Methodology

To establish the ACs of 120 PSTs (aged between 19 and 23 years) in teacher training for elementary school, we have given them a voluntary MCQ with an explanation of sixty minutes duration (see Appendix). It is important to note that the questionnaire was entirely voluntary for PSTs to complete; they accepted, and we are grateful for the participants' willingness to contribute to our research.

The participants were encouraged to explain their answers in a non-judgmental and comfortable environment, ensuring their responses were free from the pressure of a formal exam and any potential bias.

So, to fill out the questionnaire, they had to refer to their impromptu conceptions of phenomena related to Earth and Planetary Science. They had taken courses during their secondary school on topics related to the seasons, the moon phases, and the Earth-Moon-Sun interaction during their secondary school. Most indicated that they did not remember the concepts studied. In this regard, we clarified that this is not an exam. Instead, it is an opportunity for them to compare their answers with the scientists during the course, providing a reassuring guide.

Our questionnaire is more than just a series of questions. It's an interactive learning tool that engages students in a dynamic thinking process. With three MCQs and detailed explanations as illustrated in Appendix, it's designed to uncover students' thought processes and reasoning. The first MCQs were designed to test the students' understanding of the differences in Moon and Earth temperatures. The second focused on the variation in the size of a person's shadow throughout the day. The third delved into the formation of lightning. In each case, the students were given the task of choosing among different statements we provided, which best explained the phenomenon in question. They were also entrusted with the responsibility of justifying their choices. If they disagreed with the provided options, they had the freedom to choose none of the statements and propose their own, accompanied by an explanation. The number of statements varied depending on the question, with question 1 having 6 statement responses, the second 5 statement responses, and the third four statements (see Appendix).

For the second question, we drew on a study that categorized the PSTs ACs [8] about the size of a shadow, identifying five conceptual representations. Each of these representations was then presented as an item in our MCQ (see Appendix-Question #2).

For question 1 (Earth-Moon-Temperature), we identified six distinct conceptual representations. Similarly, for question 3, we found five unique representations (see Appendix). These representations were identified through a paper-and-pencil questionnaire completed by around a hundred PSTs, a key part of our didactics course designed to inform our study.

Our research, which involved administering MCQs and analyzing PSR's explanations, is a comprehensive endeavor that provides a deep understanding of students' thought processes. We meticulously determined the percentage of students' choices in each statement and rigorously verified if the PSR's explanations were: 1. False: The explanations are false compared to accepted scientific explanations; 2. Partially correct: The explanations put forward include elements of the answer that are scientifically correct and other elements that are incorrect; 3. Incomplete: The explanations put forward are scientifically correct but are incomplete.

We then compared the students' answers to the scientific responses in a thorough manner, qualifying them as correct, incorrect, or partially correct regarding scientific answers. From a methodological point of view, this analysis procedure ensured the reliability and accuracy of our findings.

3 Results: Objective and Data analyses

In the following section, we will present the objectives pursued by each of the 3 MCQs, followed by our scientifically backed answers. These answers are based on highly credible references that emphasize the conceptual foundations of the questions studied in this research without calculation (i.e., qualitative explanation) [50-52].

Note that this qualitative aspect is crucial in the context of research on student reasoning in problem-solving relating to phenomena belonging to different fields of knowledge in science, such as those studied in the present research.

Such references ensure our study's scientific rigor and credibility. We will also present the qualitative analysis of the collected data, further reinforcing the scientific basis of our research.

3.1 Objective and Data Analyses: Question #1 Earth-Moon-Temperature

Question #1 aims to determine whether students will use the phenomenon of sunlight's absorption and scattering as it reaches the Earth's and the Moon's surfaces to explain why the temperature is much higher on the Moon than on Earth (see Appendix). This understanding is not just academic, but it has real-world implications. Unlike the Moon, the Earth has an atmosphere that serves as a shield, a protective barrier that reduces its warming by the Sun's rays. When the Sun's rays reach the Earth, a fraction is reflected into space by clouds, atmospheric particles, and the Earth's surface. The oceans and continents absorb the other fraction and then are emitted back into space through thermal infrared radiation. The infrared radiation is, in turn, absorbed by certain gases present in the atmosphere, such as carbon dioxide, methane, oxygen, nitrogen, and water vapor, which rebroadcast this heat towards the Earth's surface. The oceans and continents absorb the other fraction and then are emitted back into space through thermal infrared radiation. In turn, infrared radiation absorbed by these gases creates a delicate balance with their unique properties, rebroadcasting this heat towards the Earth's surface. This process, known as the greenhouse effect, is a natural regulator, maintaining the Earth's temperature within a stable range essential for human and animal life; without it, our planet would be cold and hostile and not very likely to support life. However, this delicate balance is disrupted by excessive industrialization, profoundly impacting the Earth's atmosphere. If we do not take urgent action to address this issue, the consequences could be catastrophic. The primary sources of the increase in the temperature of the Earth's globe are related to greenhouse gas emissions following various human activities such as deforestation, fossil fuel combustion, intensive agriculture, and poor waste management. These activities and industry development (i.e., the refrigeration industry and aerosols) cause the emission of significant amounts of greenhouse gases, particularly chlorofluorocarbons (CFCs).

Greenhouse gases, with their disruptive effect on solar and terrestrial radiation, are causing a rapid rise in the Earth's surface temperature and sea level due to melting glaciers. They are also depleting the ozone layer, a crucial shield against harmful UV radiation. Notably, the average global temperature surged during the 20th century, underscoring the urgency of the greenhouse gas issue.

Surprisingly, the Moon may significantly influence Earth's warming. A study in New Scientist [53] suggests that the Moon's gravitational pull-on Earth could be a direct contributor to the release of a substantial amount of methane related to the tides.

The Moon's atmosphere, with its unique properties, is 100 billion times less dense than Earth's. Unlike Earth, the low gas density of the lunar atmosphere does not allow the reflection of rays by the ionosphere, the atmosphere, and the clouds. This distinct characteristic results in the Moon's surface being significantly hotter than Earth's when exposed to light rays. The Moon's atmosphere, which contains gases found in Earth's atmosphere, such as methane, carbon dioxide, and carbon monoxide, was detected by detectors placed by astronauts on the Apollo missions, highlighting the unique nature of the Moon's atmosphere.

However, the Moon's thin atmosphere, unable to retain light rays like Earth's, leads to a rapid and stark temperature drop when its surface is not illuminated. This unique property creates extreme conditions, making lunar exploration a thrilling yet challenging endeavor [54].

Table 1 provides a breakdown of the number of students for each statement, followed by some students' responses justifying their choice and explaining their reasoning.

Table 1. Number of respondents (N) in each statement and the student's explanations analyses

Statements percentages/ Pre-service Teachers' ACs
Statement 1 [20%-24/120]: The temperature on the Moon is higher than on Earth because the Moon is closer to the Sun than Earth.
"The rays reach the Moon more quickly, and that is why the temperature is higher when the Moon is illuminated by the Sun." E_7 "The light of the Sun is produced by the emission of photons (light energy). This energy is produced by the thermal energy of the Sun. Thus, the closer we are to the Sun, the higher the temperature because we are closer to the light source." E_8 "The heat source from the Sun must travel a greater distance to reach the planet. However, the Earth's air composition can also explain this phenomenon." E_{29}
Analyses
Statement 1 is false because the Moon is a satellite of the Earth and orbits around it. This is a fact that can be observed and verified. The Moon is, therefore, sometimes closer to the Sun than the Earth, and sometimes it is further away; it is enough to observe the phases of the Moon to see this variation in distances. For example, when the Moon is located between the Earth and the Sun (e.g., the new Moon), while at the full Moon, the latter is located behind the Earth. Moreover, the distance between the Moon and the Earth is negligible compared to their distance from the Sun. To reiterate, the Moon's distance from the Sun varies due to its orbit around the Earth, and the thermal radiation it receives is minimal. The reasoning put forward by E_7, E_8, and E_9 is wrong since, for them, the thermal radiation coming from the Sun heats the Earth less than the Moon since the latter is closer to the Sun. It is important to remember that very little thermal radiation (thermal energy) reaches the Earth, and the Moon compared to the light rays (light energy), which interact with the matter that composes the atmospheric layers of the Moon and the Earth, as explained above.
Statement 2 [12%-14/120]: The Moon casts its shadow on the Earth, which decreases the amount of radiation the Earth receives from the Sun.
"The Moon casts a shadow on the Earth, which causes some absences of light, so its temperature is lower." E_{20} "The Moon is not always closer to the Sun since it orbits the Earth. When it is between the Sun and the Earth, it generates shadow and penumbra on the Earth, which explains the temperature difference." E_{22} "It is just that the Moon casts a shadow on the Earth compared to the Sun, so the heat of the light travels less quickly." E_{28}

Analyses
Indeed, the Moon sometimes casts its shadow on the Earth, but this is a rare and fascinating event that we call a solar eclipse. When the Moon positions itself between the Earth and the Sun, it creates shadows on the Earth, a phenomenon that usually only lasts a few minutes. And it's worth noting that this event does not affect the average temperature on Earth, so there's no need to worry about any drastic changes.
Statement 3 [21%-25/120]: The temperature on Earth is lower than on the Moon because Earth has an atmosphere that protects it from the Sun's rays.
"The Moon is not protected from the Sun's rays by an ozone layer, while the Earth is, which explains this temperature difference." E_1 "The Earth receives less heat from the Sun because the rays are deflected when entering our atmosphere, so the speed is not the same, and less heat is produced." E_3 "On the Moon, there is no atmosphere whose role is to cool the Sun's rays." E_9 "As they pass through the atmosphere, the rays lose their power and therefore their heat." E_{13} "The Earth's ozone layer reflects several hot and dangerous light rays for the Earth, which is why we do not have such a high temperature on Earth." E_{15}
Analyses
The student's answers illustrated below are incomplete because they lack explanations of the phenomenon of absorption and scattering of light as it enters the Earth's atmospheric layer and the near absence of the lunar atmosphere, as explained above.
Statement 4 [18% (22/120]: The temperature on the Moon is higher than on Earth because the Moon is smaller than Earth.
"It depends on the distance, the source of light, and the object's size. Since the Moon is smaller than the Earth, it will be hotter according to the law of rectilinear light propagation." E_{10} "I think it is because of the size of the Moon. Since it is smaller and receives the same light, it is hotter than the larger Earth." E_{11}
Analyses
Statement 4 is incorrect. The Moon is smaller than Earth, with a three times smaller diameter. This size difference, however, does not directly explain the Moon's higher temperature, as the planet is not isolated. Despite its larger size, the Earth maintains its temperature due to the greenhouse effect, a natural phenomenon where part of the infrared radiation emitted by the Earth's surface is absorbed. Understanding this effect is crucial to comprehending Earth's climate, as this surface, in turn, receives radiation from the Sun, a crucial part of our more extensive celestial system.
Statement 5 [16%-19/120]: The temperature on the Moon is higher than on Earth because the Moon's color allows it to absorb more heat.
"Since the Moon is white, it absorbs all the rays coming from the Sun while the Earth reflects many of them." E_2 "The Moon is in orbit around the Earth, constantly changing position. The high temperature is due to the dark color of the Moon, which absorbs heat." E_{18} "This is because the Moon, by its color, absorbs all the rays of the Sun, while the Earth reflects many of them. The Moon can, therefore, absorb more heat." E_{26} "The Moon reflects lighter than the Earth. The reflected light causes the creation of thermal energy." E_{30}
Analyses
The reflection of light described by these students is called albedo, introduced by Johann Lambert (1728-1777). Note that the albedo represents the proportion of light energy returned by an illuminated body. It corresponds to the fraction of light reflected by surfaces. A highly reflective surface will have a very high albedo; the darker the surface, the more rays it absorbs, which increases temperature. However, the albedo of the Moon is 0.2, reflecting only 12% of the light [49]. This albedo is lower than that of the Earth. PSTs E_2 and E_{30} wrongly thought that the Moon reflected more rays than the Earth. They also improperly associated that reflective surfaces captured more rays when the opposite occurs. However, they all correctly concluded that the Moon warmed more than the Earth under the effect of the Sun's rays. This understanding is a significant step in grasping the concept of albedo, a concept that they now understand and can confidently apply. The Moon's and Earth's temperatures are due to the reflection of the rays on the atmosphere and not related to the color of the ground surface.
Statement 6 [13%-16/120]: The temperature on Earth is lower than on the Moon because the Earth's surface has shadow areas.
"The Sun is much bigger than the Moon, so it projects light onto a larger part of the Moon. The Earth has more shadows and penumbras, which means the temperature is lower (see diagram)." E_{14} "The Earth is closer to the Sun, but that is not all. The Moon constantly receives the Sun’s rays, and since the Earth rotates on its axis and around the Sun, a shaded part of the Earth is always present. Thus, it never receives all of the Sun’s rays, meaning its heat is less." E_{27}
Analyses
The regions of the Earth that are not very exposed to the Sun's rays are colder. According to NASA, the average temperature felt on Earth is $+15^0$C thanks to the presence of the atmosphere, which distributes the heat over its entire surface.

3.2 Objective and Data analyses: Question #2 Shadow-Sun-Earth

Question #2 was crafted to unlock the student's potential to comprehend complex phenomena, such as the intricate influence of Earth's rotation on our shadow changes throughout the day (see Appendix 1). In general, the size and shape of a shadow change with the position (angle and distance) of the light source relative to the position of the object casting the shadow because the object blocks more or less light. Since the Earth rotates on its axis, the Sun's angle relative to a person on the Earth's surface changes.

It's important to note that the Earth's rotation is the primary driver of these changes. Technically, the distance between that person and the Sun also changes. However, this change is so tiny that it can be confidently ignored for practical purposes (i.e., much smaller than the distance between the Earth and the Sun). So, the length of shadows changes throughout the day because of the change in the relative angle between the Sun and the object, casting the shadow as the Earth rotates on its axis. So, when the Sun is low, the rays that reach us create a slight angle with the ground, casting a greater shadow. Conversely, when the Sun is high, the light rays form a larger angle with the ground, casting a shorter shadow.

These concepts, taught in the universe, Earth, and space at primary and secondary levels in Quebec, are not just academic knowledge. They have direct relevance to our daily lives. For instance, understanding the change in shadow length can help determine the best time for outdoor activities or the direction of a compass.

In primary school, each student is exposed to the functioning of the solar system, particularly the link between the rotation of the Earth and the cycle of days and nights. They also learn about the cause of seasonal changes, such as the shape of the Earth's orbit around the Sun and the inclination of the Earth on its axis, and how these factors influence the length of shadows and the Sun's apparent position.

Students are tasked with understanding the practical implications of the length of a shadow, a phenomenon that changes throughout the day due to the Earth's rotation and over a year because of its axis's tilt. This understanding is not just theoretical but has real-world applications, making it of significant importance in the field of Earth science and physics education.

As we delve into the subsequent analysis, we will uncover the conceptual hurdles that Pre-Service Teachers (PSTs) often face in grasping this subject.

Table 2 presents the distribution of students for each statement, along with some students' responses to justify their choice and explanation.

Table 2. Number of respondents (N) in each statement and the student's explanations analyses

Statements percentages/ Pre-service Teachers' ACs
Statement 1 [15%-18/120]: The size of our shadow changes throughout the day because the Earth rotates on its axis, which causes the sun's movement.
"The earth turns and makes the sun seem to change place, so the lighting angle changes." E_{11} "Because the earth turns, and when the earth turns, the sun changes place. That is why the shadow changes color." E_{17}
Analyses
This statement is incomplete. One complete rotation (360°) of the Earth on its axis corresponds to one day. As the Earth rotates, the relative angle of the Sun also changes, and therefore, the length of the shadows varies.
Statement 2 [28%-34/120]: The size of our shadow changes throughout the day because the intensity of the Sun's light; a more vigorous intensity corresponds to an enormous shadow.
"Because in the morning, your shadow will be average because the sun is average. It will be big in the afternoon because that is the time of day when there is more sun. In the evening, there will be almost none because the sun is all gone, or almost all gone." E_1 'Because the light must be strong so that our shadow is like us, the less light, the less shadows." E_{14}
Analyses
This statement is false. As pointed out above, the length of a shadow is related to the position of the light source relative to the position (angle and distance) of the object casting the shadow, not the intensity. It is fascinating to note that during a day, the Earth's rotation on its axis significantly changes the relative angle between a person and the Earth, thereby altering the length of their shadow. Understanding this concept of shadow length is not just fascinating, but also significant in our understanding of natural phenomena.
Statement 3 [32%-38/120]: The size of our shadow changes throughout the day because the sun moves during the day.
"That it's because the sun rises and sets. It changes places, so your shadow gets bigger and smaller." E_{15} "Because the sun changes place." E_{16} "Because the sun moves during the day." E_{18} "Because if the sun is low, its shadow is bigger, and when it is higher, it is smaller." E_{21}
Analyses
This statement is incorrect. The Earth moves in two ways simultaneously: rotation and revolution. Rotation is the Earth's spinning on its axis, which causes day and night. Each rotation takes one day. Revolution, on the other hand, is the Earth's movement around the Sun, which causes the change in seasons. Each revolution takes one year. From a person's point of reference to the Earth's surface, these movements cause the Sun's appearance to change throughout the day and the year. These changes in appearance have historically been attributed to the Sun's movement around the Earth, a conclusion drawn from careful observation (this model is called the geocentric model). Later, Nicolaus Copernicus proposed the heliocentric model, in which the Earth revolves around the Sun.

Statement 4 [15%-18/120]: The size of our shadow changes because the Earth revolves around the sun.
"Because the Earth revolves around the Sun, the Sun is at different angles during the day." E_5 "Because the Earth revolves around the Sun." E_{20}
Analyses
This statement is partially correct. The Earth revolves around the Sun, but this is not the cause of the change in the length of a shadow during the day. The Earth's rotation on its axis, which occurs predictably every day, is what brings about day and night. As the Earth rotates, the relative angle of the Sun changes, leading to the variation in shadow length.
Statement 5 [10%-12/120]: The size of our shadow changes throughout the day because of the Earth's distance from the Sun; the Sun is closer to the Earth in the afternoon than in the morning or evening.
"In the morning, the sun is far from the earth, but when it is afternoon, the sun is closer to the earth, and in the evening, it is the same for the morning." E_{19}
Analyses
It is important to note that this statement is partially correct. The length of shadows changes during the day not due to the change in the distance between the sun and the object but because of the change in the relative angle between the sun and the object casting the shadow. It's a common misconception that we're here to clarify.

3.3 Objective and Data analyses: Question #3 Earth-Cloud-Lightning

Question 3 is a deep dive into the fascinating and complex lightning phenomena. Lightning, as we know, usually occurs in thunderstorms (see Appendix). A thunderstorm can initiate when a warm, moist air mass meets cold ambient air and rises into the atmosphere to form a thundercloud. At high altitudes, the temperature drops due to the reduced pressure, and the moist air changes from gas to a liquid (water droplets) or solid (crystals) state, releasing energy in the form of heat. This condensation occurs thanks to particles such as dust at a low temperature, called a condensation nucleus. A cumulus cloud then forms and continues to grow and spread vertically. Eventually, its shape stabilizes and becomes that of a cumulonimbus cloud. Inside the cloud, strong winds play a crucial role in lightning formation. These winds cause the tiny water droplets suspended on the particles to collide with crystals, tearing electrons from them and becoming negatively charged. Due to gravity, the tiny water droplets, being heavier, end up at the bottom of the cloud, while the lighter crystals end up at the top. This separation of charges due to gravity leads to the accumulation of opposing electrical charges at the base of the cloud.

On the other hand, positive electrical charges gather at the top of the cloud, setting the stage for an electric field to take center stage inside the cloud. When the electric field's value surpasses the dielectric strength of air, an insulator and electrical discharges come to life. These discharges, under the influence of the powerful electric field, trigger the ionization of the air, a process of profound significance. It transforms the air into a conductor by separating electrons from the atoms, creating ions. This transformation is key, as it enables the passage of electrons from one end of the cloud to another in the ionized air. Understanding these complex processes is crucial due to learning; electric current emerges, a direct consequence of the ionization phenomena.

Table 3 presents the number of students for each statement, followed by some students' responses to justify their choice and explanation.

Table 3. Number of respondents (N) in each statement and the student's explanations analyses

Statements percentages/ Pre-service Teachers' ACs
Statement 1 [20/120-17%]: The collision between cold air and warm air produces energy in the clouds in the form of lightning.
"It is the friction between hot and cold air rubbing together. That is why we see heat lightning in the summer. Lightning does not need rain to form." E_2 "When hot and cold air currents meet, electrical energy is formed in the clouds. When the clouds can no longer retain so much of this electrical energy, it is released towards the ground, and this is how lightning is formed and strikes the ground." E_5
Analyses
Inside cumulonimbus clouds, strong currents of warm, humid air rise, and cold, dry air descend. The friction creates a difference in electrical charge, eventually causing an electrical discharge (lightning).
Statement 2 [24/120-20%]: The positive charges accumulated at the top of the cloud collide with the negative charges located at the bottom of the cloud. The earth, which is already charged, attracts these charges. Thus, lightning is formed and hits the ground.
"The ground is negatively charged while clouds are positively charged. The air resistance decreases because of the humidity in the air; this creates an electric arc, lightning." E_9 "The separation of positive and negative charges must occur in a cloud to create lightning." E_{19} "I think it is the positive and negative charges of the cloud. The positive ones are at the top of the cloud, and the negative ones are at the bottom; this creates lightning." E_{20}
Analyses
Friction between the hot, humid air currents and the cold, dry air currents creates a separation of electrical

charges. The finest, positively charged particles move toward the top, and the heaviest, negatively charged particles move toward the base. This redistribution creates a significant imbalance, a key factor in the formation of lightning. This imbalance, between the electrical charges inside and outside the cloud and between the cloud's negatively charged base and the positively charged ground, is what leads to the awe-inspiring phenomenon of lightning when it reaches a critical point due to the accumulated charges becoming too great.
Statement 3 [38/120 -31%]: A substantial accumulation of charges in the clouds favored by the humidity factor leads to the formation of lightning.
"Lightning is produced by clouds when there is a strong electrostatic build-up. Rain, which increases the humidity in the air, promotes the production and conduction of lightning to the ground." E_4 "Since the air is humid, it is electrically charged. When it rains, or the air is very humid, the air is even more electrically charged. Lightning is formed from its electrical charges." E_{16} "Lightning is formed by an electrostatic charge conducted by the air and the water it contains, descends to dry land. Some friction probably causes this charge." E_{30}
Analyses
As precised higher, during thunderstorms, the cumulonimbus is highly electrically charged: the charge of the top of the cloud, composed of light ice crystals, is generally positive, while that of the base of the cloud, composed of water droplets heavier than the ice above, is generally negative.
Statement 4 [18/120-15%]: Lightning is the light that comes with thunder.
"Lightning, the luminous manifestation of an electrical discharge, is a powerful force in the natural world. It heats the air to a very high temperature and occurs within clouds, or from a cloud to the ground, shaping the environment we live in." E_{15} "Lightning is the light that accompanies lightning: at the moment of the electrical discharge during the formation of thunder, the gases in the atmosphere and on the path of the electrical discharge will heat up and ionize under the effect of this electrical discharge and emit light." E_{22}
Analyses
Lightning is an electrical discharge that occurs between clouds and the ground. It consists of lightning and thunder (a violent detonation).
Statement 5 [20/120-17%]: Lightning is formed by the combination of several factors, such as high temperature, water drops (humidity), and wind, which result in the ionization of the air.
"The creation of electricity comes from the friction between various substances. During a storm, the clouds in the sky, therefore the fine water droplets in suspension, are very agitated by the high temperature causing the storm. This increase in temperature creates friction between the droplets, and at a certain moment, this stored energy is released, which forms lightning." E_{23} "Thanks to the factors: electricity rate, wind strength, and temperature. Several electric fields are formed when there is much electricity in the air. If the temperature is high enough, the latent electricity will be activated. If it is strong enough, the wind creates friction between the different electric fields, which will form lightning. Lightning is therefore formed by the friction between the different electric fields found in the air." E_{29}
Analyses
The factors highlighted in this statement are indeed involved in lightning formation. However, the link between these factors and lightning formation is not specified. It is crucial to understand these concepts. The justifications advanced demonstrate serious conceptual difficulties in linking these factors with lightning. As the temperature rises, the air can hold more water as vapor. At higher altitudes, this vapor condenses, forming clouds. The air movement within these clouds leads to particle collisions, altering their electrical charge. When the voltage reaches a critical level, lightning is unleashed. With its immense power, this lightning ionizes the air in its path, transforming it into a conductor and significantly impacting its surroundings.

4 Discution and conclusion

A tiny percentage of PSTs answered correctly based on scientific reasoning. The majority have provided answers, and some of their ACs result from a misunderstanding of the concepts of heat and temperature when developing their response (e.g., the Sun heats the Moon more than the Earth, hence the temperature difference). In this regard, many students confuse the notions of heat and temperature to interpret phenomena in the everyday context [34-36], which probably explains the use of this misconception to elaborate on the temperature differences on the Moon and the Earth as highlighted in the analysis of our data (Question #1).

Our research has revealed a common misconception among several PSTs and school students, as evidenced by the international literature we have synthesized in our introduction [5-12]. This misconception pertains to the relationship between light intensity and shadow size. It is a significant finding that most children believe the size of an object's shadow changes based on the light's intensity. As educators and researchers, we have a crucial role in recognizing the prevalence of these misconceptions and implementing targeted interventions in multiple contexts to correct them, thereby empowering us to shape a more accurate understanding of this fundamental concept.

We have also identified among many PSTs specific conceptual errors that result from teaching rather than from their personal experience with the phenomena studied. For example, the formation of lightning (Question #3) between a cloud and the Earth's ground is explained by a collision between positive and negative charges. The confusing use of scientific notions is highlighted in several studies. In the case of the question about the size of the shadow, most of the conceptual difficulties encountered by teachers are due to their personal experience of the movement of the Sun relative to the Earth.

This research results align with the work that proposes teaching strategies focused on conceptual conflict, as highlighted in the introduction [43-47]. So, the PST ACs and their corresponding scientifically accepted counterparts summarized in Table 4 are interesting in developing many constructivist environments centered on conceptual change. However, we must confront the PST ACs with those developed throughout history by renowned scientists.

Also, the MCQ constructed (see Annex) to know the PSTs ACs allows teachers to identify their students' ACs rapidly.

Table 4. Summary of PSTs ACs and their corresponding scientifically accepted counterpart

PSTs ACs	Scientific accepted conceptions
Earth-Moon-Temperature	
Ozone is responsible for the temperature difference between the Earth and the Moon.	The atmosphere and Sun light interaction are responsible for the Earth's and the Moon's temperatures. As for the ozone layer which contains a high concentration of ozone (i.e., a gas composed of 3 oxygen atoms); its protects the Earth from ultraviolet radiation emanating from the Sun which is harmful to life.
The atmosphere is responsible for the Earth's temperature difference and the Moon's.	All the gases present in the atmosphere (e.g., methane, carbon dioxide, water vapor) are responsible for the greenhouse effect and, therefore, the constant temperature on Earth.
Light rays from the Sun do not slow down as they enter the atmosphere because the speed of light is constant.	Light rays from the Sun slow down as they enter the atmosphere because the atmosphere is a more refractive medium than space.
There is no atmosphere on the Moon to cool the Sun's rays.	Although the Moon has an atmospheric layer, it is extremely thin or insignificant compared to Earth's. The Sun's rays are not cooled but absorbed by the matter that makes up the atmosphere.
The closer a planet is to the Sun, the higher the surface temperature becomes because it is closer to the light source.	The closer a planet is to the Sun, the higher the temperature on its surface if its atmospheric layer is thin because fewer rays are absorbed.
The Earth's atmosphere has the role of cooling the Sun's rays.	The role of the Earth's atmosphere is, among other things, to absorb part of the solar rays composed of photons.
The Moon receives the same amount of light from the Sun, which is hotter than the larger Earth.	The Moon receives more light rays from the Sun not because of its size but because of its insignificant atmospheric layer compared to Earth.
Sun-Earth-Shadow	
The Sun moves during the day, so the shadows vary.	The Sun's angle on stationary objects changes with the Earth's rotation, so shadows vary throughout the day. The Sun's motion is just an apparent illusory position.
The variation in sunlight intensity results from the Sun's movement.	The variation in sunlight intensity is due to the angle at which the Sun's rays hit the Earth, which changes with the time of year.
During the day, the Sun moves across the sky in a path that forms an arc, a consequence of the Sun's movement around the Earth.	During the day, the Sun appears to move across the sky in a path that forms an arc, a consequence of the Earth orbiting the Sun and rotating about its axis.
Earth-Cloud-Lightning	
Storm clouds are electrically charged.	Storm clouds are electrically charged because they are made up of tiny water droplets and ice crystals that constantly move, collide, and rub against each other.
A thundercloud contains positive and negative charges.	The lower part of a thundercloud contains negative charges, while its upper part has positive charges. Ice crystals, negatively charged by friction with water droplets, exhibit a unique behavior as they descend to the lower part of the cloud. In contrast, water

	droplets, positively charged by friction with ice crystals, also display a unique behavior as they ascend to the upper part of the cloud.
Moisture in the air allows clouds to discharge when they reach the ground.	A charged cloud (positively and negatively) discharges when the difference between the opposing charges (upper part of the cloud) and the positive charges (lower part of the cloud) (e.g., electric potential difference) is more significant.
The friction of water droplets in a cloud causes the cloud to become electrically charged.	A cloud becomes charged due to the friction between water droplets and ice crystals.

Appendix

Paper and pencil questionnaire

Question #1

The temperature on the Moon's surface can reach up to 120 ^{O}C when it is in the Sun's spotlight, a stark contrast to Earth's more moderate climate. In fact, it can reach up to 50 ^{O}C in Death Valley in the United States, highlighting the significant difference between the two celestial bodies.

According to you, which of the following statements below best explains this temperature difference between the Earth and the Moon:

❒ The Moon's temperature is higher than Earth's because the Moon is closer to the Sun than Earth.
❒ The temperature on Earth is lower than on the Moon because the Moon casts its shadow on the Earth's surface.
❒ The temperature on Earth is lower than on the Moon because Earth has an atmosphere that protects it from the Sun's rays.
❒ The temperature on the Moon is higher than on Earth because the Moon is smaller than Earth.
❒ The temperature on the Moon is higher than on Earth because the Moon's color allows it to absorb more heat.
❒ The temperature on Earth is lower than on the Moon because the Earth's surface has shadow areas.
❒ None of these statements: …………………………….

Explain your answer choice as best you can:
……………………………………………………………

Question #2

Which of the following statements best explains how the size of our shadow changes throughout the day:

❒ The size of our shadow changes throughout the day because the Earth rotates on its axis, causing the Sun to move.
❒ The size of our shadow changes throughout the day because of the intensity of the Sun's light; a more vigorous intensity corresponds to an enormous shadow.
❒ The size of our shadow changes throughout the day because the Sun moves during the day.
❒ The size of our shadow changes because the Earth revolves around the Sun.
❒ It is important to note that this statement is partially correct. The length of shadows changes during the day not due to the change in the distance between the Sun and the object but because of the change in the relative angle between the Sun and the object casting the shadow.
❒ None of these statements: …………………………….

Explain your answer choice as best you can:
……………………………………………………………

Question #3

Which of the following statements best explains how lightning is formed:

❒ The collision between cold air and warm air produces energy in the clouds in the form of lightning.
❒ The positive charges accumulated at the top of the cloud collide with the negative charges located at the bottom of the cloud. The earth, which is already charged, attracts these charges. Thus, lightning is formed and hits the ground.
❒ A substantial accumulation of charges in the clouds favored by the humidity factor leads to the formation of lightning.
❒ Lightning is formed by combining several factors, such as high temperature, water drops (humidity), and wind, which result in the ionization of the air.
❒ None of these statemen: ……………………………….

Explain your answer choice as best you can:
……………………………………………………………

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