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Teaching K-12 Particle Physics as an Advocate: A STEM Personal Journey into Radio Wave Science and Technology Research

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Abstract

Science instruction is often criticized for focusing on the memorization of discrete concepts, facts and laws. The focus students perceive science as a set of *final form* ideas suggests little change over time[1]. There is often a focus on one “right answer” rather than an exploration of ideas that includes incorrect or partially correct explanations [2]. However, research and reform efforts identify evidence as an essential component of science classroom instruction to actively engage students in science practices [3]. This paper advocates for evidence-based student learning of radio wave science and student-led discovery of electron density as a prognostic indicator of disrupted radio communicationsover multipleEarth-Moonregions of space.Propagation of radio waves is affected due to [4]. TEC changes in plasma and electron densities, formation of ionospheric plasma sheath due to spacecraft reentry, increased interaction of electrons, ions, and molecules present in the atmosphere with radio waves. For these reasons, required areprediction and warning systems are required that predict the associated geomagnetic activities in advance.Scientific evidence fosters the work of science learners from individually learning final form (i.e. evidence, or system failures) and isolated facts (i.e. parametric data) to actively participate in knowledge construction for understanding existing policy and research. Students will develop conceptual cognitions resulting from making sense of “scientific evidence” as phenomena is explained.

Keywords: Global positioning system (GPS),radio wave communications,total electron content (TEC), electron flux, plasma ionosphere, lunar plasma exosphere

Background

Different radio communication links (land, land-to-air, air-to-air) covering different atmospheric and ionospheric conditions, include several components having a plethora of physical principles and processes, with their own independent or correlated working characteristics and operating elements. A simple scheme of such a radio communication link consists of a transmitter, a receiver, and a propagation channel. The main output characteristics of such a link depend on the conditions of radio propagation in different kinds of environments,

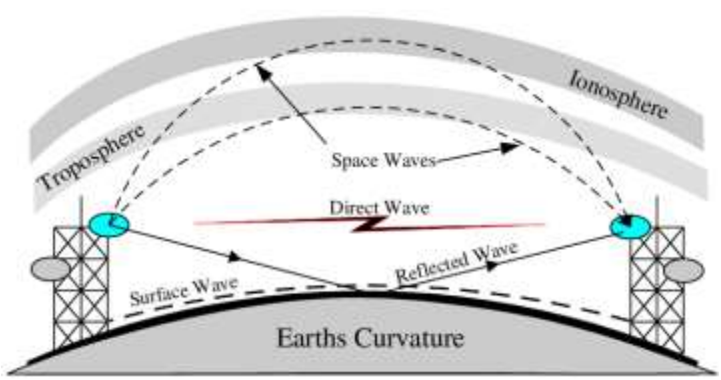


Figure 1

Radio waves propagate from one point to another in a vacuum or into various parts of the atmosphere. As a form of electromagnetic radiation, radio waves are affected by such phenomenaas reflection, refraction, absorption, polarization, and scattering[5]. Regarding radio frequency, electromagnetic waves are generated and radiated, not electrons. This is a consequence of current -i.e. the movement of electrons in a conductor (the antenna) driven by a time varying voltage. The current in the antenna generates both electric and magnetic fields and this field is radiated. At the receiving antenna, the time varying field induces a current in the receiving antenna, and as a result, a detectable voltage. Electron flow is confined to within the transmitting and receiving antennas, and what is flowing between the antennas is electromagnetic fields, not electrons.

The propagation of radio waves is affected by the ionosphere. The velocity of radio waves changes when the signal passes through the electrons in the ionosphere. The total delay suffered by a radio wave propagating through the ionosphere depends both on the frequency of the radio wave and the total electron content (TEC) between the transmitter and the receiver. At some frequencies the radio waves pass through the ionosphere. At other frequencies, the waves are reflected by the ionosphere.When propagating through Earth's ionosphere, the radio waves interact with free electrons along the transmission paths, introducing group delay and phase advance[6].The effects of varying conditions on radio propagation help determine what frequencies to choose for amateur radio communications, to design for reliable mobile telephone systems, or to operate in radar systems.Different types of propagation for radio transmission systems include

- *Line-of-sight propagation* wherein radio waves travel in a straight line from the transmitting antenna to the receiving antenna.
- *Line of sight transmission* used for medium-distance radio transmission, such as cell phones,wireless networks,television broadcasting, radar, and satellite communication (such as satellite television).

All devices that use RF are potentially vulnerable to interference, including radio, cellular, radar, satellite, Wi-Fi, Global Positioning System (GPS), unmanned aircraft system (UAS) communications and control systems, and other technologies.Radio frequency (RF) interference results from the effect of unwanted energy due to one or a combination of emissions, radiations, or inductions upon reception in a radio communication system, that manifestsas performance degradation, misinterpretation, or loss of information which could be extracted in the absence of such unwanted energy. Effects of interference can range from mild disruption or delays in data throughput to a complete loss of service[7].

elecommunication between satellites and the ground applies high enough radio frequencies (RF) that permit the signal to pass through the ionosphere, while ground-to-ground communication makes use of reflection from the ionosphere. Thus, as ionospheric properties vary during space weather events, RF communication is also affected. Consequently, the signal can be distorted, fade or disappear totally, and the signal can propagate along unusual paths and to unexpected distances. Satellite navigation systems having a large number of different applications that rely on ionospheric plasma vary in a wide range of temporal and spatial scales, which makes the determination of the influence on RF signals difficult [8].

Terrestrial Weather	Space Weather
Neutral gas physics	plasma physics
"Playground": atmosphere	"playground": interplanetary space, magnetosphere, ionosphere, and atmosphere
Efficient satellite monitoring	few satellites
Extensive global ground network	set of local ground networks with different instruments
Regional-scale modeling	global modeling
Public and professional customers	professional customers
Economic impacts clear	direct and indirect economic impacts under discussion

Table 1. Comparison Between Terrestrial Weather and Space Weather [9].

Introduction

The Geostationary Operational Environmental Satellites (GOES) are a series of key satellites National Oceanic and Atmospheric Administration have used to monitor weather and space weather since 1975. With multiple series of space-weather instruments onboard for measuring particles, the magnetic field, solar irradiance, and solar image monitors, electron flux measurements indicate the intensity of the outer electron radiation belt at geostationary orbit. Measurements are made in two integral flux channels, one channel measuring all electrons with energies greater than 0.8 million electron Volts (MeV) and one channel measuring all electrons with energies greater than 2 MeV. Electron Event ALERTS are issued when the >2 MeV electron flux exceeds 1000 particles/(cm^2 sec- steradian). High fluxes of energetic electrons associatedwith deep-dielectric spacecraft chargingoccurs when energetic electrons penetrate into spacecraft components and buildup charge within the material. When the accumulated charge becomes sufficiently high, anomalous behavior in spacecraft systemsmay result in temporary or permanent loss of functionality.

NOAA Space Weather Scales

Category		Effect	Physical measure	Average Frequency (1 cycle = 11 years)
Scale	Descriptor	Duration of event will influence severity of effects		
Radio Blackouts			GOES X-ray peak brightness by class and by flux*	Number of events when flux level was met; (number of storm days)
R 5	Extreme	HF Radio: Complete HF (high frequency**) radio blackout on the entire sunlit side of the Earth lasting for a number of hours. This results in no HF radio contact with mariners and en route aviators in this sector. Navigation: Low-frequency navigation signals used by maritime and general aviation systems experience outages on the sunlit side of the Earth for many hours, causing loss in positioning. Increased satellite navigation errors in positioning for several hours on the sunlit side of Earth, which may spread into the night side.	X20 ($2x10^{-3}$)	Fewer than 1 per cycle
R 4	Severe	HF Radio: HF radio communication blackout on most of the sunlit side of Earth for one to two hours. HF radio contact lost during this time. Navigation: Outages of low-frequency navigation signals cause increased error in positioning for one to two hours. Minor disruptions of satellite navigation possible on the sunlit side of Earth.	X10 (10^{-3})	8 per cycle (8 days per cycle)
R 3	Strong	HF Radio: Wide area blackout of HF radio communication, loss of radio contact for about an hour on sunlit side of Earth. Navigation: Low-frequency navigation signals degraded for about an hour.	X1 (10^{-4})	175 per cycle (140 days per cycle)
R 2	Moderate	HF Radio: Limited blackout of HF radio communication on sunlit side of the Earth, loss of radio contact for tens of minutes. Navigation: Degradation of low-frequency navigation signals for tens of minutes.	M5 ($5x10^{-5}$)	350 per cycle (300 days per cycle)
R 1	Minor	HF Radio: Weak or minor degradation of HF radio communication on sunlit side of the Earth, occasional loss of radio contact. Navigation: Low-frequency navigation signals degraded for brief intervals.	M1 (10^{-5})	2000 per cycle (950 days per cycle)

* Flux, measured in the 0.1-0.8 nm range, in $W m^{-2}$. Based on this measure, but other physical measures are also considered.

** Other frequencies may also be affected by these conditions.

URL: *www.swpc.noaa.gov/NOAAscales* April 7, 2011

Table 2.

The Total Electron Content (TEC) is the total number of electrons present along a path between a radio transmitter and receiver.The more electrons in the path of the radio wave, the more the radio signal will be affected. For ground to satellite communication and satellite navigation, TEC is a good parameter to monitor for possible space weather impacts.

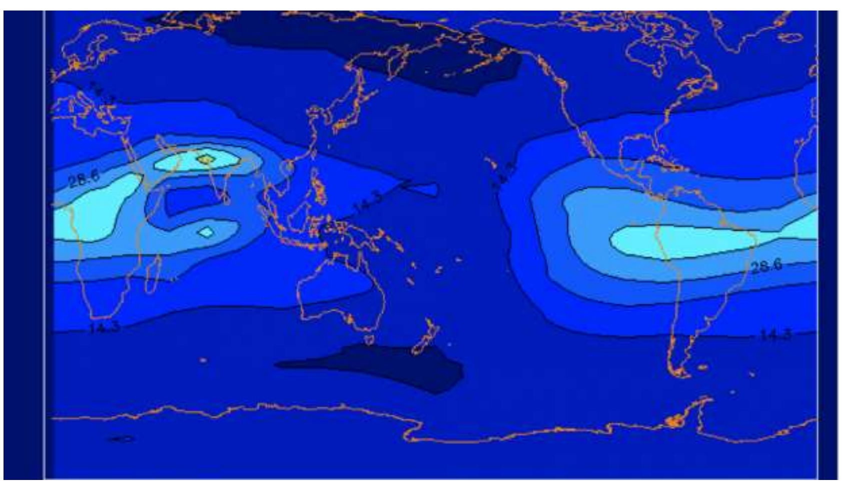
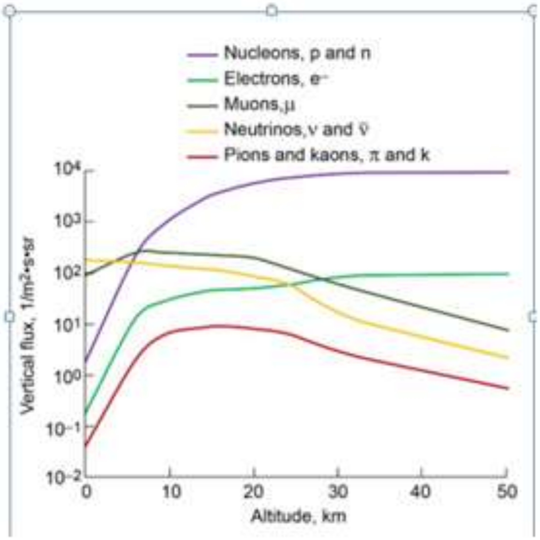


Figure 2. TEC. Space Weather Prediction Center National Oceanic and Atmospheric Administration

TEC maps are used to estimate the GPS signal delay due to the ionospheric electron content between a receiver and a GPS satellite. Modified by changing solar Extreme Ultra-Violet radiation, geomagnetic storms, and the atmospheric waves that propagate up from the lower atmosphere, TEC in the ionosphere impacts the propagation of radio waves. The change in the path and velocity of radio waves in the ionosphere has a big impact on the accuracy of satellite navigation systems such as GPS/GNSS. Neglecting changes in the ionosphere TEC may introduce tens of meters of error in the position calculations.

Geomagnetic storms create large disturbances in the ionosphere. The currents and energy introduced by a geomagnetic storm enhance the ionosphere and increase the total height-integrated number of ionospheric electrons, or the Total Electron Count (TEC). GPS systems cannot correctly model this dynamic enhancement, and errors are introduced into the position calculations. This usually occurs at high latitudes, though major storms can produce large TEC enhancements at mid-latitudes as well.



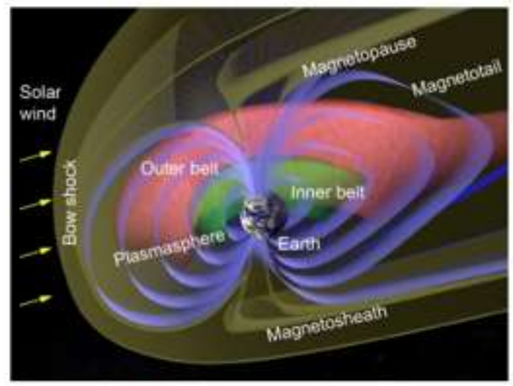


Figure 4.—Structure of Earth magnetosphere with magnetopotentials in blue, inner radiation belt in green, and outer radiation belt in red.

Figure 3.

Depending on the location and local time, a wide range of physical processes take place to formulate the ionospheric conditions that are critical for the reliable performance of technological systems relying on radio waves. In the polar regions, commonly observed are the Polar Cap Patches (PCP) of enhanced plasma density.The ionosphere, a crucial layer of Earth’s upper atmosphere, extends from about 50 to 600 kilometers above the Earth’s surface. Ionospheric plasma is composed mainly of electrons, positively charged ions, and neutral gases. The dynamic nature of these components, influenced by solar and terrestrial factors, gives the ionosphere its unique characteristics and impacts [10].The ionosphere is an additional background environment composed of charged particles that is well-known to result in spacecraft charging, and in the worst case, cause arcing or unwanted electrostatic discharges. While the ionospheric plasma density is typically an order of magnitude (or more) lower than the atmospheric neutral gas density, electrostatic charging can lead to the formation of plasma sheath and wake structures around an object that artificially increase its effective collecting area [11].

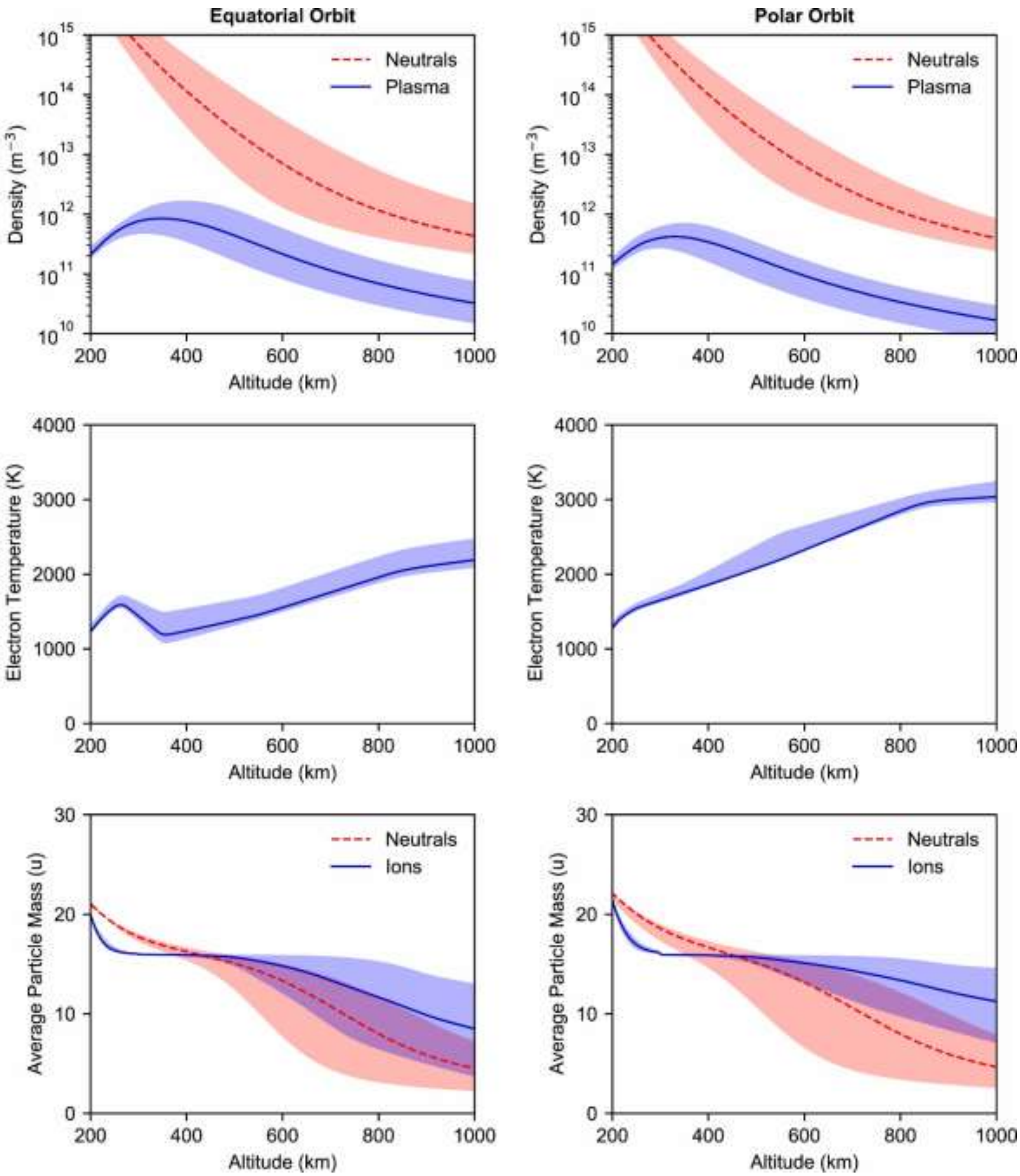
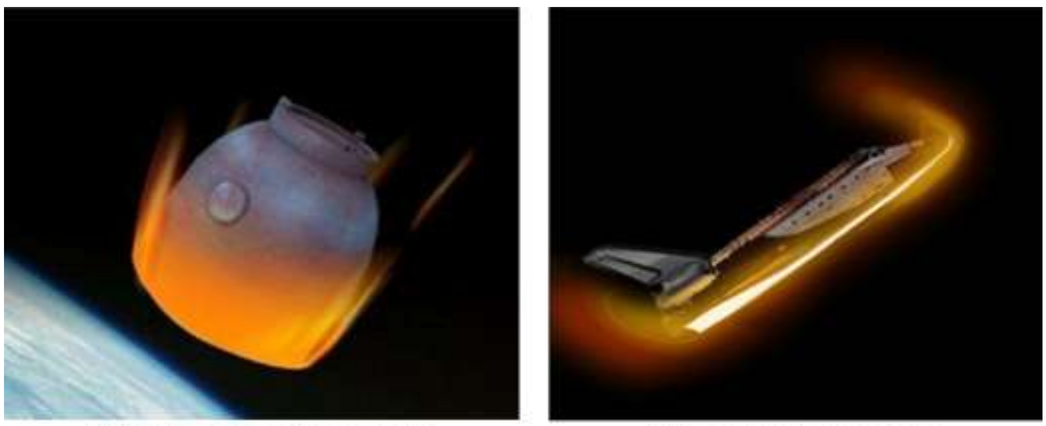


Figure 4. Neutral and plasma density (top row), electron temperature (middle row), and average neutral and ion mass (bottom row) as a function of altitude. The left column shows results for a longitude-averaged equatorial orbit, while the right column shows results for a longitude- and latitude-averaged polar orbit. The shaded regions indicate the spread between minimum and maximum conditionswhile the solid and dashed lines show the average.

Regarding plasma-satellite current balance, simple conducting object placed in the ionosphere will charge up until reaching the floating potential [12]. At this point, the net electron and ion current to the object is zero and no further charging occurs. In addition to direct collection of electrons and ions from the background plasma, several other phenomena affect current balance and determine the floating potential, including: photo-emission, field-emission, thermionic-emission, and secondary electron emission due to electron, ion, or neutral bombardment [13]. As the floating potential is established self-consistently to ensure current balance, it is not possible to actively change the potential of an object relative to a background plasma unless an additional current path is provided to enable current balance. This can be achieved through differential biasing whereby one part of a spacecraft is biased relative to another. In this case, a net positive ion current is collected at one part and this is balanced by a net electron current collected by the other part. Thus, active spacecraft biasing requires two or more separated collecting surfaces (or the use of an electron/ion gun). The interaction of differentially biased electrodes and plasmas has been well-studied within the context offundamental plasma physics and several industrially relevant plasma devices. In addition to the applied bias voltage, the relative collecting area of electrodes has a strong effect and can lead to positive ion or negative electron sheaths, double-layer formation, or the appearance of instabilities [14].

Observations from the European Space Agency's Swarm mission showed ionospheric plasma irregularities based on in-situ electron density data obtained with the Langmuir probe and the total electron content data from the onboard GPS receiver. Data for the irregularity parameters were derived from the electron density in terms of the rate of change of density index and electron density gradients[15]. Ionospheric plasma irregularities with irregularity parametersderived from the electron density, included the rate of change of density (ROD), rate of change of density index (RODI), and the large-scale electron density gradient (∇Ne).



(a) Reentry process of return capsule (b) Space shuttle return process

Figure5. Reentry process of spacecraft [16]

With applications such as near-space development, deep space exploration, and round trips between the ground and space, spacecraft reentry into the earth or interstellar atmosphere poses significant challenges. During the reentry, the intense friction between the spacecraft surface and the surrounding gas generates a layer of thermally induced plasma known as the plasma sheath, causing substantial EM wave transmission energy (signal). In severe cases, signal loss occurs, resulting in the “blackout” phenomenon. Currently, the traditional method of transmitting information during reentry is based on the store-and-forward method. However, it is essential to establish continuous Tracking, Telemetering, and Command (TT&C) communication during normal and regular round-trip reentry processes for the future. Therefore, the plasma sheath suggests a distinct, specialized channel, particularly for the design of TT&C communication systems for spacecraft. The plasma sheath, influenced by spacecraft attitude adjustments, Angle of Attack (AOA) variations, turbulence disturbances, ablation, and other factors, acts as a highly dynamic, time-varying transmission medium. The time variation introduces random fluctuations in both the amplitude and the phase of the transmitted signal. Furthermore, the spacecraft reentry involves a wide range of flight altitudes, resulting in a large fading span of the channel and nonstationary characteristics. In terms of the EM wave transmission of the plasma sheath, the traditional method regards the plasma sheath as a uniform plasma to calculate wave propagation[17]; however, the actual plasma sheath is nonuniform and dynamic. In addition to the influence of the height velocity on the nonuniform change of the internal medium of the plasma sheathmodel, the random disturbance of turbulence in the plasma sheath medium is also an important factor affecting wave transmission.

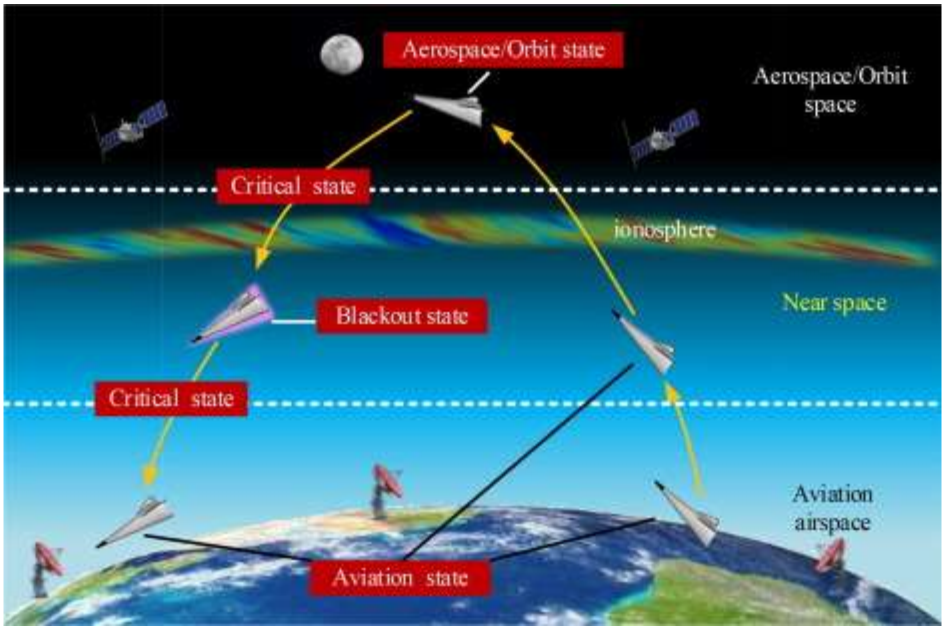


Figure 6.

In the process of spacecraft reentry relying on shortwave propagation, ionospheric reflection is also required to achieve over-the-horizon communication, as illustrated in Fig. 6.

The speed of the reentry spacecraft may reach up to *Ma* = 10 or even higher. When the spacecraft quickly passes through the ionosphere of the large airspace, the time-varying fine and coarse multipath effects and the rapid change of the propagation mode in the flight space lead to high dynamic, time-varying, and nonstationary channel characteristics between the ground station and the spacecraft, and its communication link will be seriously affected. Most importantly, in addition to the influence of the high maneuver of the reentry spacecraft on the channel, the high dynamic propagation effect attached to the plasma sheath will complicate the establishment of the entire integrated channel. When the speed of a spacecraft reaches *Ma* = 20, the electron density reaches approximately 10^{20} cm^{-3}, and the plasma frequency approaches terahertz [18].This presents an opportunity to overcome blackout issues by utilizing higher-frequency terahertz or laser technology, which offer strong penetrability and wide bandwidth. The laser band provides a higher communication frequency, and device development in this area is relatively mature, having been successfully applied in space communication and other research fields [19].. Terahertz band, situated between the microwave and light bands, offers several advantages. It can penetrate the plasma sheath and provide a large bandwidth, high communication frequency, and good directionality. Compared with laser beams, terahertz beams are more effective in overcoming challenges related to capturing, tracking, and aiming light wave beams. With the development of terahertz devices and terahertz communication systems in recent years, the terahertz band has been experimentally verified to achieve km-level long-distance communication [20].

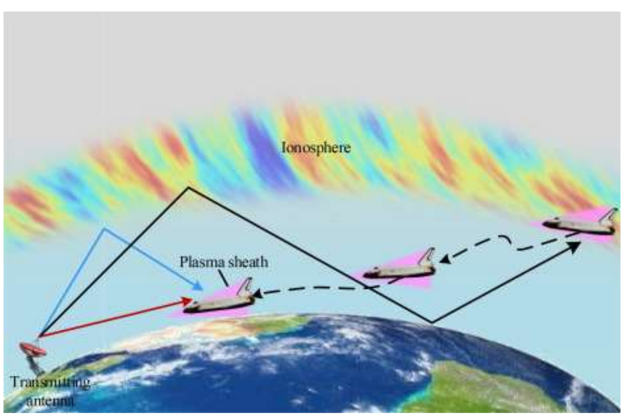


Figure 7. Shortwave integrated channel environment for spacecraft.

Objects in Low-Earth Orbit (LEO) experience a range of environmental conditions that influence their trajectories. Drag due to the residual background atmosphere is conventionally viewed as the primary perturbing factor.Using atmospheric properties from the Mass Spectrometer and Incoherent Scatter radar (MSIS) model and ionospheric properties from the International Reference Ionosphere (IRI), plasma-induced drag in LEO can be significant and may have important orbit prediction implications for space domain awareness and space traffic management.[21]

Problem

Unfortunately, students often interpret "data as factual rather than constructed and open to interpretation" [22]. Instead of considering data as constructed, students tend to objectify evidence as self-evident [23]. Scientists work to *make sense* of nature—to develop understandings of how and why nature works in the ways that it does [24]. This sensemaking requires three "transformations" of data or the information observed in nature [25].

Transformation 1 --- to evaluate what raw data becomes the selected data or evidence.

Transformation 2 --- to evaluate how the evidence can be manipulated to locate patterns.

Transformation 3 --- to evaluate how the patterns fit, or not, scientific theories or explanations.

Situating science ideas within real world contexts "plays a powerful role in facilitating student learning through both motivational and cognitive means" [26]. Consequently, scientific evidence used in K-12classrooms should focus on information that is phenomena-based, consisting of empirical data about phenomena in the natural world. Even if a phenomenon cannot be directly observed in a science classroom, learning activities can still be designed to provide more direct links to phenomena. Per last year's presentation "Science as Final Form Ideas vs Science as Practice — Teaching High School Physics in Space Weather Studies**",** a class activity was provided to introduce students to reading one of NOAA's products (e.g. TEC)and how such readings were applied torisk management of radio communications.

Purpose

This paper aims to show evidence to actively engage student learning of radio wave science and observe the significance of electron density as a prognostic indicator of disrupted radio communications including that of future Moon-Earth communications. Scientific evidence fosters the work of science learners from individually learning final form (i.e. evidence, or system failures) and isolated facts (i.e. parametric data) to actively participate in knowledge construction for understanding existing policy and research. Students will develop conceptual cognitions resulting from making sense of "scientific evidence" as phenomena is explained.

Methods and Results

In order tofor students to notonly interpret "data as factual"and encourage studentcomprehensive interpretation of the data, proposed is to translate student sensemaking into curricular transformations of the three mentioned the Problem Section.

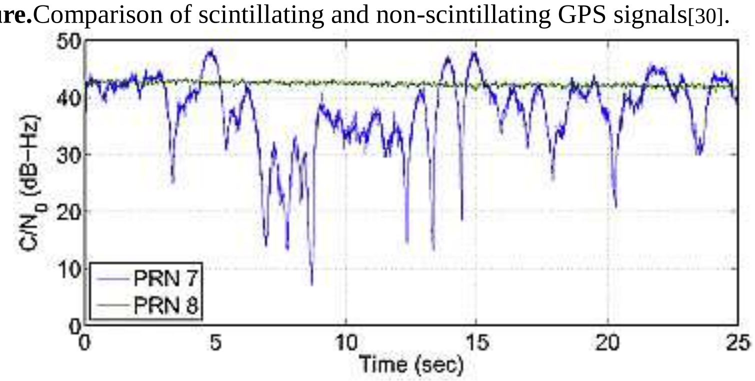
Case 1. Students will develop capability Transformation 1 --- to evaluate what raw data becomes the selected data or evidence by considering Figure 5 as a visual depiction of re-entry spacecraft undergoing plasma sheath and a prompted inquiry of how plasma/ plasma sheath relates to disrupted radio wave propagation.Propagation of radio waves is affected due to TEC, changes in plasma and electron densities, formation of ionospheric plasma sheath due to spacecraft reentry, increased interaction of electrons, ions, and molecules present in the atmosphere with radio waves.The total delay suffered by a radio wave propagating through the ionosphere depends both on the frequency of the radio wave and the total electron content (TEC) between the transmitter and the receiver [27].

Table. Nominal Received GPS Signal Power and Received $C/N_0$the expected carrier-to-noise (C/N_0) ratio for a receiver tracking a satellite at zenith given a typical noise power density of -205 dBW-Hz [*Spilker*, 1996].

SV Block IIR-M/IIF	Frequency	P or P(Y)	C/A or L2C
Signal Power	L1	−161.5 dbW	−158.5 dBW
	L2	−161.5 dBW	−160.0 dBW
C/N_0	L1	43.5 dB-Hz	46.5 dB-Hz
	L2	43.5 dB-Hz	45 dB-Hz

The space segment of the GPS architecture is a constellation of 24–28 satellites in circular orbits at 26,600 km radius with a 55 degree inclination. They are in six orbital planes whose ascending nodes are equally spaced 60 degrees apart. Each satellite transmits at exactly the same two frequencies: L1 = 1575.42 MHz and L2 = 1227.6 MHz. The satellite signals are separated by modulating each carrier with a pseudorandom noise (PRN) code unique to each satellite, forming a code division multiple access link (CDMA). There are two codes on L1: the coarse acquisition code (C/A) and the encrypted precise code (P(Y)). On L2 only the P(Y) code is transmitted. Most civilian receivers only use the L1 C/A code signal. This is adequate for accuracies of 5–15 m. Military receivers use the P(Y) code on L1 and L2, achieving accuracies of 3–5 m. By receiving on two frequencies, the dispersive properties of the refractive ionosphere can be measured, the ionospheric total electron content (TEC) calculated, and the ionospheric error removed. Some civilian receivers can also calculate TEC using L1 and L2 by cross-correlating the two signals against each other without knowing the encrypting bits on the P(Y) code. To appreciate the effects of scintillations on GPS signals, it is important to illustrate the nominal received GPS signal strength[28]. GPS technical specifications for the interface between the space segment and the user segment can be found in the NAVSTAR Global Positioning System Interface Specification[29].

Figure. Comparison of scintillating and non-scintillating GPS signals[30].



To understand the variations in signal power caused by scintillations, it is illustrative to compare a non-scintillating signal to one that is scintillating, as is done. The signal on PRN 7 is an example of a strongly scintillating signal with an S_4 index of 0.9. The signal amplitude both increases and decreases as the diffracted signals add constructively and destructively. Tracking of PRN 7 was performed using a nonreal time digital storage receiver with a Kalman filter tracking loop [*Humphreys et al.*, 2005] and most, if not all, GPS receivers would fail in this environment. The ~1–2 dB peak-to-peak variation in the signal power of the non-scintillating signal on PRN 8 is due to signal sampling and quantization effects, finite filter bandwidth, thermal noise, inter-channel modulation, receiver clock noise, and multipath.

Case2. Students will develop capabilityTransformation 2 --- to evaluate how the evidence can be manipulated to locate patterns.

At other frequencies, the waves are reflected by the ionosphere. Since radio wave propagation delaysare TEC-dependentbetween the transmitter and the receiver,radio waves pass through the ionosphereat specific radio frequencies.If the frequency is too high, the wave will pass straight through the ionosphere. If it is too low, the strength of the signal will be very low due to absorption in the D region. The definition of the frequency to be used for radio communication is an important parameter for healthy propagation. Energetic electrons, protons, and α particles from the sun contribute to an extraordinary production of ions and electrons in the ionosphere, particularlyin the E- and D-layers. The increase electron densitycan cause a total breakdown in short wave communication.The ultraviolet waves striking the ionosphere are of different frequencies, causing several ionized layers to be formed at different altitudes [31]

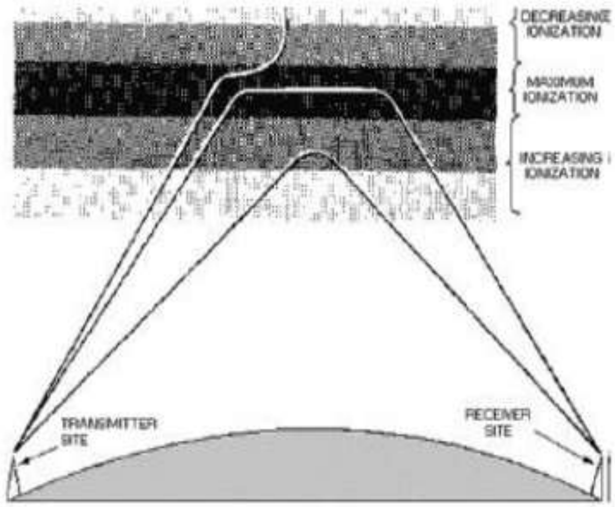
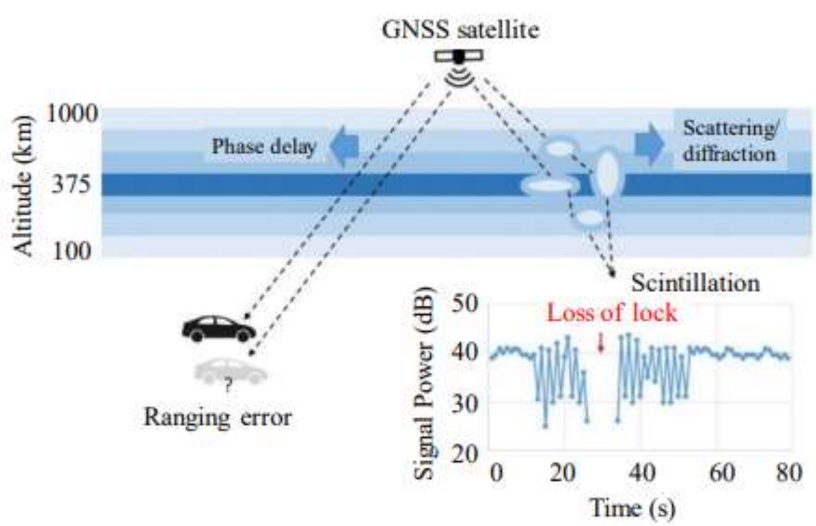


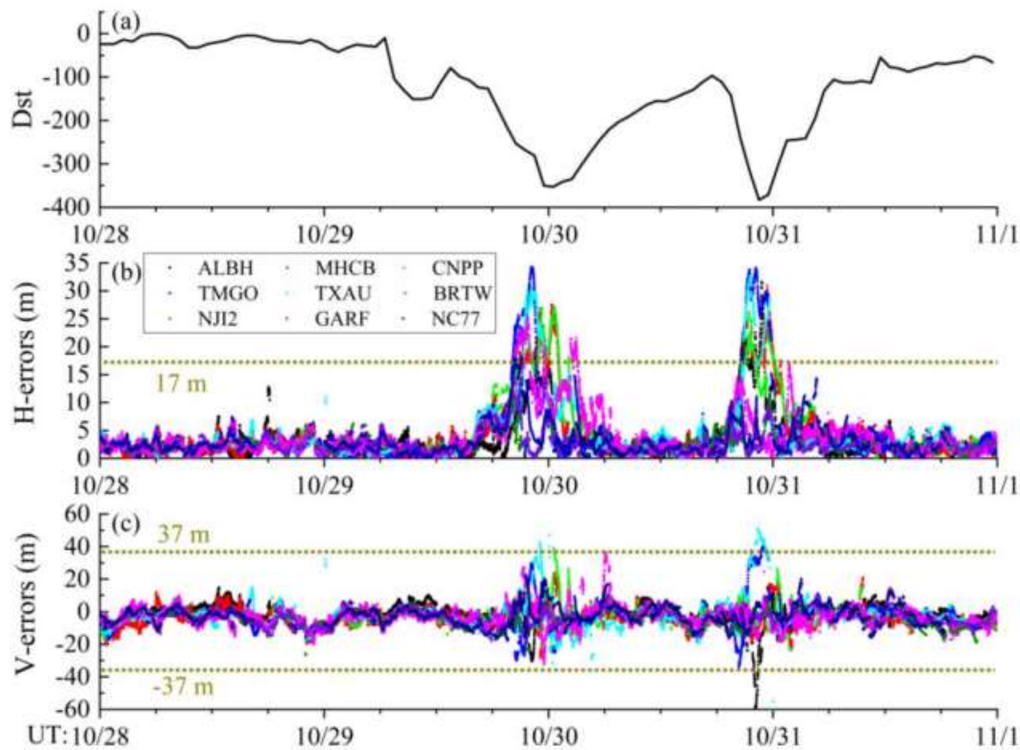
Figure. Effect of ionosphere density on radio wave propagation

Figure 2 shows a TEC map used to estimate the GPS signal delay due to the ionospheric electron content between a receiver and a GPS satellite further elaborates the above Figureto correlate with effects of ionospheric density.Students learn that a plasmamedium constitutes the ionosphere, and further inquiry reveals ionospheric plasma consists of neutrals, ions, and electrons.Radio waves interact with free electrons along the transmission paths, introducing group delay and phase advance in their propagation. Figure 4 shows that ionospheric plasma density is lower than the atmospheric neutral gas densityenabling electrostatic charging to form plasma sheaths and wake structures around an object that artificially increase its effective collecting area.Although the floating potential is established self-consistently to ensure current balance, plasma irregularities actively change the potential of an and the respective differential biasing causes a net positive ion current to collected at one part of the spacecraft to be balanced by a net electron current collected by the other part. Again, the causative pattern for disruptive radio wave propagations indicates electron density.And, TEC measurements significantly indicates threshold levels for forecasting Warning Alerts. NOAA's Space Weather Scales correlate tolevels of radio blackouts [32].

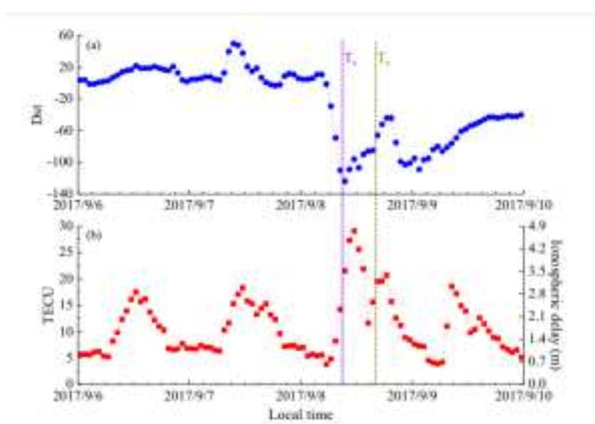
Increased TEC and ionosphereirregularities caused by space weather can lead to ionospheric scintillation [33]. Severe scintillation circumstances make it difficult to determine a position and prohibit a GNSS receiver from grabbing onto the signal [34]. Less severe scintillation circumstances may cause positioning results to be less accurate and confident [35]. Figure. An illustration of ionospheric impacts on GNSS [36]



Aircraft communications mainly rely on the VHF, but HF communication is the only means of communication when flights fly over the poles. Space weather can cause HF communication blackouts, affecting normal flight operations in the polar region. However, space weather can generate ionospheric disturbances that result in HF communication blackouts.Ionospheric irregularity occurring on the morning of 31 October 2003 had TEC levels that were more than 60 TECU. Figure 3.6. (a) The time-series Dst, (b) GNSS positioning horizontal errors, and (c) GNSS positioning vertical errors of nine CORS.



As shown in Figure 3.9(a), a two-dip intense geomagnetic storm occurred during 8-11 September 2017, with the minima Dst = -122 nT at Hong Kong 10:00 local time (LT) on 8 September and -109 nT at 01:00 LT on 9 September. Figure 3.9(b) shows that there was a sharp increase in the ionospheric TEC towards ~12:00 LT.Figure 3.9. (a) The provisional Dst and (b) the TEC variation and ionospheric delay in the Hong Kong area during an intense geomagnetic storm shows the correlation.



Case 3. Students will develop the capability Transformation 3 --- to evaluate how the patterns fit, or not, scientific theories or explanations.

To inform the general public about both current and future space weather conditions and their potential impact on individuals and various systems, the space weather intensity is indicated by the Space Weather scales provided by NOAA. The Kp-index is the **global geomagnetic activity index** that is based on 3-hour measurements from ground-based magnetometers around the world. Each station is calibrated according to its latitude and reports a certain K-index depending on the geomagnetic activity measured at the location of the magnetometer.Table 6.1 lists the scales of geomagnetic storms (measured by Kp values), solar radiation storms (measured by Flux level ≥ 10 MeV particles), and radio blackouts (https://www.swpc.noaa.gov/noaa-scales-explanation). In addition, the average frequency of space weather events in different scales is quantified. Table 6.1. NOAA space weather scales of Geomagnetic storms, Solar radiation storms, and Radio blackouts (1 cycle=11 years).Dst (Disturbance Storm Time) equivalent equatorial magnetic disturbance indices are derived from hourly scalings of low-latitude horizontal magnetic variation.

Description	Scale	Physical measure	Average Frequency
Extreme	G5	Kp=9	4 per cycle
	S5	10^5	Fewer than 1 per cycle
	R5	X20	Fewer than 1 per cycle
Severe	G4	Kp=8 or 9-	100 per cycle
	S4	10^4	3 per cycle
	R4	X10	8 per cycle
Strong	G3	Kp=7	200 per cycle
	S3	10^3	10 per cycle
	R3	X1	175 per cycle
Moderate	G2	Kp=6	600 per cycle
	S2	10^2	25 per cycle
	R2	M5	350 per cycle
Minor	G1	Kp=5	1,700 per cycle
	S1	10	50 per cycle
	R1	M1	2,000 per cycle

To show how TECpatterns fit scientificexplanations of disrupted radio wave communication, Warning Alerts issued by NOAA's Space Weather Center scale of TEC-spec radio blackout levels based on ionospheric delays. Ionospheric delay occurs because the ionosphere affects the propagation path and speed of radio waves, making the former typically longer (due to refraction) and the latter less than in a vacuum. The ionospheric delay is related to the plasma density between the receiver and the s/c. The total electron column density is called the slant Total Electron Content (TEC), which in turn could be recalculated into vertical TEC, or VTEC. Global VTEC maps are needed to calculate ionospheric delay and GNSS signal propagation errors for users with single frequency receivers. Dual-frequency GNSS receiver data are used to calculate and remove the contribution of ionospheric delay using two of the broadcast frequencies from the GNSS satellites. When dual-frequency reception is not available, single-frequency GNSS receivers rely on ionospheric models and data from the dual-frequency ground reference station network to estimate VTEC values. Any sudden and localized changes that are not reflected in the model or in the VTEC measurements will cause errors for users of single frequency receivers[37].

Discussion

Student sensemaking of satellite radio wave communications of curricular transformationsneed not be limited to LEO. Students may further be challenged to employ the same model for learning the science of radio communications per lunar plasma exosphere.The structure and dynamics of the lunar ionosphere are mostly unknown at the present stage. A crosslink lunar radio occultations (RO) mission would address the current lack of observational capacity of the lunar ionosphere, providing an unprecedented observational picture of its structure and dynamic behavior through a broad range of solar wind and magnetospheric conditions. Such observations are required to determine the physical mechanisms governing lunar ionospheric formation and loss, determine its role in the electrodynamics of the near-Moon environment and coupling within the broader environment encompassing the Earth's magnetosphere and ionosphere, and assess the potential safety hazards of the lunar ionosphere for humans and satellite/surface equipment and its potential effects on radio communication and navigation systems. These observations are also essential for development of modeling and predictive capabilities for lunar ionosphere structure and dynamics and may be integrated into models of the Earth's magnetospheric plasma environment. Radio Instrument Package for Lunar Ionospheric Observation **(**RIPLIO) observations would address several science goals relevant to the renewed interest in lunar and space exploration and potential lunar habitation[38]. From lunar ionosphere density estimates based on limited past observations, lunar ionospheric densities may be calculated from the differential phase of dual-frequency VHF links between two or more satellites in lunar orbit. Simulations of dual-satellite crosslink occultations show 10s of complete RO plasma density retrievals may be obtained per lunar day, depending on orbital configurations. A thorough feasibility study is required to determine the operational and system requirements of a lunar RO mission.

Conclusion

Science instruction is often criticized for focusing on the memorization of discrete concepts, facts and laws. The focus students perceive science as a set of *final form* ideas suggests little change over time [39]. There is often a focus on one “right answer” rather than an exploration of ideas that includes incorrect or partially correct explanations [40]. However, research and reform efforts identify evidence as an essential component of science classroom instruction to actively engage students in science practices [41]. This paper advocates for evidence-based student learning of radio wave science and student-led discovery of electron density as a prognostic indicator of disrupted radio communications over multiple Earth-Moon regions of space. Propagation of radio waves is affected due to TEC, changes in plasma and electron densities, formation of ionospheric plasma sheath due to spacecraft reentry, increased interaction of electrons, ions, and molecules present in the atmosphere with radio waves. For these reasons, required are prediction and warning systems are required that predict the associated geomagnetic activities in advance. Scientific evidence fosters the work of science learners from individually learning final form (i.e. evidence, or system failures) and isolated facts (i.e. parametric data) to actively participate in knowledge construction for understanding existing policy and research. Students will develop conceptual cognitions resulting from making sense of “scientific evidence” as phenomena is explained.

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