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Introducing Astronomy as a Tool for Greenhouse Gas Education

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To my best friend and grandmother Katja - Your believe in me kept me going! And in loving memory of my grandfather Mirko, who would have been immensely proud - Budi svoj!

Acknowledgments

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Abstract

This master's thesis describes the conceptual development and implementation of an astronomical outreach program tailored for the improvement of scientific literacy in participants - introducing astronomy as a tool for greenhouse gas education. Further, pedagogical theories were adapted to implement this outreach program in a middle school. This hybrid approach connects a scholastic setting with a clear outreach endeavor. The improvement in the participants scientific literacy concerning planetary atmospheres and greenhouse gas education was evaluated through repeated quizzes. The results - including answers from the students' feedback - indicate a favorable perception of this outreach program's new approach as well as an improvement in the participants' scientific literacy.

Zusammenfassung

Diese Masterarbeit beschreibt die konzeptionelle Entwicklung und Umsetzung eines astronomischen Outreach-Programms, das auf die Verbesserung der wissenschaftlichen Kompetenz der Teilnehmerinnen und Teilnehmer zugeschnitten ist und Astronomie als Instrument zur Aufklärung über Treibhausgase einführt. Außerdem wurden pädagogische Theorien angepasst, um dieses Programm in einer Mittelschule umzusetzen. Dieser hybride Ansatz verbindet den schulischen Rahmen mit einem klaren Outreach-Ansatz. Die Verbesserung der wissenschaftlichen Kenntnisse der Teilnehmer und Teilnehmerinnen in Bezug auf die Planetenatmosphäre und die Aufklärung über Treibhausgase wurde durch wiederholte Quizfragen bewertet. Die Ergebnisse - einschließlich der schriftlichen Rückmeldungen - zeigten eine positive Wahrnehmung und Wirkung dieses neuen Ansatzes des Outreach-Programms.

Contents

1. Introduction

1.1 Context

Earth's climate receives a lot of research attention. Due to severe, often irreversible damages to the worldwide natural environment its implications move increasingly faster into the spotlight (Guilyardi et al., 2018; Masson-Delmotte et al., 2021). In human history it is confirmed that combating negative climate effects (i.e., natural disasters) has always been necessary. This struggle was led with varying methods and success over time (Wright, 2004; Jones, 2019). Regardless, the deeper workings of Earth's climate remained a mystery for many human generations (Hayden, 2004; Edwards, 2013).

Only the emergence of technological and numerical advancements in the last decades of the 20th century combined with knowledge in scientific fields such as chemistry, physics, earth sciences enabled scientists to merge their knowledge into an interdisciplinary climate science, helping deduce the physical laws governing Earth's planetary climate (Solomon, 2007; Burroughs, 2007). The transmission of this scientific knowledge to a worldwide public - outside of academia or governmental institutions - mostly dates from the emergence of mass media (TV, internet, social media) (Storksdieck and Stylinski, 2010). This necessary knowledge transmission generally covers the conclusions which natural scientists have come up with through their research, but seldom create a general scientific literacy to enable the public to follow the scientific line of reasoning on climate matters. This in turn, makes it easier for people to doubt and openly question research findings on climate change (Sagan, 2011). Scientific outreach in public education is therefore a key instrument to gather support and future brainpower in the field of climate action (Hung, 2022).

An under-explored path in climate outreach programs is the use of a scientific field specializing on the general research of planets, their atmospheres as well as their atmospheric properties, which are determined by the planets' chemical composition and characteristics. Astronomy as a scientific field with a broad spectrum of research – from observational sciences (ground based as well as space based), computational sciences (computing for telescope technology as well as the analysis of complex observational data or mathematical predictions), astrophysical sciences (application of theoretical physics for numerical simulation purposes) and much more – offers a highly differentiated view on planetary research and its findings (Weigert et al., 2012; Kutner, 2003). Astronomy can appear to be "aloof" from Earth-bound sciences as it generally stands outside the politically much contested and debated topic of climate research. This public position enables astronomy to use its potential as an interdisciplinary voice in public education on climate processes, but without being forced to restrict its conveyed contents to planet Earth case alone. Research results on neighboring planetary atmospheres gathered by observational data and numerical simulations are a new way of comparing chemical compositions in atmospheres and analyzing their effect on any given planet (Johnstone et al., 2018; Laštovička, 2013). The conveyance of climate science through this research field would consequently make it possible to describe scientific methods used to analyze specific properties of an atmospheric composition (i.e. specifically greenhouse gases) and deduce physical processes (i.e. changes in planetary climate) from a new perspective.

1.2 Thesis aims and outline

The aim would therefore be to create an astronomical scientific outreach program fostering scientific literacy in relation to greenhouse gas education. Participants of this outreach program should have a basic knowledge in physics in order to understand natural laws governing astronomy research. The reason behind this requirement is the following, the chemistry governing planetary atmospheres is built on physical properties of matter (i.e., atoms and molecules), which in turn demands at least a beginners understanding in physics (Finlayson-Pitts and Pitts Jr, 1999;

Pierrehumbert, 2010).

Many adults are lacking a repeated exposure to these contents in their daily life since leaving school. Therefore, it might be more challenging to initiate this type of outreach program with an adult audience as it would have to cover more basics in physics, and would take up more resources on time and material (Knowles et al., 2005).

Continuing this train of thought, an ideal audience to initiate this outreach project would be an adolescent audience still at school and being taught physics on a regular basis. A certain degree in understanding can be expected starting from a certain age group or school grade, and therefore the outreach program could be set in a middle school. For a detailed curriculum of the Austrian science education in middle school please refer to (Leh, last visited on 09/30/23) and 3.1.2. In addition, teaching student classes on this topic makes the outreach project's output more efficient considering it from different angles, such as the already established teaching- and learning framework in school, resources for school projects, and the possibility of reaching a large group of people still open to new knowledge (Bowater and Yeoman, 2012).

Consequently, the aim of this thesis will be to describe the development and implementation of an outreach program tailored for middle school students. The project's intention will be to promote knowledge in astronomy and planetary climate research. This approach will be entirely embedded in astronomical concepts.

Furthermore, this thesis will attempt to answer the question whether an improvement in the participant's understanding of physical concepts governing greenhouse gas evolution in planetary atmospheres can be observed over the project's period of two weeks. This question will be answered by a repeated evaluation of the participants knowledge on the subjects through daily quizzes. The thereby provided data will help recognize any occurring development in the participants scientific literacy. The results will decide on the impact this astronomy outreach initiative has as an interdisciplinary approach to the transmission of climate education in school.

The next paragraph presents the structure of the thesis: The first section gives an overview on the scientific background for this outreach program. The second section on methodology informs about the creation of this educational outreach program for middle school students, as the design of this project requires connecting educational science with astronomy to develop age-appropriate and engaging content. The scientific pedagogical methods used to identify key astronomical concepts for middle school students will be presented, before outlining the intended interactive learning experience for the outreach program units in the third section. The fourth section presents the data analysis and its findings preparing for the conclusion of this action based research in the fifth section.

2. Background

2.1 Astronomical tools for greenhouse gas education

The project's intention is to promote knowledge on the planetary greenhouse effect through astronomical tools. The conceptual approach will be embedded in physical concepts used for astronomical observations of planetary atmospheres. This chapter gives an idea of the theoretical background, which later was adapted to an age-appropriate content for middle school students. For further explanation on the implementation see chapter 4. It is not intended in this chapter to describe all physical terms from scratch. However, it will give an overview of fundamental concepts and principles related to this thesis' outreach program and refer to literature for more detailed explanations.

2.1.1 Physical concepts on electromagnetic radiation

To understand the evolution of a planetary greenhouse effect, participants need first to understand how and why radiation is being absorbed in a planetary atmosphere. Initiating the topic of radiation through the concept of an electromagnetic wave was the starting point. The figure below represents an electromagnetic wave, and the oscillation of its electric and magnetic field perpendicular to the direction of wave propagation.

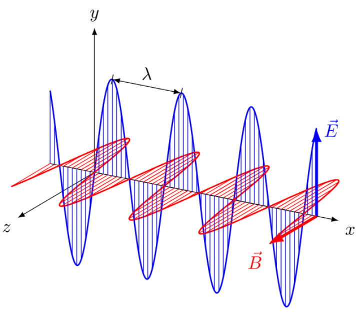


Figure 2.1: A linearly polarized electromagnetic wave (Figure taken from EM- (last visited on 11/8/23))

The subsequent equations (2.1.1) show the time and position depending $\vec{E}(x,t)$ and $\vec{B}(x,t)$ fields:

$$\begin{aligned}\vec{E}(x,t) &= \vec{E}_0 \cos(kx - \omega t + \phi_E) \\ \vec{B}(x,t) &= \vec{B}_0 \cos(kx - \omega t + \phi_B)\end{aligned} \tag{2.1}$$

Polarization

The propagation of an electromagnetic wave is contemplated when considering its interaction with atmospheric matter. Since the polarization of an electromagnetic wave describes the direction of its electric field in a specific plane, different scenarios were named, such as unpolarized wave, where the field oscillates in various directions, as well as the most common polarization types: the linear polarization, where the field oscillates in a straight line, the circular polarization, where the field rotates in a circle, and the elliptical polarization, where linear and circular polarization are combined (Hanslmeier, 2023).

Maxwell equations

The reaction of electric and magnetic fields to charges and currents (as present in a planetary atmosphere), and how they interact with each other is described by the Maxwell equations (2.1.1), subsequently presented. For a full derivation of the wave equation please refer to Wagner et al. (2020).

1. **Gauss's Law for Electricity:**
$$\nabla \cdot \mathbf{E} = \frac{\rho}{\varepsilon_0}$$

2. **Gauss's Law for Magnetism:**
$$\nabla \cdot \mathbf{B} = 0$$

3. **Faraday's Law of Induction:**
$$\nabla \times \mathbf{E} = -\frac{\partial \mathbf{B}}{\partial t}$$

4. **Ampère's Law with Maxwell's Addition:**
$$\nabla \times \mathbf{B} = \mu_0 \mathbf{J} + \mu_0 \varepsilon_0 \frac{\partial \mathbf{E}}{\partial t}$$

Phase velocity

Our case of interest is the wave-like propagation of electromagnetic fields in a material medium such as light travelling through atmospheric layers (Wagner et al., 2020). In this instance, the electromagnetic wave's phase velocity v_p gives insight into the physics of propagation in a medium. As shown by the equation below, the refractive index n of a medium (i.e material) indicates how much the speed of light is reduced in a medium (compared to its speed in a vacuum).

$$v_p = \frac{c}{n} \tag{2.2}$$

Since it has been experimentally shown that the phase velocity of electromagnetic waves in vacuum matches - within the margins of error - with the speed of light in vacuum, this serves as a starting point for interpreting light as an electromagnetic wave, and thus, for the unification of electrodynamics and optics (Wagner et al., 2020). Highlighting the link between electrodynamics and optics gives a theoretical background from which to progress towards the topic of observational methods in astronomy.

The electromagnetic spectrum

The presence of radiation in a planetary atmosphere can give away important information on the atmospheric properties through observing its frequencies, reflection-, absorption-, transmission-, or scattering-effects. Therefore, the electromagnetic spectrum is an essential concept to convey: Recalling its large range over all frequencies of electromagnetic radiation, it corresponds to wavelengths of several thousand kilometers to subatomic scales, spanning from below 1Hz to above 1025Hz (Wagner et al., 2020).

Wavelength	Energy or frequency	Radiation type
10^{-6} nm	1240 MeV	Gamma radiation
10^{-2} nm	124 keV	X-rays (X)
1.0 nm	1.24 keV	UV
$\approx 1\,\mu$m	1.24 eV	Visible light
$10\,\mu$m – 1 mm	0.124 eV – 0.0012 eV	IR
10 mm	30,000 MHz	Microwaves (radar)
10 cm	3000 MHz	UHF
100 cm	300 MHz	FM
10 m	30 MHz	Shortwave
1000 m	300 kHz	Longwaves

Figure 2.2: Table of electromagnetic spectrum (Table taken from Hanslmeier (2023))

An overview of the electromagnetic spectrum was given with a descriptive figure 4.3 relating the wavelength to the frequency, and the temperature of objects at which this radiation is the most intense wavelength emitted. In addition, the figure shows technical applications for specific wavelengths, and - more importantly for this projects topic -, whether this wavelengths can penetrate the earth's atmosphere.

Important relations

Further important relations defining the electromagnetic wave's interaction with a medium - explained in Hanslmeier (2023) - were also discussed. The relation between the wavelength λ and the frequency ν:

$$c = \lambda \nu \tag{2.3}$$

The relationship between the energy E of a photon (quantum particle of light) and the frequency ν, the refractive index, n:

$$E = h\nu \tag{2.4}$$

where $h = 6.626 \times 10^{-34}$ Js is the Planck's constant.

The refractive index n of a medium, which can also be related to the wavelength of light in a vacuum (λ_0) and the wavelength of light in a medium (λ).

$$n = \frac{\lambda_0}{\lambda} \tag{2.5}$$

Furthermore, scattering phenomena relevant in observations of planetary atmospheres were pointed out, since the atmospheric layers generally harbor larger particles and smaller molecules creating scattering effects for photons. Based on (Andrews, 2010) and (Klose, 2016), it was stressed that the scattering of photons can also provide information on the target particle's size, which can be helpful when determining atmospheric constituents.

First, the Rayleigh Scattering, for which the intensity I of the light particles after the scattering event is inversely proportional to the fourth power of the wavelength λ was described:

$$I \propto \frac{1}{\lambda^4}$$

Secondly, the Mie Scattering, for which the mathematics is much more complex and requires solving Maxwell's equations for the specific sizes and refractive indices of the particles was mentioned. It was noted that, in general it follows that Rayleigh scattering applies when

$$2\pi r \ll \lambda$$

and Mie scattering applies when

$$2\pi r > \lambda$$

Further scattering processes describing the interaction between a photon and an electron such as the Compton scattering, or Thompson scattering were shortly touched on.

Light refraction and dispersion through a prism

To make spectroscopic techniques for the observation of radiation more tangible for participants, a demonstration of refraction of light by a prism was conducted 4.1.2.

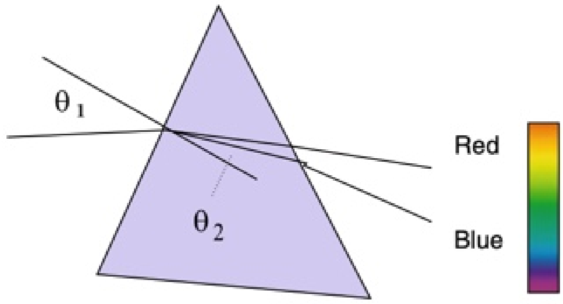


Figure 2.3: A prism (Figure taken from Hanslmeier (2023))

In this context, the (complex) refractive index, n (representing the phase velocity of light in the medium), was used to describe both the refraction and absorption of light in the medium, using k representing the attenuation of the wave as it propagates through the medium:

$$\tilde{n} = n + ik \tag{2.6}$$

Additionally, the concept of dispersion was also presented. The basics for the light separation into its constituent colors as it passes through the prisms medium was explained. The wavelength as the cause for different speeds within the medium and the emerging spectrum of colors was discussed with the participant group:

The deviation angle (δ) for light passing through a glass prism with a refractive index, n, and an angle of deviation θ was given by:

$$\delta = \theta_1 + \theta_2 - A \tag{2.7}$$

θ_1 being the angle of incidence, θ_2 the angle of emergence, and A the prism's apex angle. Since the deviation angle in the prism depended on the wavelength of the incoming light wavelength, it was discussed that prisms could also be used to investigate the wavelength spectrum of captured light. Based on this concept, instruments called prism spectrometers were presented (Wagner et al., 2020).

Further, to observe the IR and UV parts of the non-visible light spectrum two further demonstrations were done for UV fluorescence and IR detection 4.1.2.

The above-mentioned demonstrations and concepts were then used to analyze images showing planets and other astronomical objects observed in the visible or infrared range of the electromagnetic spectrum 4.1.2.

Emission and absorption lines

The project progressed by linking the prior concepts with the analysis of chemical compounds in a planetary atmosphere, further describing the interaction of radiation with constituents in the atmospheric layers. Participants were led to understand how spectral lines form for atomic and molecular compounds, and how they are used to deduce distinct chemical properties in matter. To do so, the physical concept behind atomic and molecular characteristics underlying varying spectral lines were presented. The periodic table which summarizes every element with its inherent energy state was therefore revisited, and its importance for the understanding of molecular compounds highlighted (Williams and Viti, 2013).

The following postulates by N. Bohr (Hanslmeier, 2023) were presented for the description of the emergence of atomic emission and absorption lines:

"(...) an atomic system has stationary (non-radiative) states with certain discrete energy values.

$$E = h\nu \tag{2.8}$$

These values can only transition from one stationary state to another stationary state. If the transition is associated with emission or absorption of radiation, its frequency is related to the energy change by the frequency condition. (...).

$$dE = E_f - E_i \tag{2.9}$$

where E_f, and E_i, are the final and initial energy levels, respectively.

Secondly, bound electrons can only exist in quantized energy states. (...). The ionization energy represents the energy required to remove an electron from the nucleus's influence. Beyond the ionization limit, the electron can have any kinetic energy. Because of the discrete energy states of the electrons bound to an atom, the spectral lines are formed. At the transition from n=2 to n=1 energy of the amount δE is released." (Hanslmeier, 2023, p. 150).

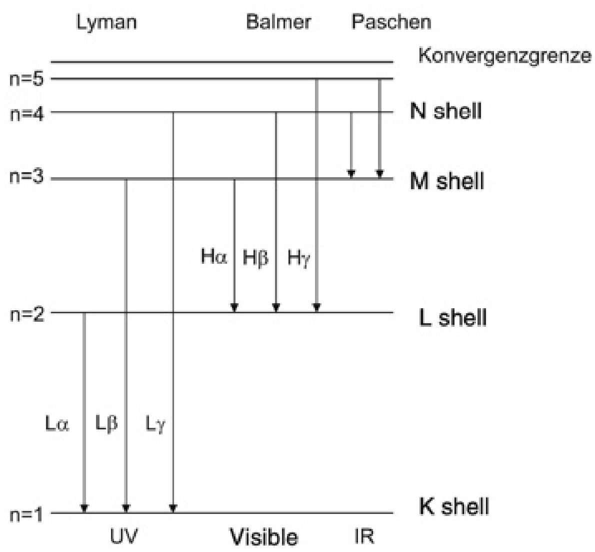


Figure 2.4: Transitions for the hydrogen atom (Figure taken from Hanslmeier (2023)).

A depiction on the blackboard was helpful when illustrating how an emission line is created. Drawing an incoming photon with an energy hν being absorbed. The excited electron then falling back to an energetically lower shell, releasing excess energy as a quantum of light. The emergence of an absorption line is depicted analogous, with no excess energy being released (Hanslmeier, 2023).

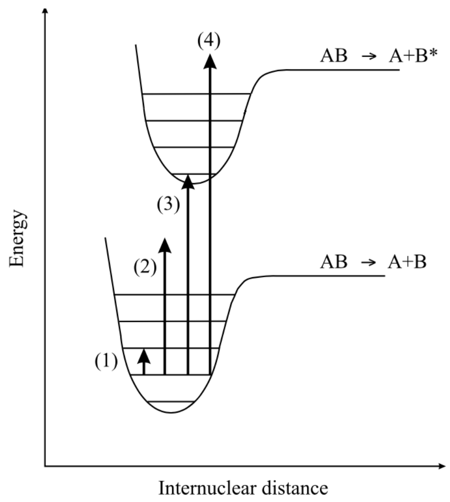
For the benefit of the project participants, it was important to stress that transitions described above are exclusive for electronic transitions in an atom, and can be observed due to the electrons change in discrete energy levels through sharp lines for emission and absorption.

Molecular lines

After explaining the source for emission and absorption lines in atoms, the next step is to highlight the difference for the emergence of molecular line spectra.

Andrews (2010) states that in general atomic spectra are defined by transitions between individual electronic states. In comparison, the more complex molecular spectra *"have additional degrees of freedom associated with vibration and rotation"*. Further, it is explained that molecules show transitions *"that have no counterpart in atoms."* (Andrews, 2010, p. 64).

The molecular lines can be divided in three categories of observed spectra (excluding transitions with kinetic energy): the rotational transitions, the vibrational transitions, and – prior described - the electronic transitions:



Schematic energy diagram for a diatomic molecule. See text for details.

Figure 2.5: Transitions in a molecule (Figure taken from Andrews (2010)).

For explanation purposes the figure 2.5 and its description were used: *"Several transitions are shown in Figure 2.5 by vertical arrows. These are (1) the absorption of a photon, giving rise to an infra-red transition from one vibrational level to another vibrational level in the ground-state molecule; (2) photo-dissociation to two ground-state atoms; (3) absorption giving rise to a transition from a vibrational level of the ground state to a vibrational level in the excited state; and (4) photo-dissociation to one ground-state atom and one excited atom. Note that transitions (1) and (3) lead to discrete energy changes δE whereas (2) and (4) lead to continuous energy changes."* (Andrews, 2010, p. 66).

This affects the observation of molecular transitions in atmospheric spectra. When molecular transitions occur the vibrational and rotational energies both change, giving rise to a distinct effect. Since rotational energy differences are on a much smaller scale than vibrational energy differences *"(. . .) in terms of atmospheric spectra, rotational effects lead to 'fine-structure splitting' of* *vibrational spectral lines. Transitions from rotational sub-levels of one vibrational level to rotational sub-levels of another vibrational level therefore give rise to complex vibration–rotation spectral bands in the infra-red."* (Andrews, 2010, p. 64).

It was pointed out that compared to atomic spectra, the molecular transitions present a broadened spectral line due to changes between discrete energy levels from electronic, rotational, and vibrational states: *"Molecules may undergo transitions (...) in the near-infrared range, (..) the far-infrared, or in the millimetre to submillimetre range of the electromagnetic spectrum. The equivalent of a single atomic line corresponding to an electronic transition is – for a molecule – replaced by a set of many lines."*(Andrews, 2010, p. 65).

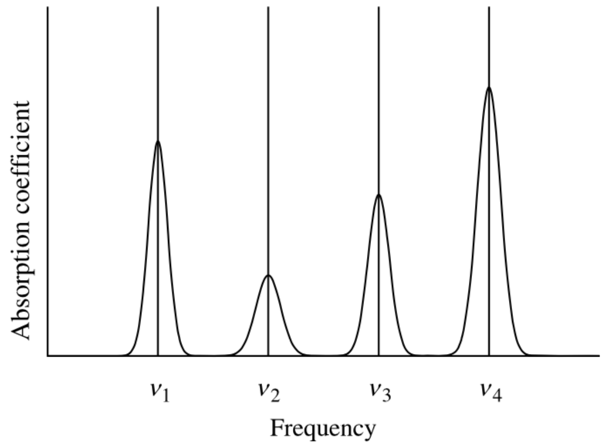


Figure 2.6: A schematic diagram of some broadened spectral lines centred at four frequencies, $v1$, $v2$, $v3$ and $v4$. Unbroadened lines would consist of sharp peaks at these frequencies, as indicated by the vertical lines.(Figure taken from Andrews (2010)).

The next topic consists of explaining the application of technical instruments used to detect and analyze atomic or molecular transitions in a medium interacting with radiation: the diffraction grating spectroscope combined with a CCD-chip.

Following Palmer and Loewen (2005) explanations, it can be stated that the application of diffraction gratings in astrophysics yields valuable information on *"the composition of and processes in stars and planetary atmospheres, as well as (...) clues to the large-scale motions of objects in the universe."* (Palmer and Loewen, 2005, p. 30).

2.1.2 Observational techniques for atmospheres

Diffraction grating

The different types of diffraction gratings used in combination with a CCD-chip for recording spectra of atomic and molecular lines were pointed out. Its use in spectral analysis, and research in wavelength composition was then described. Especially, the gratings ability to separate an electromagnetic spectrum into its monochromatic components with high precision was stressed.

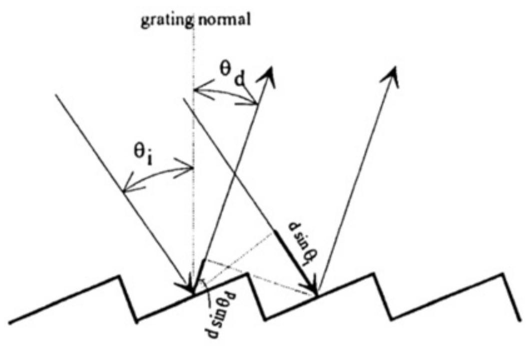


Figure 2.7: Diagram for phase relation between the rays diffracted from adjacent grooves(Figure taken from Loewen and Popov (2018))

A further introduction in Palmer and Loewen (2005) was used to illustrate the workings of a diffraction grating. It describes the diffraction grating as *"a collection of reflecting (or transmitting) elements separated by a distance comparable to the wavelength of light."* The diffracting elements can be illustrated as a *"pattern of transparent slits (or apertures) in an opaque screen, or a collection of reflecting grooves on a substrate (also called a blank)."* The basic property (fundamental physical characteristic) of a diffraction grating being *"the spatial modulation of the refractive index."* During the diffraction process, *"an electromagnetic wave incident on a grating will have its electric field amplitude, or phase, or both, modified in a predictable manner, due to the periodic variation in refractive index in the region near the surface of the grating."* (Palmer and Loewen, 2005, p. 14).

The general grating equation shows the optical concept behind the diffraction technique, in which category most grating systems fall, when *"restricted to cases in which the incident and diffracted rays lie in a plane perpendicular to the grooves"* (Palmer and Loewen, 2005, p. 22):

$$d(\sin\alpha + \sin\beta) = m\lambda, \tag{2.10}$$

d representing the spacing between grooves, θ the diffraction angle, λ the wavelength, and m the order of the diffraction.

The modified grating equation will be adapted in cases the incident light beam is not perpendicular to the grooves. Using several integers for m:

$$cos\varepsilon(\sin\alpha + \sin\beta) = Gm\lambda, \tag{2.11}$$

G = 1/d being the groove frequency or groove density, and ε the angle between the incident light path and the plane perpendicular to the grooves at the grating center.

As C. Palmer explains, depending on the researched objects the diffraction grating surface can vary in order to reach the best resolution adapted to a specific source. The level of resolution depending on the number of grooves, which decides the order of diffraction. The resulting series of spectral lines - atomic or molecular lines - then allow conclusions on the presence of elements in a source. The intensity of the spectral lines giving evidence on temperature, density and other parameters of observed objects (Palmer and Loewen, 2005).

As mentioned before, a charge-coupled device (CCD) is used in combination with a diffraction grating to read out the spectral lines. Its function is subsequently explained.

Charge-coupled device

As described in Lesser (2015) a Charge-Coupled Device (CCD) is an integrated circuit designed to move electrical charges generated by incoming photons from an observed light source from the active photo-sensitive area to the read-out electronics. CCDs therefore convert an optical signal into an electrical signal, which renders a digital image.

"A charged coupled device (CCD) is a small chip (about 1 cm^2) consisting of a large number of light-sensitive pixels (typical sizes today are 4000 by 4000 pixels). Each of these pixels can be compared to a photocell that accumulates charges. These charges are then read out line by line by means of complicated electronics and result in the image. The great advantage is the almost

100 % quantum yield." (Hanslmeier, 2023, p. 134).

CCDs in combination with a diffraction grating form a very sensitive spectrograph (Palmer and Loewen, 2005). As mentioned, molecular lines detected by a spectrograph can be used for different research purposes (analyzing the composition, temperature, density, motion of molecular regions), one of them being the research of planetary atmospheres and the monitoring of gas concentrations in atmospheres, namely CO_2 and C_2H_4 (Andrews, 2010).

Observational methods

Building on the above mentioned concepts and techniques, the project then progresses to a new topic: Observational methods used in analyzing Earth's and neighbouring planetary atmospheres in the Solar system. Following the information given in Klose (2016) and Andrews (2010) it can be noted that whether in the field of weather forecasting or the field of planetary atmospheric research the applied instruments and underlying physical concepts are the same.

Depending on atmospheric altitude different observational techniques will be useful - as can be partially seen in figure 2.11: For ground-based measurements instruments such as a radiometer, spectrometer, lidar or radar system, or telescopes with spectroscopy equipment are used. Continuing to tropospheric regions, the measurements can be done through airborne instruments carried on balloons (radiosondes, aerosol counters, spectrometers, spectro-radiometers, infrared and microwave radiometers, photometers, chemical samplers, and more). Further, going to altitudes in the stratosphere, the same instruments on research balloons or even air-crafts are used. In the mesosphere and upper atmospheric layers similar instruments on rockets come into play (Klose, 2016).

Some of the above-mentioned methods for measuring data are in situ techniques, where the analyzing instruments are placed near the observed and measured source. Other methods are remote sounding techniques, used when instruments near the source are not applicable. Orbiting instruments in space (i.e., satellites) fall into this category. Since there is no contact with the source material, it requires instruments specifically measuring the electromagnetic radiation emitted, scattered, or transmitted by the atmosphere (Andrews, 2010). A representation of Earth's global satellite system is given in the below figure 2.8.

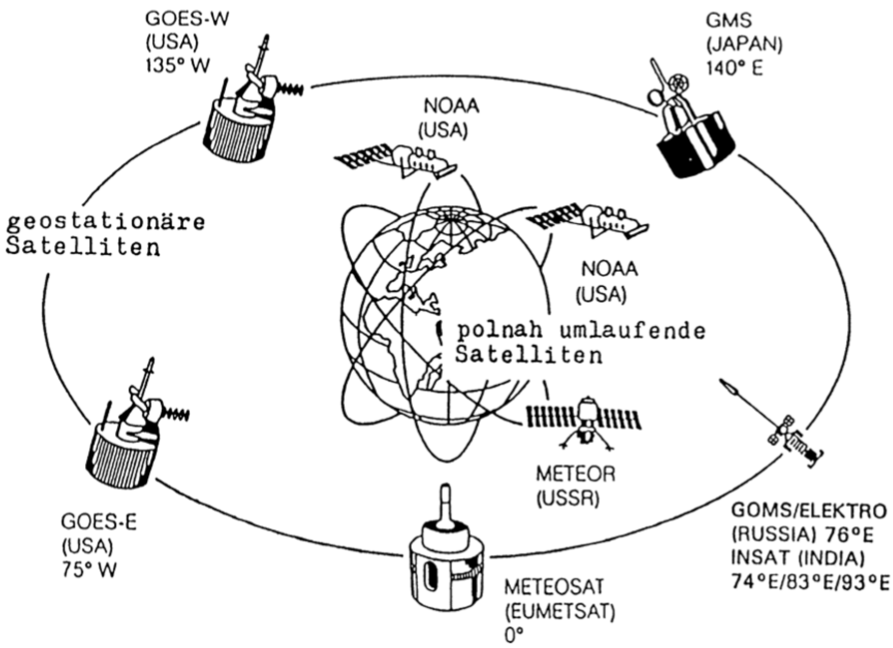


Figure 2.8: Global satellite system (Klose, 2016))

These remote sounding techniques can be divided into two types:

On the one hand, the passive remote sounding, where it measures *"the radiation (...) of natural origin, for example thermal radiation emitted by the atmosphere, or solar radiation transmitted or scattered by the atmosphere (most space-borne remote-sounding methods are passive)"* (Andrews, 2010, p. 171).

As Klose (2016) mentions satellite borne high-resolution radiometers measuring the outgoing radiation by Earth and its atmosphere. This yields raster images in the visible (TV - thermal visual (near-infrared) - and VIS) and infrared (IR) spectral range as well as in a water absorption band (VW). The collected data is used to determine cloud height and wind fields, as well as CO_2, CO_3. In addition to the radiometers required for the image data, *"modern satellites are equipped with spectrometers that can detect both reflected and selectively absorbed UV and IR radiation in a pixel-like manner and assemble them into UV or IR images. Processes of selective absorption or emission of photons by atoms and molecules in the atmosphere are utilized, so that if the wavelength and intensity of the selective radiation are known, conclusions can be drawn about optically active components and their concentration."* - as exemplified by the table below 2.21, (Klose, 2016, p.199-200, p.204, f. - Translated with DeepL.com (free version)).

	Konzentration	Temperatur-erhöhung	natürlicher Treibhauseffekt	anthropogener Treibhauseffekt
		33 K	prozentual	prozentual
Wasserdampf (H_2)	0,50 ppm	20,6 K	62%	4%
Kohlendioxid (CO_2)	400,00 ppm	7,2 K	22%	54%
Methan (CH_4)	1,72 ppm	0,8 K	2,5%	17%
FCKWs und andere	0,25 ppb	0,6 K	2,5%	14%
Ozon (O_3)	0,03 ppm	2,4 K	7,0%	7%
Distickstoffoxid (N_2O)	0,31 ppm	1,4 K	4,0%	4%

Figure 2.9: Greenhouse gas concentration for Earth's atmosphere (Klose, 2016))

On the other hand, *"active remote sounding, a transmitter (e.g. a radar, lidar) is used to direct pulses of radiation into the atmosphere, where they are scattered by atmospheric molecules, aerosols or inhomogeneities of atmospheric structure; some of the scattered radiation is then detected by a receiver."* - as exemplified by figure 4.9 (Andrews, 2010, p. 172).

Examples for scattering aerosols in Earth's atmosphere are given in the below table 2.10 .

Art	Teilchenradius	Verhältnis ($2\pi r/\lambda$)	Effekte
Luftmoleküle	mittlerer Radius 0,1 nm	etwa 10^{-3}	Rayleigh-Streuung
Dunstpartikel	100 nm–2 µm	$\sim$1–20	Rayleigh- und Mie-Streuung
Nebel/Wolken	2 µm–30 µm	$\sim$10–300	Mie-Streuung, Beugung, Absorption
Staub/Rauch	100 nm–100 µm	$\sim 1\text{–}10^3$	Rayleigh- und Mie-Streuung, Beugung, Absorption
Nebeltröpfchen	30 µm–300 µm	$\sim 3\cdot 10^2\text{–}3\cdot 10^3$	Beugung, Brechung, Absorption
Regentropfen	300 µm–einige mm	$\sim 10^3\text{–}2\cdot 10^4$	Brechung, Reflexion, Interferenz
Schnee-/Eiskristalle	50 µm–einige mm	nicht eindeutig	Brechung, Dispersion, Reflexion, Absorption

Figure 2.10: Interaction between radiation at λ=550 nm and atmospheric material (Klose, 2016))

Every method has its merits and flaws according to Andrews (2010), and must be considered when deciding on specific observations.

It is to be noted, that planetary atmospheres further away from Earth are observed via different remote techniques, which are not explained in detail, but can be read up in Hub (last visited on 21/6/24), Jam (last visited on 21/6/24), and Ari (last visited on 21/6/24).

The project then progresses to the topic of Earth's atmospheric structure, its layers, and chemical composition.

Earth's atmospheric layers

According to Klose (2016) Earth owes its current atmosphere to the balance between gravity and the intrinsic movements of the molecules and atoms contained in the atmosphere (Klose, 2016, p.9).

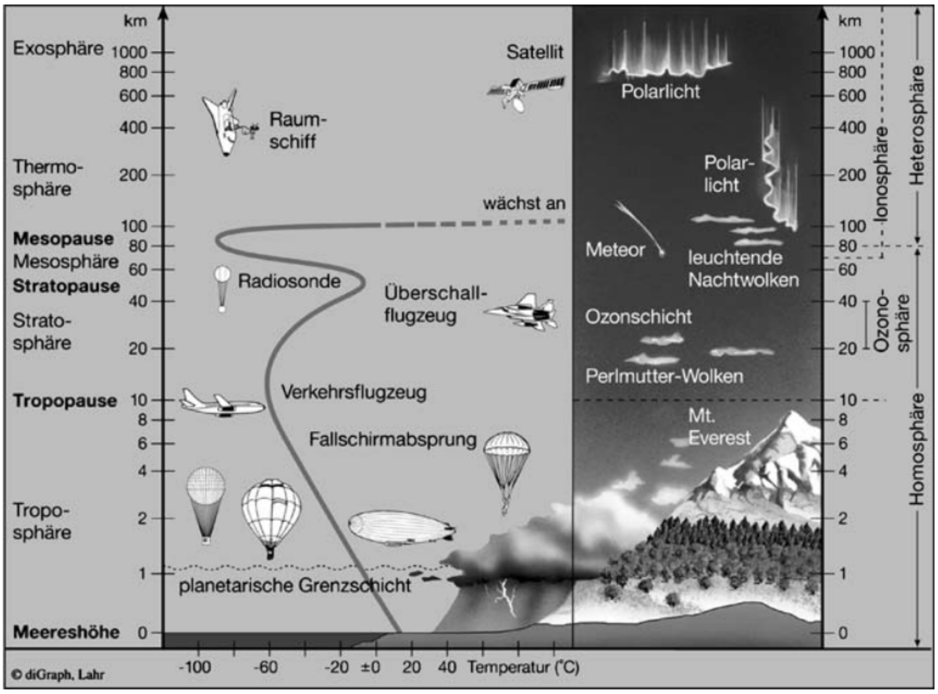


Figure 2.11: Structure of Earth's atmosphere (Klose, 2016))

In the above figure 2.11 we observe the structure of Earth's atmosphere, its altitude, and corresponding names for each layer: troposphere, stratosphere, mesosphere, thermosphere, exosphere. The figure indicates the chemically defined sections of the atmosphere: the homosphere, including the ozonosphere, ionosphere including the heterosphere. In addition, the figure depicts the different technical uses at varying altitude, moreover giving a fitted function of the temperature trend for each layer - also depicted in the figure below 2.12.

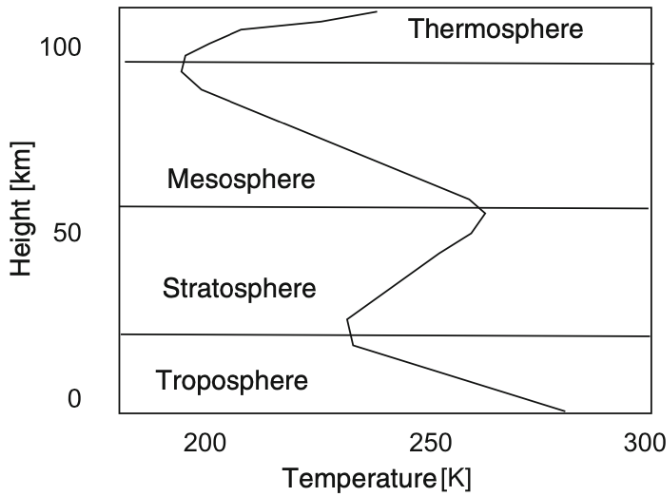


Figure 2.12: Temperature trend in Earth's atmosphere (Klose, 2016))

The following citation explains how the distinction between chemical properties and temperature in different atmospheric layers comes to be, as seen in figure 2.13 and 2.12:

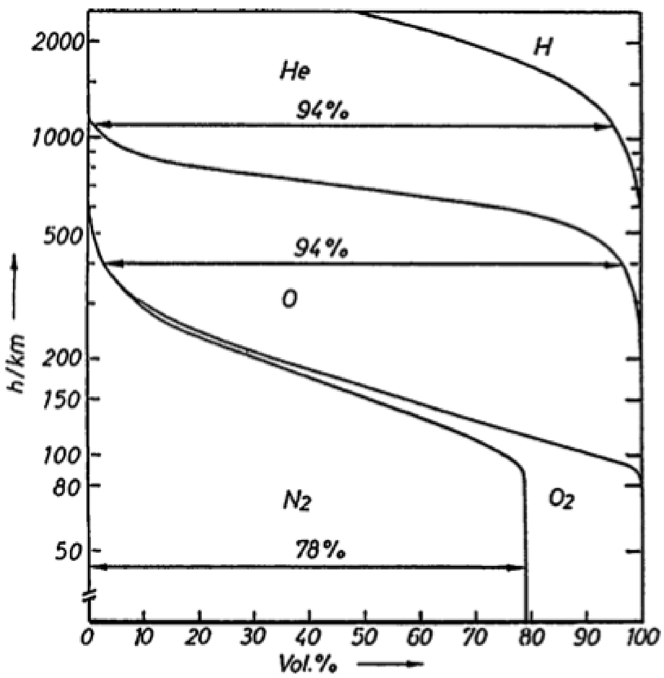


Figure 2.13: Chemical structure for Earth's atmosphere (Klose, 2016))

Following Klose (2016) explanations the homospheres' properties can be described. It is considered as a well-mixed layer, hence the name homosphere. The turbulent horizontal and vertical exchange processes resulting in a uniform chemical composition up to about 100 km in altitude. *"In this altitude range, the mean free path of the molecules is so small that the turbulent exchange through molecular diffusion is only slightly dampened. Within the homosphere, 99.999% of the Earth's "air" is found. (...), beyond which the heterosphere begins."* (Klose, 2016, p.11-13, f. - Translated with DeepL.com (free version)).

In the heterosphere, the mean free path of the molecules is larger than the turbulent displacement length, so that diffuse transport dominates. Consequently, a separation of gases occurs due to their different molar masses. *"Consequently, a separation of gases occurs due to their different molar masses. At the atmospheric boundary, only light gases like helium and hydrogen are present."* Even though these make up only an infinitesimally small fraction of the total number of atmospheric gas molecules, their small molecular mass decreases only very slowly with altitude. *"Above 150 km in altitude, atomic oxygen already dominates, as here photo-dissociation (breaking of molecules by shortwave radiation) plays a significant role alongside molecular diffusion. At 400 km in altitude, it constitutes 94% of the total gas mixture."* (Klose, 2016, p.11-13, f. - Translated with DeepL.com (free version)).

The important take away is visualized in figure 2.13: the homosphere has a uniform concentration, turbulent mixing, and an almost constant composition; whereas the heterosphere on the other hand possesses a non-uniform concentration, which shows stratification in relation with molecular weight; and the ionosphere contains highly charged particles due to its lack of UV-absorbing ozone – O_3 - and strong exposure to solar radiation. Consequently, the temperature as well as the pressure trend depend significantly on these layers properties.

Pressure profile

Concerning the atmospheres pressure profile Klose (2016) explains that due to an exponential decrease in air density and air pressure with altitude, gas molecules with small masses - like hydrogen, helium in low pressure atmospheric layers - have a higher thermal velocity than molecules with larger masses - like nitrogen, oxygen, carbon dioxide -, and therefore escape into space - the exosphere -, which is situated above 500 km - as seen in 2.11. A list of atomic masses for main constituents is given below 2.14.

- H $1{,}008\,\mathrm{g\,mol^{-1}}$
- He $4{,}003\,\mathrm{g\,mol^{-1}}$
- N $14{,}007\,\mathrm{g\,mol^{-1}}$
- O $15{,}999\,\mathrm{g\,mol^{-1}}$

Figure 2.14: Atomic masses (Klose, 2016))

Atmospheric constituents

A further analysis of predominant atmospheric constituents of planet Earth seem to highlight the planets special case due to its human inhabitants: *"In terms of its composition, a distinction is made between permanent main constituents (N_2, O_2, Ar)"* - 2.15 - *"and permanent trace gases (all other noble gases, H_2, N_2O)"* - 2.16 - *"and highly variable components that fluctuate significantly in space and time (especially H_2O, CO_2, CH_4, O_3, SO_2, CO as well as other anthropogenic trace gases)"* - 2.17. *"The largest volume share of dry air according to Tab 2.15 is made up of molecular nitrogen (78%), followed by molecular oxygen (21%), the noble gas argon (0,9%), and the greenhouse gas carbon dioxide (0,04%). The values given in the tables 2.16 and 2.17 were selected accordingly. Among the trace gases, particularly hydrogen, carbon dioxide, methane, and ozone significantly affect the Earth's energy balance. Moreover, our atmosphere also contains solid and liquid components of various natures and origins as suspended particles and dust. The variable trace gases are included in the table up to altitudes of about 100 km."* (Klose, 2016, p.10-11, f. - Translated with DeepL.com (free version)).

Tabelle 2.1 Zusammensetzung der Atmosphäre bis in ca. 100 km Höhe (Hauptbestandteile)

Hauptbestandteile Gas	Chemisches Symbol	Molmasse (10^{-3} kg mol^{-1})	Volumenanteil	Parts per Million (ppm)
Stickstoff	N_2	28,013	0,7808	780 800,0
Sauerstoff	O_2	31,999	0,2095	209 500,0
Argon	Ar	39,948	0,0093	9 300,0
Kohlendioxid	CO_2	44,010	0,0004	400,0
trockene Luft	ohne	28,965	1,0000	1 000 000,0

Figure 2.15: Main constituents until 100 km (Klose, 2016))

Tabelle 2.2 Zusammensetzung der Atmosphäre bis in ca. 100 km Höhe (nicht variable Spurengase)

Spurengase Gas	Chemisches Symbol	Molmasse (10^{-3} kg mol^{-1})	Volumenanteil	Parts per Million (ppm)
Neon	Ne	20,183	$1{,}8 \cdot 10^{-5}$	18,000
Helium	He	4,003	$5{,}2 \cdot 10^{-6}$	5,200
Krypton	Kr	83,800	$1{,}1 \cdot 10^{-6}$	1,100
Wasserstoff	H_2	2,016	$5{,}0 \cdot 10^{-7}$	0,500
Distickstoffoxid	N_2O	44,013	$3{,}1 \cdot 10^{-7}$	0,310
Xenon	Xe	131,300	$8{,}7 \cdot 10^{-8}$	0,087

Figure 2.16: Non variable trace gases until 100 km (Klose, 2016))

Tabelle 2.3 Zusammensetzung der Atmosphäre bis in ca. 100 km Höhe (variable Spurengase)

Spurengase Gas	Chemisches Symbol	Molmasse (10^{-3} kg mol^{-1})	Volumenanteil	Parts per Billion (ppb)
Methan	CH_4	16,043	$1{,}7 \cdot 10^{-6}$	$1{,}7 \cdot 10^{3}$
Kohlenmonoxid	CO	28,011	$9{,}0 \cdot 10^{-4}$	$0{,}09 \cdot 10^{3}$
Ozon	O_3	47,995	$5{,}0 \cdot 10^{-8}$	15 – 50
Schwefel-wasserstoff	H_2S	34,076	Spuren	$5 - 90 \cdot 10^{3}$
Schwefeldioxid	SO_2	64,063	Spuren	2 – 0,05
Ammoniak	NH_3	17,031	Spuren	4 – 0,01
Stickstoffdioxid	NO_2	44,013	Spuren	2 – 0,03
Methanal	CH_2O	30,063	Spuren	2 – 0,20

Figure 2.17: Variable trace gases until 100 km (Klose, 2016))

When presenting the permanent main constituents of Earth's atmosphere (N_2, O_2, Ar), it can be noted that greenhouse gases CO_2, O_3, CH_4, N_2O, and H_2O are not part of the selection due to their high variability in the atmosphere. Their general low volume share seems negligible at first glance, when opposed to more prominent constituents. Therefore, to explain why greenhouse gases have such a vital effect on a planetary atmosphere, their properties must be elaborated. As seen in 2.5, it should be remembered that greenhouse gases are atmospheric molecules, which interact with radiation. Revisiting the physical concept of energy transitions in the observed electromagnetic spectrum, the following applies to molecular compounds in the atmospheric layers: *"(...) energy transitions from rotational sub-levels of one vibrational level to rotational sub-levels of another vibrational level (...) give rise to complex vibration–rotation spectral bands in the infra-red."* (Andrews, 2010, p.64).

It is noted that the best way of observing these molecular spectral bands is therefore with an infrared spectrometer.

C. Andrews further answers, why permanent main constituents in Earth's atmosphere (i.e. N_2, O_2) are not of same interest as greenhouse gases: *"A very important consequence (...) is that dipole transitions cannot occur for diatomic molecules with identical nuclei, such as the two most prevalent atmospheric gases N_2 and O_2. Symmetric molecules of this type have zero dipole moments and hence cannot interact directly with thermal infra-red radiation, through either vibrational or rotational transitions. The same is true of transitions involving only excitations of the 'symmetric stretch' ν1 mode of CO_2" - 2.18 - " which also has a zero-dipole moment."* (Andrews, 2010, p.64).

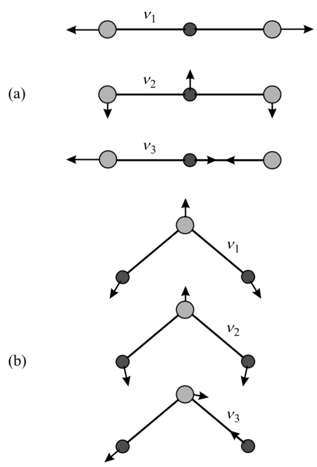


Figure 2.18: Schematic illustration of vibrational normal modes of triatomic molecules (Klose, 2016))

"However, transitions involving triatomic modes such as the others illustrated in Figure 2.18 do lead to changes in electric dipole moment and can therefore interact strongly with thermal infra-red radiation, subject to appropriate selection rules. This explains why the major species $N_2$and O_2 are effectively transparent to thermal infrared radiation, and why minor species such as CO_2, H_2O and O_3 act as 'greenhouse gases' and play a dominant role in the Earth's radiation balance and hence in determining the climate (...)." (Andrews, 2010, p.65).

2.1.3 Greenhouse gases and their impact

From this point on, the outreach project participants should have reached a sufficient level of scientific literacy to follow the scientific line of reasoning when it comes to the role of greenhouse gases as indicators for a planetary climate. The last paragraphs in this section will therefore give all the necessary information on atmospheric greenhouse gases, and their impact on different planetary atmospheres - such as the greenhouse effect. The greenhouse gases present in Earth's atmosphere - CO_2, CH_4, N_2O, H_2O and O_3 - will be described next.

Atmospheric water vapor

According to Klose (2016) water vapor concentration in Earth's atmosphere lies in between 1 to 4% in total. The percentage in the atmosphere varies regionally, depending on oceanic, warm, or arid, water-poor geography: The main source being the evaporation of water from the tropical oceans, from which it enters the atmosphere. *"Since the water vapor content is temperature-dependent, its concentration rapidly decreases with altitude due to the vertical temperature decrease. (...). 90-95% occur below an altitude of 5 km."* (Klose, 2016, p.13 - Translated with DeepL.com (free version)). As a result of air traffic natural evaporation dominates the natural greenhouse effect, since it is much greater than anthropogenic emissions from combustion processes.

Atmospheric carbon dioxide

Based on recent CO_2 measurements with infrared spectrometers, there are 0.04 volume % of carbon dioxide in the Earth's atmosphere (vgl. Klose (2016)). Its lifespan in the atmosphere amounts to a range between 300 to 1000 years.

Atmospheric *"carbon dioxide is one of the main components of the Earth's atmosphere, currently accounting for almost 0.040% by volume. It is essentially permeable to sunlight, but absorbs part of the radiant energy emitted by the earth in the IR range, i.e. it retains the heat of the sunlight near the earth's surface in the form of long-wave counter-radiation."* (Klose, 2016, p.22 - Translated with DeepL.com (free version)).

The reason why heat is trapped near Earth's surface is explained by high CO_2 concentration in the troposphere, due to CO_2 sources on the ground level:

"Carbon dioxide enters the atmosphere as a result of anthropogenic emissions from the burning of coal, natural gas and oil (including transport), together with the clearing of tropical rainforests and boreal coniferous forests and the destruction of the soil, and has been accumulating there to an increasing extent since the beginning of industrialization, so that its proportion has risen from 280 ± 10 ppm around 1800 to 400 ppm at present, which corresponds to an increase of around 36% in around 200 years." (Klose, 2016, p.23 - Translated with DeepL.com (free version)).

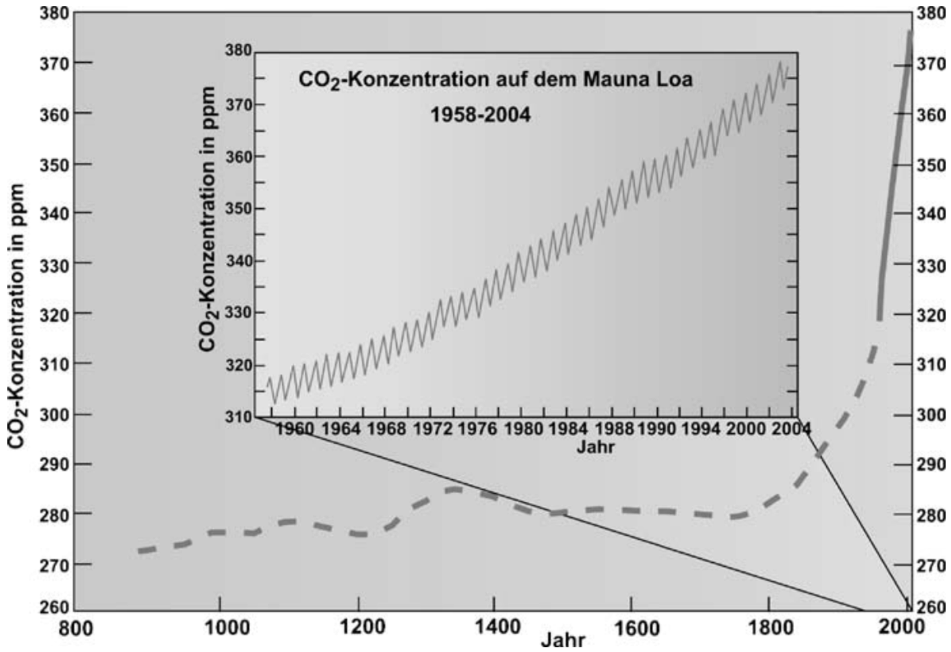


Figure 2.19: CO2 concentration over past 100 years (Klose, 2016))

According to Klose (2016) this high concentration corresponds to the CO_2 levels about 700,000 years ago, times of a significantly warmer and ice-free Earth climate. The presented information gives a strong indication of CO_2' role as a greenhouse gas. Especially, the fact that only small changes in the total atmospheric volume percentage of CO_2 are initiating drastic climate changes in history is noticeable.

Atmospheric methane

Research shows that methane is the second most important greenhouse gas after carbon dioxide, and currently has a concentration of about 1.8 ppm (Klose, 2016). *"According to Warneck 1988,* *its pre-industrial concentration was 0.7 ppm, and according to the IPCC 2001, it has since increased by 145%."* (Klose, 2016, p.25 - Translated with DeepL.com (free version)).

Klose (2016) further explains that methane is produced through microbiological processes during the decomposition of organic materials in anaerobic conditions and is currently entering the atmosphere in increased quantities due to the expansion of rice cultivation, intensified livestock farming, the growth of the world population, the burning of biomass, the growing number of landfills, and the gradual thawing of permafrost soils. Methane remains approximately 12 years in the atmosphere. *"Methane is chemically degraded primarily through reactions with the hydroxyl radical OH in the troposphere, which mainly occurs through the interaction of UV radiation with tropospheric ozone (...). Additional sinks for methane result from chemical reactions in the stratosphere and its breakdown by soil bacteria."* (Klose, 2016, p.25 - Translated with DeepL.com (free version)).

Atmospheric ozone

Klose (2016) states that triatomic oxygen O3 - ozone - alongside water vapor, carbon dioxide, and methane is one of the most important trace gases in the atmosphere. *"Due to its chemical structure, it acts as a strong oxidant and destroys nearly all organic compounds. (...). In the troposphere, the ozone concentration only amounts to 15 to 50 parts per billion (ppb), but in highly polluted air, it can reach up to 500 ppb. (...). Comparing stratospheric ozone with the tropospheric mixing ratio (...), it results that about 90% of the ozone content of a vertical air column is located in the stratosphere."* (Klose, 2016, p.14 - Translated with DeepL.com (free version)).

According to B. Klose its lifespan of a few days to weeks in the atmosphere is short compared to other greenhouse gases. Further following her explanations the tropospheric ozone has two different sources.

"On one hand, it reaches the lower layers through transport processes from the stratosphere, and on the other hand, it is created through the photochemical oxidation of carbon monoxide, methane, and other hydrocarbons with the involvement of nitrogen oxides and water vapor (see Graedel 1994)." (Klose, 2016, p.14 - Translated with DeepL.com (free version)).

Nitrogen oxides, as so-called precursor substances, are released by motorized traffic and industry. According to Klose (2016), there is a clear difference between the ozone concentration in the northern and southern hemispheres.

"The increase of ozone in the troposphere is linked to an intensification of the greenhouse effect, as due to its absorption bands in the near-infrared at λ = 4.8; 5.8 and 6.7 µm and at λ = 9.6 µm in the thermal infrared, it particularly retains the long-wave radiation emanating from the Earth's surface" (Klose, 2016, p.15 - Translated with DeepL.com (free version)).

Further following this explanation, at an altitude of about 25 km - in the stratosphere - exists an optimal ratio between the oxygen concentration and the intensity of UV radiation, such that a maximum of ozone production is established here.

Atmospheric nitrous oxide

As the fourth most important greenhouse gas in the atmosphere with a lifespan of about 120 years *"(...) nitrous oxide is reduced exclusively by photolysis or by reaction with odd oxygen in the stratosphere."* (Klose, 2016, p.25 - Translated with DeepL.com (free version)). According to Klose (2016) its pre-industrial concentration was 275 ppb(v) and has grown at a rate of 0.8 ppb to currently 320 ppb. As stated by Häckel 1993 the majority of anthropogenically released dinitrogen oxide comes from the bacterial degradation of fertilizers in waterlogged or compacted soils (GOODALE and HACKEL, 1953).

Atmospheric window and absorption range of Earth's atmosphere

Elaborating on Earth's atmosphere and its constituents: One very important phenomenon is the absorption of incoming and outgoing radiation by atmospheric gases, thus hindering certain parts of the electromagnetic spectrum from reaching Earth's surface or hindering infrared radiation from Earth to escape back into space (Klose, 2016). Recalling the atmospheric constituents with the help of tables 2.15, 2.16, and 2.17, where each constituent is an absorber in a certain wavelength range: *"In the ultra-violet, the main absorbers are molecular oxygen (O_2) and ozone. (...). The absorption of infra-red radiation by the six most significant gaseous absorbers is conveniently summarized in figure 2.20."* (Andrews, 2010, p.72).

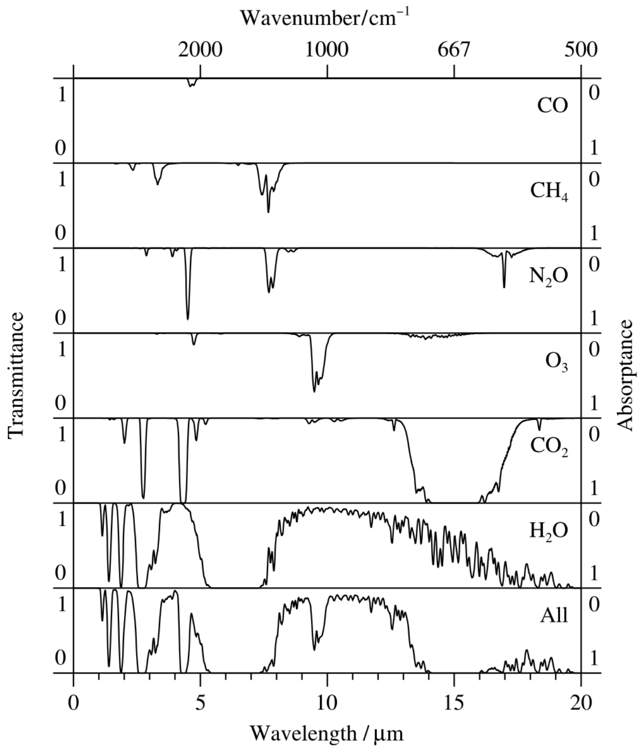


Figure 2.20: Infrared absorption spectra for six strongly absorbing gases and for the six gases combined (Andrews, 2010))

"The bottom panel of figure 2.20 shows the total long-wave absorption due to all gases. There is a broad region from about 8 to 13 μm, called the atmospheric window, within which absorption is weak, except for a band near 9.6 μm associated with O_3." (Andrews, 2010, p.73). The only two atmospheric windows transparent to electromagnetic radiation are the optical window - from 290 nm (near UV) to 1 μm (near infrared) - and the radio window - from 20 MHz to 300 GHz (Hanslmeier, 2023).

Further, it is noted that even though the absorption areas are a source of noise for Earth-based observations, they do also provide information about the type, distribution, and concentration of the absorber: *"For gases that are distributed consistently by volume percentage with altitude, the temperature of the absorbing gas and thus the vertical temperature distribution can be derived. This applies to CO_2 and O_2 at 4.3 and 15 μm, and O_2 at 5 mm."* (Klose, 2016, p.25 - Translated with DeepL.com (free version)).

Klose (2016) also describes the general measurement process: One conducts several very narrow-band measurements in small spectral intervals, so that radiation from different high-altitude layers is received. With strong absorption, representative radiation values and thus temperatures for the stratosphere are obtained, and with weak absorption, for the lower troposphere. With a variable altitude distribution of the gas, knowledge of the temperature distribution can yield information about the gas itself, for example, vertical water vapor profiles in the area around 6.7 μm. In the microwave range (8 mm) additional statements can be made about the total water content as well as the liquid water content of the clouds.

In any case, these atmospheric windows are essential for the heating and cooling regime on Earth. On the one hand, it enables the heating of the planet by solar radiation reaching the planet's surface, and on the other hand, it allows the necessary cooling by allowing (thermal infrared) radiation from Earth's surface back into space (Hanslmeier, 2023).

The greenhouse effect on Earth

As noted, Earth's atmosphere and its greenhouse constituents let short wavelengths in the visible light pass to the surface. After the surface heats up due to the absorption of radiation, Earth re-emits long wavelengths of thermal infrared radiation back to the atmosphere. As seen in 2.20, certain parts of the infrared spectra become easily absorbed on the way back to space due to strongly absorbing gases (N_2O, O_2, CO_2, H_2O, CH_4 and O_3). These in turn become re-emitted in the atmospheric layer, in which it was first absorbed (Klose, 2016). Remembering that strong absorbing greenhouse gases such as CO_2 and H_2O are situated in the atmosphere's lower layers, it can be concluded that the troposphere – the habitat for all living organisms – is continually heated by this greenhouse effect.

It is important to note, that the natural greenhouse effect is responsible for the overall habitable temperature on Earth (Cubasch et al., 1992): *"According to Cubasch 2000, the natural greenhouse effect of 33 K is composed of the contributions from water vapor at 20.6 K, carbon dioxide at 2.7 K, tropospheric ozone at 2.4 K, nitrous oxide at 1.4 K, methane at 0.8 K, and CFCs"* - chlorfluorocarbon - *"at 0.6 K. Thus, water vapor is the most significant natural greenhouse gas, accounting for nearly two-thirds of the greenhouse effect."* It is further derived that about *"(...) 39% of the thermal radiation emitted by Earth is absorbed by the atmosphere."* (Klose, 2016, p.26 - Translated with DeepL.com (free version)).

The above described natural greenhouse effect, which is a prerequisite for a habitable

Earth must be opposed to the anthropogenic greenhouse effect producing an uncontrolled and increasing warming effect:

"(...) since the start of industrial development around 1850, humans have been causing an additional greenhouse effect by increasing the proportion of natural greenhouse gases and by emitting new greenhouse gases (CFCs) into the atmosphere." (Klose, 2016, p.27 - Translated with DeepL.com (free version)).

According to Hansen 2005 (Hansen et al., 2005) these gases accumulate in the atmosphere and result in an additional driving force for the climate. Hansen calls it 'climate forcing'. It describes the fact that Earth currently has an unbalanced energy budget of 0.5 to 1.0 watts per square meter and is temporarily emitting less energy into space than it receives from the Sun, thus warming up. He further elaborates that approximately 50% of this heat is stored in the upper layers (up to 1000m) of the oceans, which is confirmed by measurements from ships and buoys.

The 2nd and 4th column in figure 2.21 indicate the contribution to Earth's temperature by (mainly anthropogenic) greenhouse gases (stemming from *" (...) the energy sector with 50%, the chemical sector with 20%, deforestation with 15%, and agriculture also with 15% (Latif 2003a)"* (Klose, 2016)) in contrast to natural greenhouse gases.

	Konzentration	Temperatur-erhöhung	natürlicher Treibhauseffekt	anthropogener Treibhauseffekt
		33 K	prozentual	prozentual
Wasserdampf (H_2)	0,50 ppm	20,6 K	62%	4%
Kohlendioxid (CO_2)	400,00 ppm	7,2 K	22%	54%
Methan (CH_4)	1,72 ppm	0,8 K	2,5%	17%
FCKWs und andere	0,25 ppb	0,6 K	2,5%	14%
Ozon (O_3)	0,03 ppm	2,4 K	7,0%	7%
Distickstoffoxid (N_2O)	0,31 ppm	1,4 K	4,0%	4%

Figure 2.21: Greenhouse gas concentration for Earth's atmosphere (Klose, 2016))

It is further noted that in addition to anthropogenic greenhouse gases, suspended pollutants with an impact on scattering processes have been increasingly added to the atmosphere: Klose (2016) explains that these *"Aerosols constitute the other significant human-caused influence factor on the climate"* (Klose, 2016, p.27 - Translated with DeepL.com (free version)). It is then stated, that due to the complexity of their effects and due to imprecise information about their quantity, the direct climate forcing can only be estimated at about 50%.

Recapitulating, the impact of the natural greenhouse effect creates an overall stable warming effect of 33 K. The anthropogenic greenhouse effect though adds additional greenhouse gases to the atmosphere, thereby causing a 'climate forcing' (Hansen et al., 2005). The climate needs to adapt to an ever-increasing warming effect.

The adaptation of a planetary climate to a non-stop increase in temperature is further elaborated in Edwards (2013). Ensuing consequences for Earth's climate and humanity were also part of a future-oriented discussion with the project's participants.

Comparison of greenhouse gas abundance in different planetary atmospheres, and its effects

For comparison purposes the neighbouring planets Venus and Mars were chosen: Comparing their atmospheric constituents it was noted, that an inverse effect to Earth's atmosphere takes place. The following relations for volume fractions in percent are given in Hanslmeier (2023):

Gas	Venus	Earth	Mars
CO_2	96.5	0.03	95.3
N_2	3.5	78.1	2.7
Ar	0.006	0.93	1.6
O_2	0.003	21.0	0.15
Ne	0.001	0.002	0.0003

Figure 2.22: Comparison of atmospheres for Venus, Mars, Earth (Hanslmeier, 2023))

Whereas Earth's permanent main constituents are N_2, O_2, Ar, and greenhouse gases only make up to 1% (excluding water vapor) - as seen in table 2.15 -, Venus's and Mars's main constituent is one greenhouse gas - namely CO_2 - with a share per volume of 96.5% for Venus, and 95.3% for Mars; whereas N_2, O_2, Ar, and Ne make up the rest. Both being terrestrial planets with solid surfaces creates a similarity to Earth, but due to such opposite atmospheric properties their climates differ strongly.

Venus's (runaway) greenhouse effect

Of primary interest for the project is Venus's run away greenhouse effect, and the resulting surface temperature of 738 K.

A. Hanslmeier explains how Venus's atmosphere and its greenhouse effect were researched: *"Measurement with the space probe VEGA (USSR, 1985) showed that at a height of 53 km room temperature prevails at a pressure of 0.5 bar. The high surface temperature can be explained by the greenhouse effect. The atmosphere of Venus contains much more CO_2 than the Earth's atmosphere. The diffuse sunlight heats the surface, and the CO_2 reflects the resulting IR radiation from the ground. Thus, the surface continues to warm until it emits enough heat to reach equilibrium with the incoming sunlight."* (Hanslmeier, 2023, p.192).

Mars's unstable greenhouse effect

Proceeding to planet Mars it can be noted, that even though Venus and Mars both lack an intact magnetosphere and have a similar CO_2 concentrations, their atmosphere still show very different processes. While Venus has a dense atmosphere with a higher gravity, and surface pressure of 93 bar, Mars's surface pressure is only 0.0007 bar, *"less than 1 % of Earth's surface pressure."* (Hanslmeier, 2023, p.202). This low gravity and lack of magnetosphere makes Mars's atmosphere prone to being constantly depleted by occurring solar winds. From the low surface pressure it can further be deduced, that the amount of CO_2 – even being the main constituent in the atmosphere – is not dense enough to support a stable greenhouse effect. Therefore, Mars is generally a cold planet with an overall temperature of 213 K (minus 60° Celsius) compared to Venus 738 K (465° Celsius) and Earths 288 K (15° Celsius).

Transition

This background sections' intention was to create a conceptual arc for the conveyance of greenhouse gas education through astronomical tools. The now following chapter on methodology will describe concepts from educational sciences that were used to reach this outreach programs' goal: the strengthening of scientific literacy in participants.

3. Methodology

The following chapter is divided into four sections: The first describing basics for scientific outreach for children, the second explaining the design process for the outreach program using theories from educational science with the aim to create an interactive and engaging learning experience for participants from middle school. The third section presents the specific teaching and learning methods applied by the lecturer and students. Whereas, the fourth section outlines the chosen setting for the course and the expected outcome.

3.1 Scientific outreach for children

3.1.1 Science communication

Science communication through different channels of public outreach can be the beginning for personal interest in a scientific field. An investment in this communication path profits society in the short and long run. Firstly, by imparting important knowledge to the public, and secondly, as an investment in the science field's future by attracting attention and subsequently, different forms of capital (Shneiderman, 2016). As the goal for the thesis is to create an effective interdisciplinary approach to the transmission of climate education in schools, the viewing of literature dealing with the topic of science communication and the transmission of astronomy concepts to children was a first step.

A read on astronomy education for a younger target group called Astrophysics for Young People in a Hurry by Tyson (2017) was the starting point. This literature is an entertaining read, since it incorporates fun facts and science jokes into the explanatory text, whose mission it is to impart knowledge on findings and theories in astronomy. The book dating from 2017 does a good job at giving an overview on questions about the cosmos for young readers. The take-away - for anyone striving to create an entertaining outreach program on astronomy for children - is that scientific outreach should be fun, and scientific explanations connected with everyday life experiences are good icebreakers for subjects that seem a bit outlandish or difficult to grasp at first.

A more theoretical book used as framework for science communication written by Lars Lindberg Christensen is The Hands-On-Guide for Science Communicators (Christensen, 2007). Its intention is to combine practical knowledge on scientific outreach projects with examples from his work environment. It contains completion lists and recommendations that can be helpful when one is planning a big communication project. Its contribution to this thesis is one important take-away, namely the need for a meticulous preparation of the material for the chosen target group.

"The narrower the target for a product, the better the product can be tailored to the target group. The importance of couching the right level of technical and scientific detail in language appropriate for the given group as precisely as possible is more important than ever. Sometimes even small short-comings here can mean that the communication fails completely." (Christensen, 2007, p.35).

Another take-away was "The Washington Charter for Communicating Astronomy with the Public". The recommendations for universities, laboratories, research organizations, and other institutions were especially of interest as they gave a common direction for objectives to aim for. Two points that seemed most relevant for this work were the advice to collaborate with funding agencies and other organizations - such as public education players, i.e. schools - to help ensure that public outreach and communication efforts have the greatest possible impact. Another advice said to "Offer communication training in academic courses of study for the next generation of researchers.", which struck me as an important recommendation (Christensen, 2007, p.246).

In the context of scientific outreach the stressing of astronomy's contribution to humanity's achievements is essential. Ancient inventions that shaped the course of civilizations, such as the season's calendar, the first clock (i.e. a sundial), the determining of the right time for planting rituals with the help of star maps for cultural purposes, geometry and path finding techniques for seafaring, the evolution of optical lenses, and many more. As well as more recent inventions, very much shaping societies all over the world: Communication satellites used for the television and internet, originally developed for space-based astronomy instruments, astronomical detectors and sensors used in material science, techniques used in astronomical observation, such as imaging and spectroscopy, adapted for Earth observation satellites to monitor weather, climate, natural disasters, and environmental changes -, and many more can be enumerated. (Hoskin, 1996; Elbert, 2014; Lillesand et al., 2015).

3.1.2 Science Education in Middle School

Science education in middle school initiates many children to their first reflections on everyday phenomena through the lenses of natural laws, mathematical equations, and scientific experiments. The level of competence the children acquire in their lessons depends on different factors: the teachers communication abilities, the students' abilities to actively listen and participate in the lesson, and the lessons level of difficulty. Specifications on what subjects are to be taught come from the school board, which in turn gets them from Federal Law regulations. For the purpose of designing an engaging and appropriate outreach program for middle school students it is essential to know what level of understanding can be expected from this target group.

The latest version for the Legal Regulation for Middle School Curricula dates from September 26, 2023, and can be found on the Austrian Education ministry's homepage (Leh, last visited on 09/30/23). According to this law, the physics lessons are to be held at least one hour per week in the second year, two hours per week in the third year, and two hours per week in the fourth year, while splitting one hour each between chemistry and physics lessons. Considering the available weekly hours for these subjects, one might conclude that the practice of natural science competence for students in middle school is not a main focus. This condition supports the idea, that an outreach program with an emphasis on natural science subjects can only benefit this target group.

The next paragraph presents the findings on the legally binding Education and Teaching responsibilities in physics lessons for Austrian middle schools according to Federal law consolidated (the complete legal regulation for secondary school curricula dating from 26.09.2023 was translated into English by DeepL.com (free version)).

"PHYSICS Educational and teaching task (2nd to 4th grade): The aim of Physics lessons is to further develop pupils' basic scientific knowledge so that they can act competently. To this end, they acquire age-appropriate specialist knowledge and use it to identify issues, acquire new knowledge, explain physical phenomena and apply physical ways of thinking and working in an age-appropriate manner. They know core aspects of the nature of physics as a natural science (the provisional nature and simultaneous reliability of scientific knowledge, the empirical and social character of the natural sciences and research as a creative process). Students are aware of how science and technology shape our material, intellectual and cultural environment. They develop skills that enable them to deal critically with problems from a physical perspective as responsible citizens." (Leh, last visited on 09/30/23)

A further important research before initiating the design process is the question on what prior knowledge middle school students bring with them. This can help determine the level of complexity for the outreach program's requirements. In addition, every school grade has a very specific competence area to be achieved by its students. Each competence area includes related physics subjects, all framed by one title.

The competence areas for physics education from 2nd to 4th grade condenses to these titles: "Competence Area Seeing and Hearing", "Competence Area Optical Systems" for second grade, "Competence Area Mechanics", "Competence Area Electricity and Magnetism", "Competence Area Energy" for third grade, and "Competence Area Weather and Climate", "Competence Area Radiation and Radioactivity" for fourth grade.

From this overview it becomes apparent, that the outreach program's intention of promoting knowledge on astronomy and planetary climate research goes perfectly with the competence area "Weather and Climate" in fourth grade. This fact helped determine the appropriate target group for this thesis' project.

3.2 Educational science

3.2.1 Cognition in adolescence

Thinking and problem solving in adolescence

In order to design the outreach program for middle school students it was necessary to understand the standard cognitive and motivational development in this age-group. The goal of teaching always presupposes that the student has the capacity to intellectually follow the taught matter, and that their cognition can store the newfound knowledge appropriately. As developmental psychology explains, research knows different developmental stages in human cognition, such as the newborn-stage, early childhood, middle childhood, adolescence, and adulthood (Piaget, 2005; Spelke et al., 1992). Middle school students are in their first puberty, therefore in their adolescence. In developmental psychology two areas are decisive for analyzing pubescent cognition: the development of scientific thinking with its ability for abstraction and the ability to solve problems.

The work by Wicki (2015) on developmental psychology explains it as follows:"It is typical of formal thinking that a person goes beyond the information found or given when solving a problem, forms hypotheses and controls variables where possible. Hypothetical thinking implies the formulation of testable assumptions, which is relevant not only in scientific thinking, which Piaget investigated, but also in the area of social relations. Variable control refers to the fact that when there are several potentially influential variables, all but one must be held constant so that the effects of systematic variation on one variable can be clearly interpreted. Young people who can think formally are therefore able to plan experiments. (...) Experimental studies show that the thinking discussed here is already possible for children from the age of 10 at the latest. (...) Overall, results show that central components of scientific thinking can be successfully taught at an early age in a school context." (Wicki, 2015, p.109 - Translated with DeepL.com (free version)).

These findings encourage the imparting of astronomical concepts that require a certain degree of hypothetical thinking, which builds on the formulation of verifiable assumptions - as stated above.

Memory in adolescence

The impact for this outreach program will be measured by analyzing results from repeated multiple-choice quizzes. Therefore, the identification of age-appropriate testing conditions is a focus. In connection with this, the memorization of astronomy contents will be reviewed. But the question on how much memory capacity can be expected from middle school students must be clarified beforehand, to help with the design of challenging but not overwhelming quizzes. Again, the work by Wicki (2015) is consulted for this purpose. Concerning the development of adolescent memorization abilities we find the following specifications:"The task of working memory is to hold one or more pieces of information in consciousness and, if necessary, to process them in order to solve a task (e.g. arithmetic problem or puzzle). Recent studies have shown that the performance of working memory continues to develop until the age of 17, which is associated with the late maturation of the pious cortex, which does not occur until adolescence (Luciana et al. 2005; Conklin et al. 2007). The fuzzy trace theory assumes that people store a past event both as an exact representation (or verbatim) and as a core statement containing only the essentials (Brainerd/Reyna 1990). Compared to the exact memory traces of the image-accurate representations, the memory traces of the core statements are imprecise (hence: fuzzy trace), but easier to recall. The fuzzy trace theory postulates that people generally prefer to represent the core statements of events without too many details (i.e. create fuzzy traces). both memory processes improve over the course of childhood. In particular, however, the basic ability to extract the central elements and core statements from detailed content and link them to each other increases significantly over the course of childhood and adolescence (Chapman et al. 2011)." (Wicki, 2015, p.112 - Translated with DeepL.com (free version)).

These findings are relevant for the choice of content as well as for the composition of the multiple-choice quizzes. As middle school ends at age 14 for most students, it can be deduced that their frontal cortex directing "the performance of the working memory" (Wicki, 2015) – is not yet fully operating. As a result, the mentioned ability of processing information to solve a task is limited. This ability which is also necessary to use deduction to easily predict an outcome based on prior information or make logical assumptions is not as pronounced for younger adolescents as for older when tackling more complex topics. For that reason, the outreach programs content - Cosmic Perspectives on Climate: Introducing Astronomy as a Tool for Greenhouse Gas Education - will be conveyed through less complex representations, such as long equations or complicated graphs with more than two axes, but instead make use of easy analogies and the narrative explanation of pictures. To this end, explanatory images will be integrated into a presentation, while the lecturer's narration will provide context relevant to the subject matter. Even though the Fuzzy-Trace Theory states that people generally prefer the core messages without to many details Wicki opposes that "The memory performance of adolescents is - (...) - clearly superior to that of children, which is not least a consequence of school attendance, which practically requires the daily memorization of vocabulary (a foreign language), terms (e.g. in geography and history lessons) or mathematical formulas. The frequent use of memory makes the use of memory strategies worthwhile and promotes insights into the sensible use of one's own memory (meta-memory). With increasing expertise in individual content areas, it is also easier for young people to link the information they have absorbed with their previous knowledge in a meaningful way, store it and retrieve it later. In this context, Wicki mentions a highly regarded study by Chi (1978)" - cited in (Schneider et al., 1993) - ", in which 10-year-old children acted as chess experts, while the laypersons consisted of adults of different ages. The task was to recall chess positions that had been shown for a short time. The child experts did better, although they performed worse than the adults in a memory span test. Such a reversal of the generally observed age effects is not only conceivable in chess, but also in other domains (cf. soccer skills)." (Wicki, 2015, p.113 - Translated with DeepL.com (free version)).

Taking this into account, it can be deduced that older middle school children in the habit of using their memorization for lessons will not only remember the presented astronomy contents for a longer time without repetition but will also connect the new information to prior knowledge, which then again makes it easier to put it in a context and memorize it. Therefore, the multiple-choice quizzes can be composed with a mixture of fuzzy-trace questions as well as more challenging expert questions without overwhelming older middle school students.

Building of interests in adolescence

The design of an engaging and relevant educational outreach program builds contact with the students interests and creates pathways to a new area of interest. An educational psychological theory by Krapp (2002) describes the development of interests in childhood and adolescence with the emergence of an initial curiosity – for example, music. Then follow the first experiences and activities – for example, with an instrument -, through which results specific knowledge and skill, which leads to a further approach. This theory can be helpful when designing the presentation of different unknown topics. Firstly, the course needs to create an initial curiosity or at least have a group of students, which already have an initial interest in astronomy. Building on this, the course needs to give the students some kind of instrument to practice – in a broader sense, getting to know the topics basics. Only then, with the emergence of some new knowledge and skill, can the students be expected to give thought to the topic in a deeper, more complex meaning.

Finding the right kind of tasks

To this end, the recommendations given by the educational scientist R. Girmes (Girmes, 2009) on how to create an engaging learning task will be implemented, to help the students develop specific knowledge and skills. The first fundamental principles for designing learning tasks is the importance of connecting every new subject matter with concepts oriented on human experience. It explains that ideally there should always be an intersection of knowledge and action allowing interdisciplinary exchange. The second principle states that the world we live in continuously generates tasks for each one of us. According to R. Girmes, schools have the duty to prepare students for lives tasks. The third principal requires that each task should attract further knowledge as new questions arise, and this knowledge should then be structured in the developing mind. Quiet places of learning should therefore be available to solidify and structure the knowledge as well as open the mind to emerging reflections.

3.2.2 Teaching and learning methods

This section discusses the 'teaching' methods implemented by the lecturer. From the start the program was meant as an interactive learning experience. It should include experiments in the physics laboratory, gamification (learning through games), excursions to places of science transmission as well as the possibility for participants to have an active conversation with researchers working in the field of astronomy and planetary science; further, framing these interactive learning methods by a classical front-of-class lecture. The idea behind this method mix is an "open lessons" approach (O'Leary, 2020). This approach describes not a precise method but implies the use of diverse methods to diversify the access to knowledge. It is meant to open the classical and sometimes limited learning process by including the pupils in the learning experience, giving them a more active and creative role compared to them only being simple listeners. This reflection led to the following order of events for the course: The first eight days would be spent getting to know new topics using the above-mentioned methods - except for excursions, which were planned for later. The first seven days concentrated on the acquisition of new knowledge, the eighth day was reserved for the filling out of a conclusive feedback and the preparation for the final two days of group excursions. The first excursion on the ninth day led to the "Planetarium Wien". Its presentation called "Deep Sky" dealt with the topic of a stars live and its cycles. The second excursion on the tenth and last day led to the Universitätssternwarte (University Observatory) in Vienna, where a researcher from the Astrophysical institute held a guided tour through this historic building - dating from 1879 - and blended the narration with the institute's modern use by today's international astronomers team.

In the early stages of the project design the evaluation of the outreach program was a priority. Therefore, it was necessary to think on different ways in which the courses topics could be transmitted to the participants and knowledge acquired easily without overtaxing the students' efforts. Following this train of thought, it was decided on excluding any memorization techniques that require the use of a pen, paper, and books. In comparison, memorization techniques focusing on attentive listening, engaging hands-on work, an understanding of connections with real life, observations from experiments, educational films, a get-together with scientists as well as the encouragement of group conversation were deemed to be reliable memorization techniques. To this end, the choice of participants from a higher school degree was implemented, since their cognitive capabilities for connecting new information with prior existing knowledge are already existing, and in regular use. Specific methods in didactics which enhanced the memorization process for the students were taken from a book by the educators Werner Jank and Hilbert Meyer (Schlabach, 1994). A very aptly formulated rule they present is: "Wir denken in Bildern und nicht in Theorien", which can be translated as: We think in pictures, not in theories. According to their pedagogical observation things we learn are always connected to the inner pictures we connect with them. This memorization method was much used in this project. Another implemented method was the "guided tour" method. The knowledge transmission from a guide during a tour through a museum is commonly referred to as a guided tour. A docent (i.e, a lecturer) trained to lead tours and provide information about the exhibits imparts context, and insights to help visitors to better understand and appreciate the exhibits. This approach was modified and adapted for this outreach program. Figures of astronomical interest were implemented in a presentation, but without adding any explanatory text. The participants were only shown pictures. The information on what they were looking at and its relevance was only transmitted through speech. This way of learning through awareness is - according to cognitive psychology – an active performance and not a passive process of perception. In accordance with Renate Girmes theory on the "right tasks", the term of "cognitive map" by Edward Ch. Tolman - as reviewed in Jensen (2006) - describes an analogy to the neurobiological networking processes in the brain connecting different areas in order to operate. The cognitive map as a psychological model describes the inner representation of concepts and things as a network (Tolman, 1948). This justified the program's approach of using different methods to induce memorization. One further pedagogical learning method was the explanation of the subject's present meaning for the students live. This was meant to operate as a motivational memorization technique. In order to have this approach work, the actual meaning in the student life must correlate with the pedagogical wished meaning Girmes (2009).

3.2.3 Settings and Outcome

All these prior described theories from educational science were used to design the following course setting for the outreach program.

Date setting: As it had to be held in an exam-free time, the end of school year was chosen as ideal period. In Austria the school year ends at the beginning of July – the course was therefore held the last two exam-free weeks of June.

Time setting: To implement a generous time-setting adapted for a to students unknown subject matter, every unit was planned to consist of three hours. One unit would be generally held within a single day. The course was held Monday to Friday from 8.15 am to 11.15 am, with one longer school break of 20 minutes and two shorter school breaks of 10 minutes in between. As two school weeks consist of ten working days, the total time for the course sums up to approximately 21 hours.

Participant setting: The chosen student group for the course are middle school students at the end of 4th grade, as they have three years of prior physics lessons on which to build an initial interest in natural sciences and astronomy. After consultations with the students' headteachers the initially intended open-to-all approach for the course registration was adapted. The headteachers explained that in addition to an initial interest the students should also show a certain degree of maturity, in order to fully profit from the two-weeks course as well as enable a peaceful environment. As a conclusion, the headteachers blocked certain students from attending due to behavioral problems. Apart from this stipulation, the registration was free for every interested student from 4th grade.

Data protection setting: As the school's directorate very correctly insisted on the necessary data protection for the under-aged program participants, every student received a fixed number to distinguish them for the quiz-setting and later evaluation process.

Location setting: The locations were the school's physics lab as well as its neighboring informatics lab. The reason behind this choice of location will be explained in the upcoming chapter.

Quiz setting: The quiz settings were designed by the author of this thesis. At the beginning of each unit the students would have to fill in a multiple-choice quiz, in order to check their initial knowledge on the upcoming subjects of the unit. On the following morning, approximately 24 hours after, the students would take the same multiple-choice quiz. This way, the answer-results can be compared and eventual improvements noticed.

The application of all these aforementioned educational and organizational methods is necessary to increase the chances of obtaining the wished outcome. To recapitulate, these methods should support the memorization process, and are the theoretical foundation for the students' increase in scientific literacy over a period of the two weeks program.

3.3 Evaluation of the project

The main evaluation method to assess the participants progress is through multiple choice quizzes. To design the evaluation documents a clear understanding of what a quiz includes is essential. Looking up the Oxford dictionary the following definition can be found:

"noun: a test of knowledge, especially as a competition between individuals or teams as a form of entertainment." (Dictionary, 1989).

This definition illustrates why this broad type of evaluation model is a sensible instrument for this study's purpose. It can be adapted to all kind of topics with a series of questions quizzing the participants knowledge and understanding. The design also encompasses multiple-choice options occasionally taking an entertaining undertone to lighten the mood. However, it should be noted, that in this outreach program's design no competition between participants is intended.

3.3.1 Design choices

After deciding on a process for evaluation, arises the next question on how the multiple choice quiz is to be designed appropriately for participants belonging to a younger age group - ranging from thirteen to fourteen years. The following parameters were considered: the time it should take to complete the multiple choice quiz, the number of questions put to the participants, the length and complexity of the questions, the length and complexity of the answers, the guarding of the participants anonymity for privacy protection, the number of possible answers – single choice or multiple choice -, the use of questions answered by rating or ranking system, the use of open-ended simple questions or more complex questions, and whether the question types should be mixed or not. Furthermore, the multiple choice quiz would be filled out once before and once 24 hours after the related unit without prior learning or repetition on the participants side. The multiple choice quiz would therefore have to test only what the participants could have remembered from the prior unit over a 24 hour span without repetition. Keeping all these requirements in mind, the necessary evaluation settings for school students was reviewed in the "School organization act for Austrian schools". It defines the standardized regulations.

3.3.2 Austrian standards for school exams

The following subsection contains a translated excerpt of the legal regulations for evaluations in Austrian schools - translated with DeepL.com (free version):

"There are legal rules for schoolwork, tests and dictations that are intended to alleviate excessive pressure.

What applies to schoolwork: 1. The subject matter for schoolwork must be announced at least one week in advance. 2. The subject matter taught in the last two lessons may no longer be the subject of school work. 3. School work may not take place after three school-free days or after a school event lasting several days. 4. It is also not permitted to carry out more than two assignments per week in general education schools and more than three assignments per week in vocational schools. 5. Schoolwork must be corrected and assessed and returned within one week. 6. A one-time repetition of schoolwork is provided for if more than half of the class has a "fail". 7. New tasks must be set for this - but on the same subject matter. 8. The deadline, which must be within two weeks (1 week in vocational schools), must be announced when the schoolwork is returned. 9. The deadline is extended by school-free days. 10. Important: The better grade always counts!

Tests and dictations: 11. Tests and dictations must be announced two teaching days in advance. 12. They may not last longer than 15 minutes in compulsory general education schools and AHS lower grades and no longer than 20 minutes in AHS upper grades. 13. Only one written examination or only one school assignment may be carried out on any one day. 14. A written examination and a school assignment on the same day are not permitted!

(https://noe.arbeiterkammer.at/beratung/bildung/schule/schularbeiten.html)

These fourteen regulations represent the standards for evaluating school children in Austria, and therefore must be considered as framework for the design of this multiple choice quizzes. The next paragraph will briefly summarize, which of these regulations were particularly considered.

The first specification states that students should have at least a week to know about and repeat the tested topic, but in this projects case, the participants did not have anything to prepare. The second specification was consciously ignored as it was the intention not the give the participants time to go over the previously learned contents – the goal was to get a real picture of how much of the newfound knowledge remained in memory after 24 hours. The regulations number 3 to 11 were not relevant to the study setting. In turn, number 12 was very relevant as it gives a clear restriction on the evaluation time, and therefore the multiple choice quizzes were designed to be completed in less than 15 minutes. Likewise, number 13 was observed, and according to the specification the program's originally planned quantity of evaluations and feedback was reduced in order to keep it at one multiple choice quiz per day. Some of the above-mentioned regulations are very important to consider, especially when holding a school project, as the children have regular school and scheduled schoolwork on days or hours the project's course is not in session. When studying for different subjects and preparing exams the school student's memory capacity can become overtaxed, and the results in the outreach programs evaluation might very well suffer because of it. Therefore, designing an evaluation system for school students must always take into account the school setting. Another essential thought guiding the evaluation design was the mental health of the school student's participants. It is necessary to acknowledge the psychological state school students are in before participating in this outreach program. The habit of being tested regularly on their knowledge and memory capacity is normal for most students. At the same time, it is a constant source of anxiety and stress for the length of active school year. Keeping this in mind, the outreach program's design wants to respect this very crucial fact. In contrast, evaluating adults with a multiple choice quiz in a voluntary course setting compared to testing children in their school setting has very different psychological resonances for each group of participants. Therefore, it is essential to diminish any possible subconscious pressure issuing from a daily routine of evaluation in the outreach program. The participants –

especially children - should enjoy and engage in the course, and never connect it with stress or a test in good performance. To this end, the course was held towards the end of school year – once exams were already over - to prevent participants from feeling any additional pressure. Also, the questions and answers in the evaluations were designed in a way to support the memory task of the younger participants.

3.3.3 Final design

The next paragraph presents the final design for the evaluation forms. Using Microsoft Forms the multiple choice quiz relating to the course units are composed of 10 questions. These are to be completed in a maximum time of 10 minutes. The quiz is designed as a multiple-choice evaluation, with three possible answers for each question. The questions are generally straightforward and short to prevent misunderstandings. The catalogue of possible answers also followed the same principal with a short and clear composition. The feedback form to be filled out at the end of the course was the only exception. It contained 25 questions with a mix of ranking system questions and open questions with space to write personal assessments. The questions were longer and more complex, but compared to the multiple choice quizzes they did not ask about accumulated knowledge, but personal assessment and feedback. This allowed for a higher level of complexity in the questions. The maximum time to fill out the feedback form were 15 minutes, which still corresponds to the evaluation standards for school students. It must be noted that the free space at the beginning of each form, where the participants would normally fill in their names, was intended for only inserting a fixed number representing a student ID. This was necessary for data privacy reasons, which were a prerequisite from the School's directorate. To view all multiple choice quizzes and the feedback form please refer to the appendix 7.1.2.

4. Outreach program

4.1 Subject structure

In this section, the format for each unit in the outreach program is detailed, covering educational topics related to greenhouse gas and planetary atmospheres.

4.1.1 Unit 1: Introduction to Astronomy

The first day of the outreach program was intended as an introduction to the topic. For that reason, the first unit was used to set the stage and provide the participants with context. In order to break the ice between the program's participants, the unit started with an initial game of "Science memory".
The goal of this game is to discuss scientific practices and get a clear idea of what characterizes a science.
Once the first basics of the concept of science were discussed, the group went forward with defining astronomy as a science in itself. To do that, the unit proceeded with the presentation of different research fields in astronomy.

4.1.2 Unit 2: The light spectrum

Experiment 1: What do you see?

On the second day of the outreach program the group gets together for a short experiment in the physics lab. Once everyone is seated, the lecturer asks the general question: "What do you believe is the most important thing humans need for observing planets, cosmic nebula, or comets?

Letting the participants give their different answers - according to their age -, the first thoughts will generally be: the eyes, good glasses, a telescope. It is unlikely that the younger participants will think of 'light' as an answer.
Without giving the right answer right away, everyone who wants to give an answer should be listened to. Part of the learning process is the questioning of preexisting knowledge, and practicing the process of reflection and combination of thoughts. Once the first and maybe second wave of guesses has ebbed, the lecturer can propose to guide the group to the right answer through an experiment.

For this experiment, the lecturer needs a well-equipped physics lab with automatic blinds that can completely shut out daylight - this is an important part of the experiment –, further it needs a flashlight and a tealight or firelighter.

The following steps describe the sequence of actions for the experiment:

1. Darken the entire room with the automatic blinds, there should be no light coming from outside or within the room.
2. Ask the group: "What do you see?" (The answer should be: "Nothing".)
3. Next, use a lighter and hold it to some nearby object.
4. Ask the group: "What do you see now?" (The answer should be: "The object or parts of it.")
5. Extinguish the lighter.
6. Now, take a flashlight and shine into the room.
7. Ask again: "What do you see now?" (The answer should be describing the objects illuminated by the flashlight.)
8. Turn off the flashlight.
9. Use the switch to turn on the room's light bulb or fluorescent tubes.
10. Ask the group: "What do you see now?" (The answer should be describing the room.)
11. Turn the switch off.
12. Open the blinds again fully to bathe the room in daylight.
13. Ask the group: "What do you see now?" (The answer should describe the room as well as everything outside the windows.)
14. Now, ask the group: "What did we need - apart from our eyes - to observe objects around us

or outside this room?"

15. Normally, some or maybe all the participants will have understood the answer by this time: "We need light to see things."

This exercise should initiate the group to the importance of light in the detection and observation of astronomical objects. Once the topic of light has been introduced the lecturer can begin the transition to next unit's theme: the light spectrum and its relevance for different observational methods in astronomy.

Next, the participants can reflect on the best surroundings for astronomical observations for a short time. Again, the way to teach the students is by leading them to the right answers through questions. Only, if this approach fails, due to a lack of interest in a specific topic, cognitive exhaustion on the participants side or a very complex topic, can the lecturer turn to the standard front-of-class presentation, which has its merits in this kind of situations.

Guided tour 2 (Guided tour 1 - in appendix)

Figure 4.1: La Silla Observatory (figure taken las (last visited on 17/5/24))

Image description for participants: This figure shows an Observatory at La Silla in Chile. The backdrop shows the night sky with a section of the Milky Way, and many bright stars.

Questions for participants concerning 4.1

1. "What could this building be?" Answer: An astronomical observatory.

2. "Where do you think is the opening for the telescope?" Answer: The dome shutter is on the roof.

3. "What time is it in this picture?" Answer: Night.

4. "Why do you think do optical earth bound telescopes observe at night?" Answer: Because the light from the stars can only be seen at night when the sun is down.

5. "What kind of objects in the sky do you see on the picture?" Answer: It shows stars, and maybe planets.

6. "What different colors do you recognize in the stars?" Answer: Orange, blue and white.

Figure 4.2: The desert around VISTA (figure taken eso (last visited on 17/5/24))

Image description for participants: This figure shows the VISTA telescope at the Paranal Observatory in Chile on its mountain surrounded by a desert.

Questions for participants concerning 4.2

1. "Why does this observatory stand on a mountain?" Answer: Because it is nearer to the sky without being overshadowed by a higher mountain.

2. "Why does this observatory stand in the desert far away from any village or city?" Answer: Because there is no light from civilization polluting the observations at night.

3. "Do you know any examples for light pollution?" Answer: In cities at night. Near a motor

highway at night. Light emitting satellites etc.

4. "Where could a location for telescopes be found that is completely free of human made light pollution?" Answer: In outer-space.

5. "Do you know the name of a space telescope?" Answer: Hubble Space T., James Webb T. etc.

Experiment 2: The prism's secret

Starting the second day with Unit 2 the group assembles in the physics lab. This unit is meant for getting to know the light spectrum, and its meaning for observations. Once everyone is seated the participants get informed of the next experiment. For this experiment a flashlight and a (glass) prism is needed. To begin the unit, the lecturer gets out a prism and explains its function and its composition, while showing it to the students 2.1.1. The following steps describe the sequence of actions for the experiment:

1. Darken the entire room with the automatic blinds, there should be no light coming from outside or within the room.
2. Turn on a flashlight.
3. Hold the prism up above your head.
4. Position the flashlight at 5 cm behind the prism.
5. Start turning the prism slowly.
6. Search the wall for the complete spectrum of the flashlight.
7. Keep turning until you have the entire color spectrum.
8. Ask the students: "What colors do you see?" Answer: All rainbow colors: red, orange, yellow, green, turquoise, blue.
9. Explain that these are the visible color parts for natural – white - light.
10. Ask: "How many colors do you see?" Answer: Five to six.
11. Ask: "Which color is at the centre of the spectrum?" Answer: It seems to be the color green.
12. Explain how the human eyes evolved to detect the visible light precisely because of the atmospheric window that lets visible light pass - seen through the prism -, and add that certain animals, such as bees, snakes, birds or fish can also detect other – to us invisible – parts either of the UV or IR light spectrum for reproduction or hunting purposes.

13. Explain where on the light spectrum UV and IR light are located. Answer: UV at 100 to 380 nm and IR at 850 to 940 nm. The former lies next to the visible color purple, the latter near the color red.

Experiment 3: UV fluorescence

Continuing with an UV fluorescence experiment, the lecturer prepares certain objects such as a white paper, fluorescent Stabilo pens in different colors. For the experiment we also need a flashlight with an UV mode.

The following steps describe the sequence of actions for this experiment:

1. Darken the entire room with the automatic blinds, there should be no light coming from outside.

2. Turn on the UV flashlight.

3. One by one point the flashlight on the different objects.

4. Explain how UV light interacts with the materials electrons and produces fluorescence.

5. Explain how natural light interacts with surface materials, and how the level of absorption, scattering or reflection decides the wavelength – color we observe and give everyday examples, as seen in 2.

6. Once the light is back, point to objects and explain what part of the light spectrum – colors - are being absorbed, what color part is scattered. Use the case of a mirror reflecting back to the observer.

7. Then, let the participants each choose an object and participate in this exercise.

This experiment should establish the understanding for the interaction of light – its photons – with the surface of objects. Participants should understand, that human eyes observe wavelengths as specific colors.

Experiment 4: IR detection

For the next experiment on IR light, the lecturer prepares a TV remote control and a smartphone with a camera, without an IR-blocking filter.

The following steps describe the sequence of actions for this experiment:

1. All students should sit in a group behind the lecturer.

2. Have one student standing before the lecturer and holding the remote control.

3. Darken the entire room with the automatic blinds, there should be no light coming from outside.

4. Turn on the camera from the smartphone and position the display facing everyone's face/eyes.

5. Tell the student standing behind the camera to push the power button of the remote control.

6. The camera shows a red signal light when the button is pushed.

7. Now, lower the camera and repeat the process without the camera.

8. Participants should see no red signal light from the remote.

9. Repeat the demonstration with the camera for the student holding the remote.

This experiment teaches the observers that human eyes cannot see IR light, and that researchers need devices with IR sensors, such as sensitive cameras, in order to observe IR-sources.

Educational videos

The next activity takes place in the PC room. To diversify the experiences on the light spectrum the unit is using educational videos on the uses of IR light and UV light. These videos are found on a video portal called "YouTube". The first video has the title: "How the sun sees you" by Thomas Leveritt. (the link: https://www.youtube.com/watch?v=o9BqrSAHbTc). This video is very educational on the natural interaction between the human skin and UV radiation. The second video has the title: "Infrared camera" by Harvard Natural Sciences Lecture Demonstration. (the link:https://www.youtube.com/watch?v=baJtBDJDQDQ). Its content consists of different demonstrations, showing temperature gradients for objects humans use daily. Both video contents must be explained separately by the lecturer after each viewing.

Guided tour 3

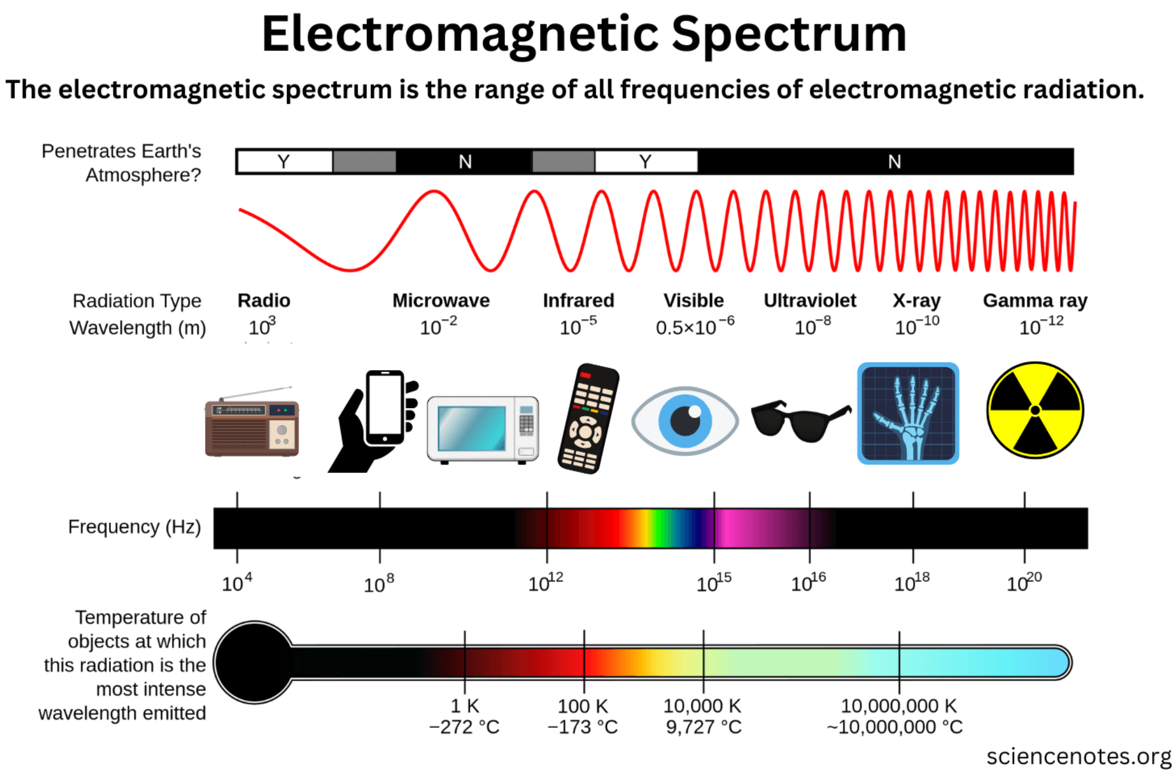


Figure 4.3: The electromagnetic spectrum (Figure taken from EM- (last visited on 11/4/23))

Image description for participants: The figure depicts an artistic representation of the electromagnetic spectrum. The red wave depicting different sections - written below - of the spectrum. Above which it say, whether the wavelengths can penetrate the atmosphere or not by Y for yes, and N for no. Pictures of gadgets and items show what the wavelengths are used for by humans. The figure also illustrates the color according to the wavelengths, as well as the temperature.

The next step after this initial introduction to the topic of the light spectrum is a more theoretical approach, illustrating a light wave with varying wavelength and amplitude on the blackboard. Next, explaining how the wavelength depicts shorter or longer wavelengths - as illustrated in 2.1.1 -, and how amplitude is related to the waves intensity.

Next to this handwritten wavelength representation on the blackboard, the lecturer shows the next figure of a light spectrum – figure 4.3 - on the projection screen, and explains the connection between wavelength and color characteristics, before continuing the unit with pictures from astronomical observations in different light spectra.

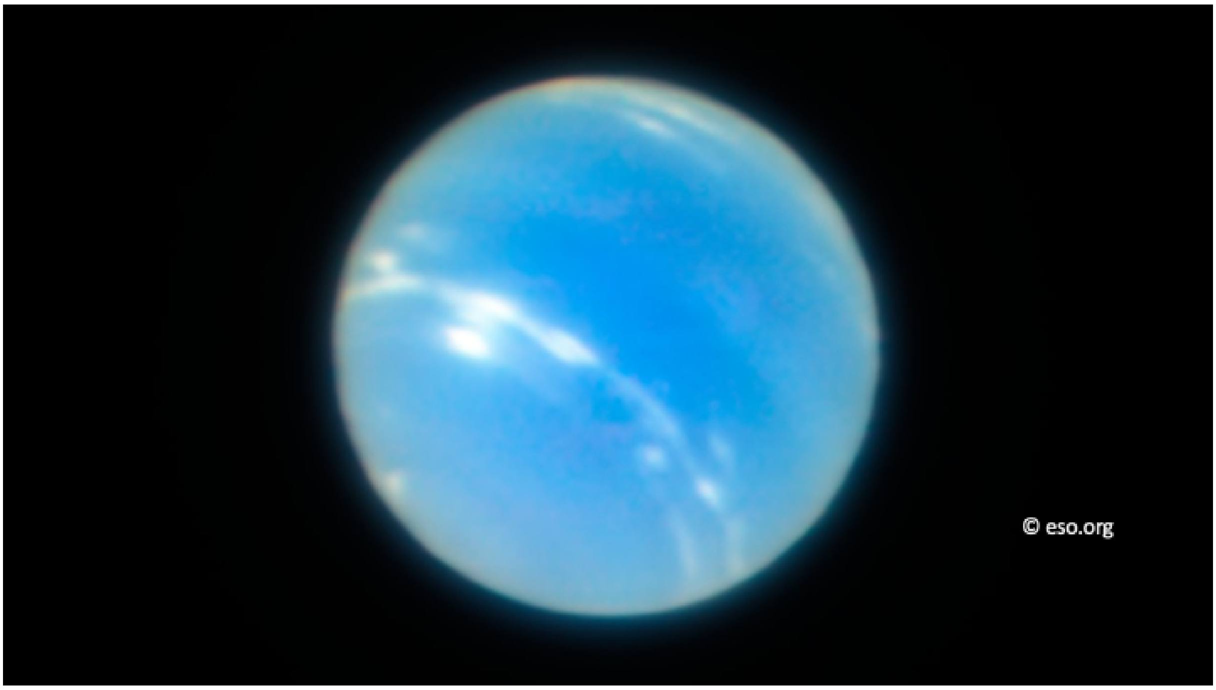


Figure 4.4: Neptune from the VLT with MUSE/Galacsi (figure taken from eso (last visited on 17/5/24))

Image description for participants: The figure shows an image of planet Neptune observed by the VLT with a spectrograph working at visible wavelength called GALACSI.

Questions for participants concerning 4.4

1. "Remembering the planet memory game from the first unit: What planet in our Solar system could this one be?" Answer: Neptune.

2. "What type of planet is Neptune?" Answer: Ice giant.

3. "Look well at its color – going back to the prior figure -, which wavelength on the spectrum does apply best?" Answer: Blue is between 450 and 495 nanometers.

4. "Is this wavelength in the optical spectrum or in the invisible spectrum?" Answer: Visible.

5. "Remembering what we learned about the wavelength: Is blue nearer to the UV or IR spectrum?" Answer: UV.

6. "Will Neptune therefore scatter shorter or longer wavelengths back to the observer?" Answer: Since we see the color blue, it must scatter shorter wavelength.

7. "Which wavelengths are therefore absorbed by its atmosphere?" Answer: Since we don't see any colors from the longer wavelengths it absorbs them.

Figure 4.5: The visible and IR telescope VISTA (figure taken from eso (last visited on 17/5/24))

Image description for participants: The figure shows an image of VISTA (Visible and Infrared Survey Telescope for Astronomy). It is located at the Paranal Observatory in Chile.

Question for participants concerning 4.5

1. "Remembering the video on IR experiments: What kind of characteristics will this IR telescope show of observed objects?" Answer: Astronomical objects that emit heat can be observed with an IR telescope.

In the next figures the lecturer introduces students to examples of astronomical IR observations.

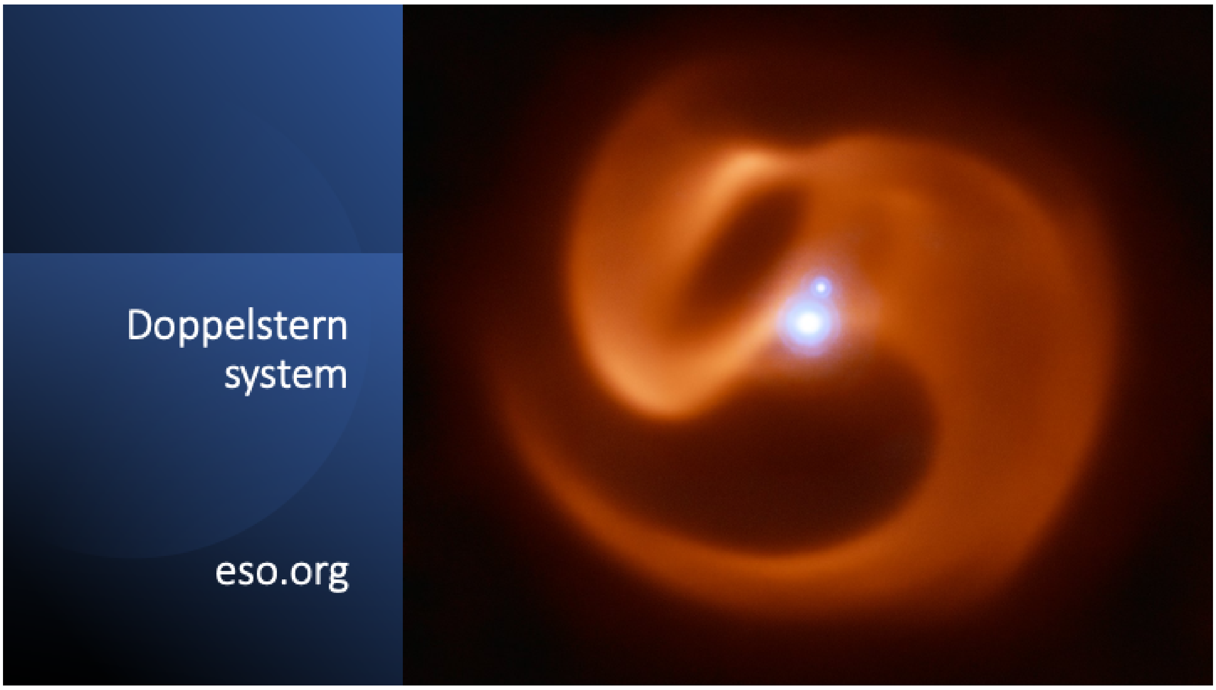


Figure 4.6: Coils of Apep (figure taken from eso (last visited on 17/5/24))

Image description for participants: The figure shows an image of the Coils of Apep, a binary star system. As it is observed in IR it reveals an extended region of hot gas surrounding the two stars.

Questions for participants concerning 4.6

1. "What could the two bright spots in this figure be?" Answer: Two stars orbiting around one another.

2. "What could the surrounding mist be?" Answer: Hot gas.

3. "Why are the central stars so bright?" Answer: As seen in the educational videos: The hotter it gets, the lighter the IR sensors display a regions. Therefore, the stars are very hot, and look white-blue.

4. "Why is the surrounding dust cloud orange?" Answer: It is cooler than the stars but still very warm.

5. "In which light spectrum is this massive binary star system observed in this picture?" Answer: Infrared.

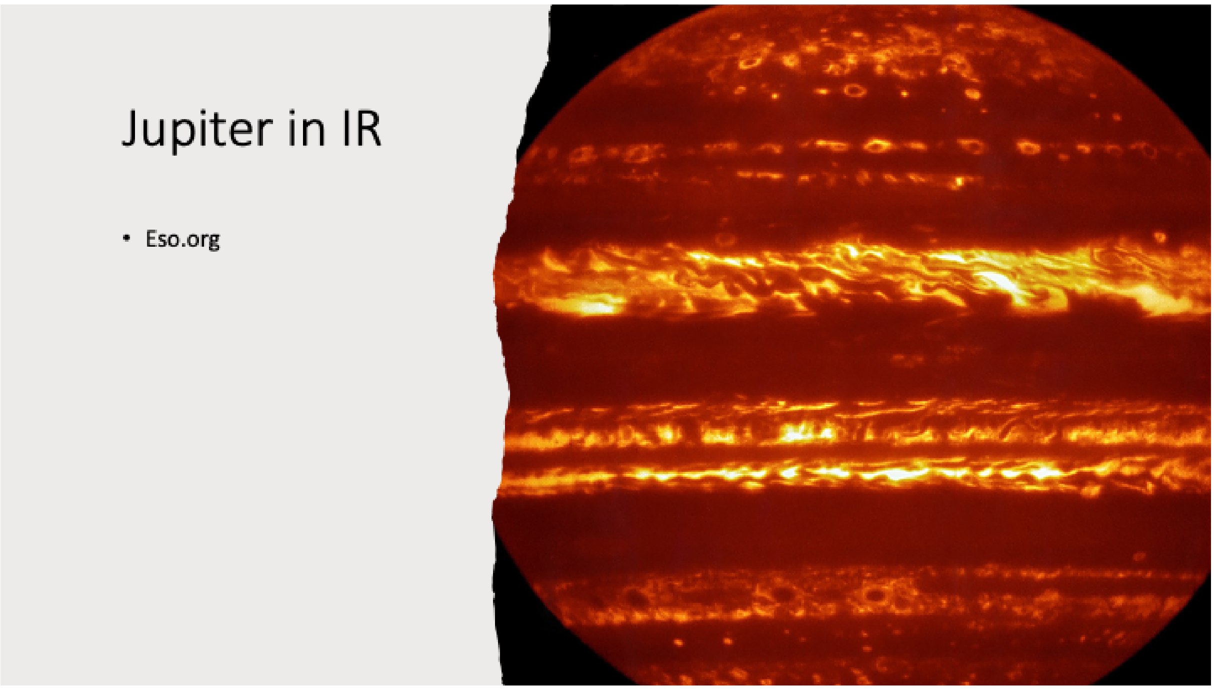


Figure 4.7: Jupiter imaged using the VISIR instrument on the VLT (figure taken from eso (last visited on 17/5/24))

Image description for participants: The figure shows an image of planet Jupiter observed with the VLT instrument VISIR, an Imager and Spectrometer for mid Infrared.

Questions for participants concerning 4.7

1. "This image of Jupiter shows different temperature areas on its atmosphere: Where are its hottest, where are its coolest regions?" Answer: The two belts in the middle are the lighter and hottest regions.

2. "What type of planet is Jupiter?" Answer: Gas giant.

3. "What could the heated areas around Jupiter's equator be?" Answer: Storms in its atmosphere.

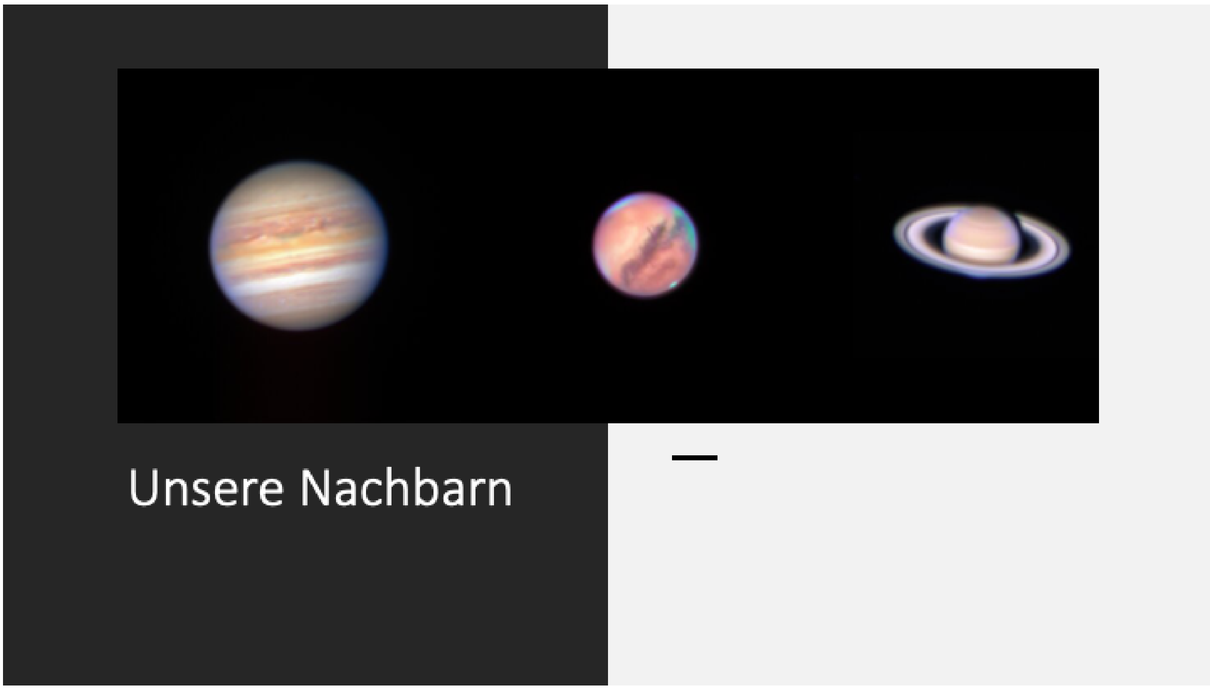


Figure 4.8: Bright planets imaged at La Silla restarts observations (figure taken from eso (last visited on 17/5/24))

Image description for participants: The figure shows images of planets Jupiter, Mars and Saturn - from left to right - observed on the La Silla Observatory in the visual spectrum.

Questions for participants concerning 4.8

1. "What planets are in this picture?" Answer: Jupiter, Mars, Saturn.
2. "Are they in their natural order in the Solar System?" Answer: No.
3. "Remembering our experiment describing the color characteristics of objects: In what light spectrum were these observations made?" Answer: In the visual spectrum.
4. "What planet types are on this picture?" Answer: Gas giants, and a terrestrial planet .

Wished outcome for Unit 2

The goal for unit 2 is to get to know the importance of the light spectrum for different astronomical observations. Another goal is to get to know some telescopes used in astronomy, and examples for observed objects. As this outreach program's subject is the use of astronomy for planetary climate education, it is essential to lead the students gently into the field of spectroscopic observations used for the determination of chemical compositions in planetary atmospheres - such as greenhouse gases.

4.1.3 Unit 3: Atmospheric layers

Guided tour 4

Starting the third day with Unit 3 the group assembles in the PC room to begin the unit in front of the projector screen. In relation with the characteristics of Earth's atmosphere, the third unit introduces the topic of layers.

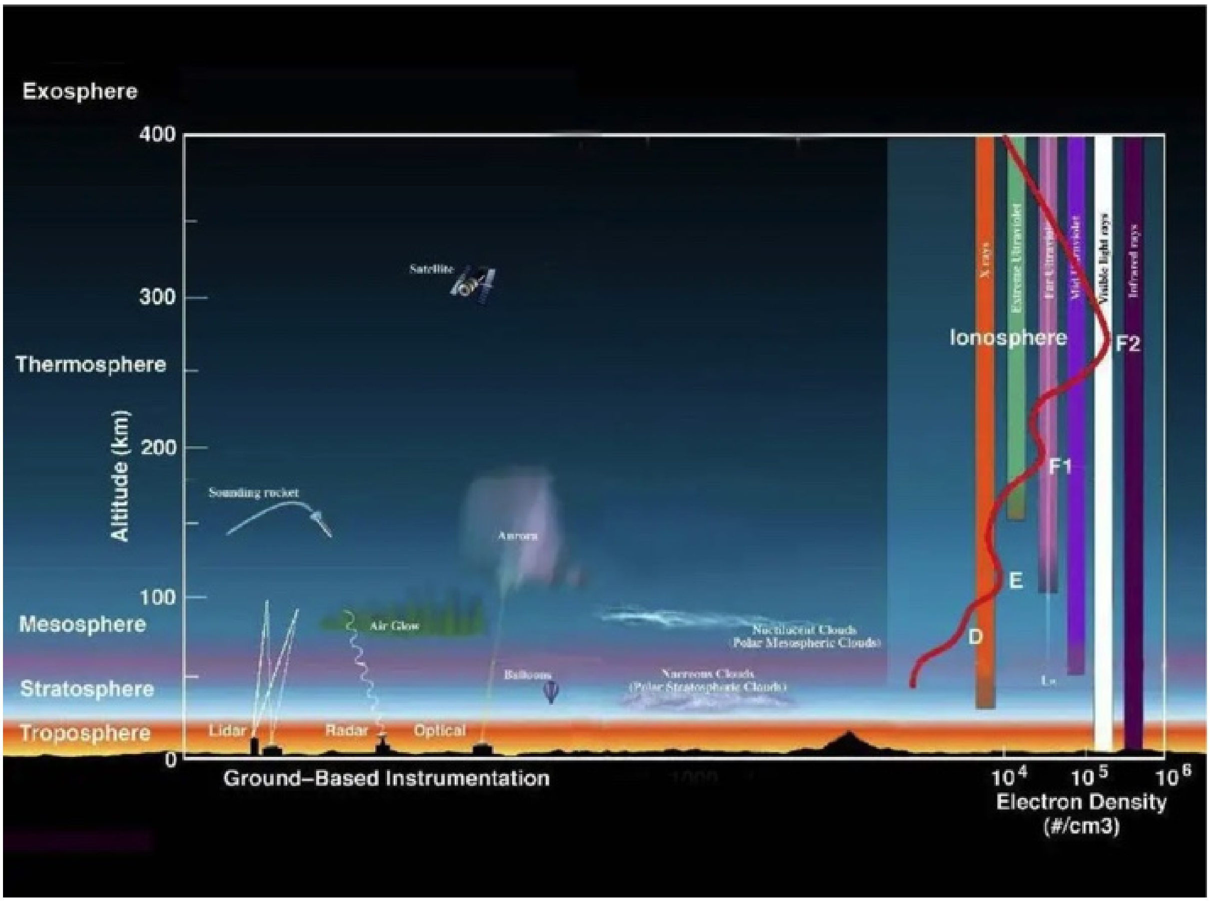


Figure 4.9: Atmospheric layers nas (last visited on 13/5/25))

Image description for participants: The figure shows an artistic rendering of Earth's atmospheric layers as illustrated on the vertical axis next to the height in kilometers. Each layer contains one or more items that illustrate human activities at different heights of the atmosphere.

Questions for participants concerning 4.9

1. "In which atmospheric layer does the atmosphere begin according to the illustration?" Answer: At sea level.

2. "Up to which layer do the mountains reach?" Answer: The tropopause.

3. "In which layer do airplanes fly? Balloons?" Answer: Troposphere, tropopause, stratosphere

for planes, troposphere for balloons.

4. "In which layer are the clouds?" Answer: Troposphere and -pause, generally.

5. "In which layer do space shuttles fly?" Answer: Exosphere.

6. "In which layer do people usually live?" Answer: Troposphere.

7. "What might be the reason that people do not live in the other layers?" Answer: We cannot breathe higher up, and there is no ground to build on.

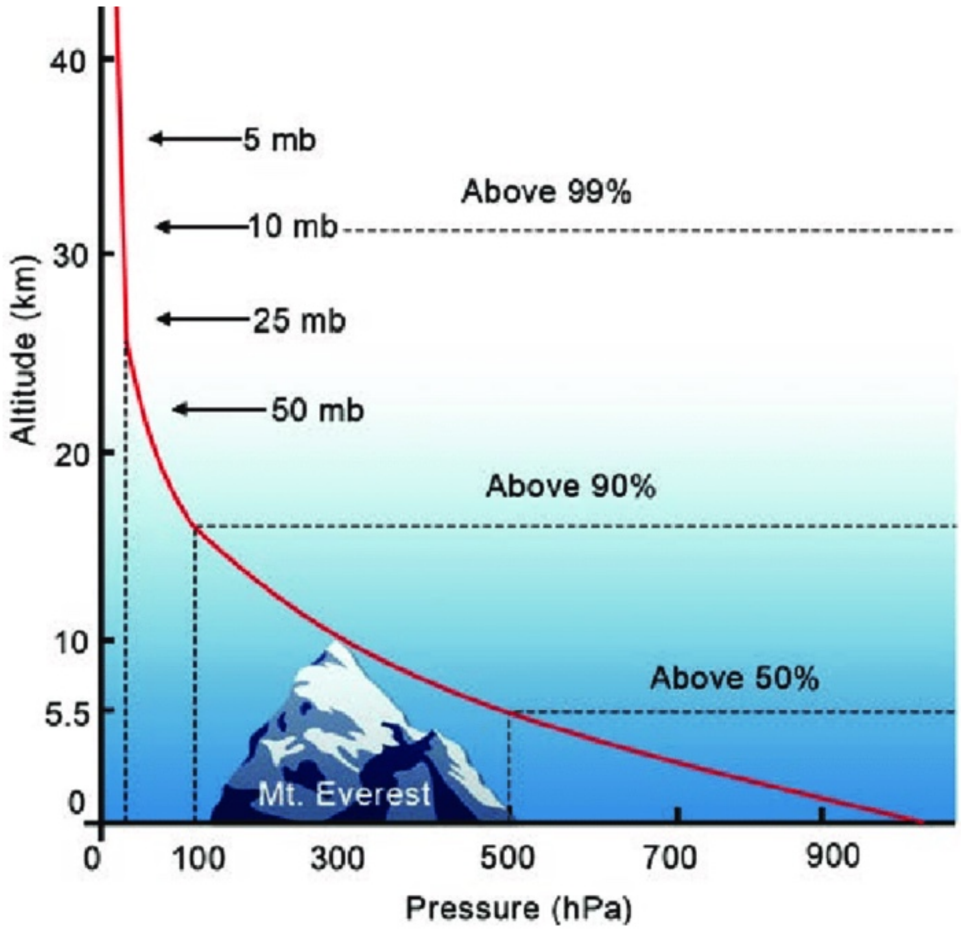


Figure 4.10: Atmospheric pressure Pacher et al. (2018))

Image description for participants: The figure shows Earth's atmosphere. On the graph the pressure is given as a function of altitude - in red - in the range of the troposphere and lower stratosphere. It can be observed that the pressure drops by a factor of 1000 in less than 50 km (km in right axis). The starting point on the surface is 1000 millibar, arriving at 50km it is less than 1 millibar. This strong decrease in pressure is accompanied by a fast decrease of the atmospheric mass, as 50 percent of the mass is below 5.6 km, and 90 percent is below 16 km. The remaining 10 percent is distributed over the other layers.

After receiving this information, the participants are able to deduce that the lowest part is also the densest part for Earth's atmosphere.

Questions for participants concerning 4.10

1. "What could the percentages along the red function indicate in this figure?" Answer: The decrease of mass in the atmosphere.

2. "Where is the densest part in the atmosphere according to the graph?" Answer: Below 5.5 km altitude.

3. "How high up can humans go without feeling difficulty in breathing?" Answer: About 2400 m for healthy humans.

4. "From what altitude did the Austrian extreme athlete Felix Baumgartner jump?" Answer: He jumped from 39.045 meters from the stratopause and landed successfully.

5. "Why was this jump dangerous in relation to this layers pressure?" Answer: In the stratopause the pressure is at 5 mb, which is 200 times less than in the troposphere. When jumping from the stratopause towards earth you become very fast due to terminal velocity because of low density and the gravity pull. One easily loses control within the jump.

Transition to Unit 4

The last two figures are intended as a transition into the topic of atmospheric molecular compositions. As the figures become more scientific and contain no artistic pictures, the lecturer is required to intensify the knowledge transmission through front-of-class teaching, and making sure the unit is not going to fast, to give every participant time to follow the explanations.

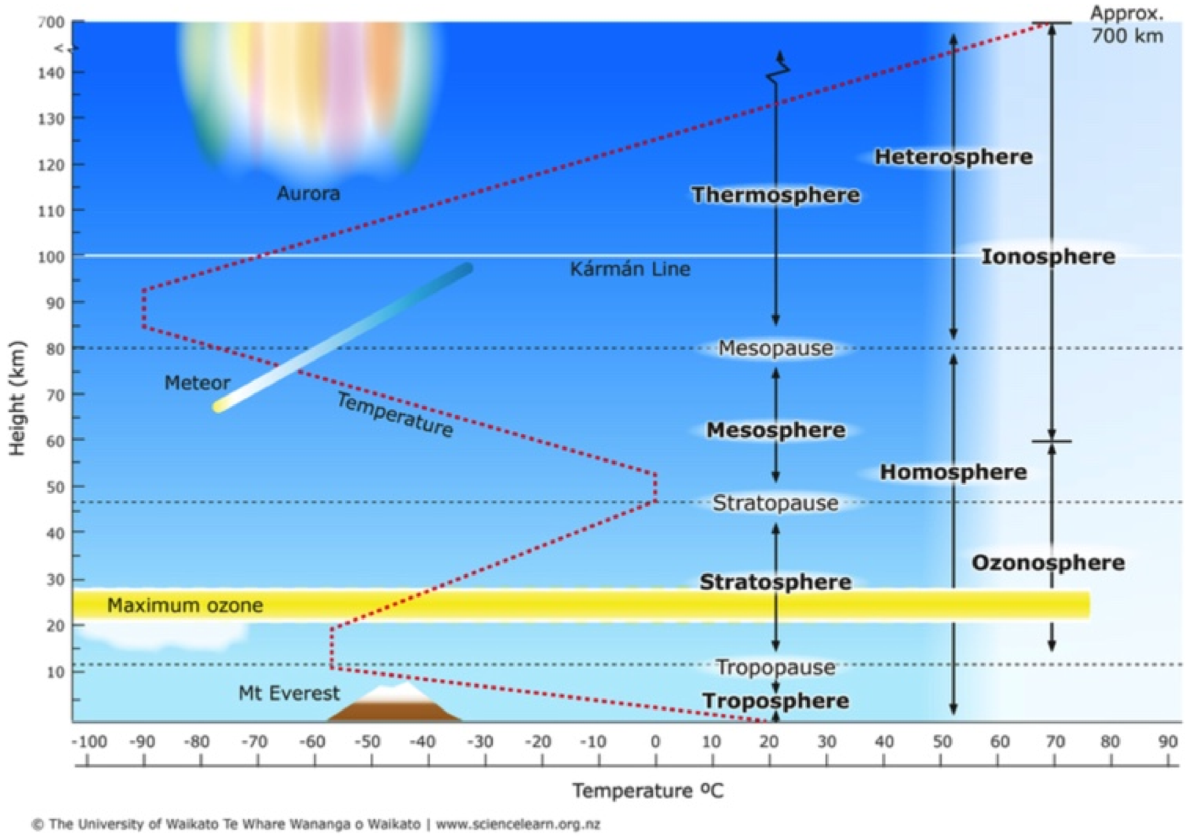


Figure 4.11: Homo-,Hetero- and Exosphere temperature trend(figure taken from hom (last visited on 17/5/24), Rights: The University of Waikato Te Whare Wānanga o Waikato)

Image description for participants: The figure highlights the distinct chemical layers of the atmosphere - the homosphere, heterosphere and ionosphere.

The homosphere, which is defined by turbulent mixing currents. That causes the chemical composition to be very homogeneous from the surface to about 100 km (78% N_2, 21% O_2). At about 80 km to 100 km altitude the constant distribution of the main constituents ends.

Above that layer starts the heterosphere. It contains a much lower density, which is why molecular collisions are much rarer. Since the atmosphere there is so thin, it is highly stratified with heavier molecules, like molecular nitrogen and oxygen settling lower, whereas lighter particles float to the top, such as helium and hydrogen (He, H_2).

The ionosphere starting at about 60 km altitude. This region includes the mesosphere, thermosphere and parts of the exosphere. The ionosphere is "ionized" by solar UV radiation, and this is where we find most ionized species.

Consequently, the Sun plays a major role in the composition and temperature profile of the atmosphere.

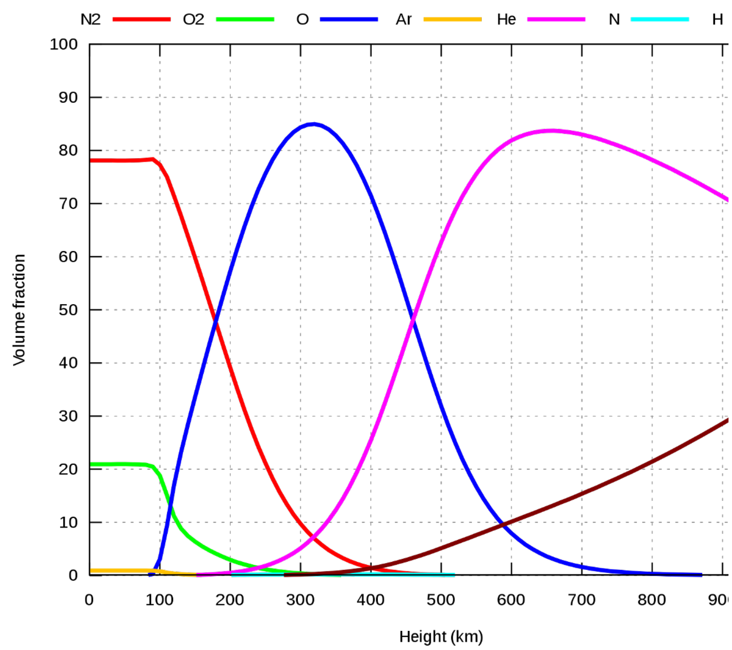


Figure 4.12: Earth's atmosphere main constituents (figure based on the MSIS-E-90 atmospheric model by nasa.gov mai (last visited on 17/5/24))

Image description for participants: The next figure further illustrates the information gained by the former slide.

The color regime for the graph shows the volume fraction - fraction of particles - for the main constituents of Earth's atmosphere as a function of height in km.

Most of the atmospheric mass range lies below 100 km, and has a constant particle composition made of nitrogen, oxygen and argon.

These constituents are constant until about 100 km, where they start declining gradually.

The graph shows an increase in atomic oxygen, what tells us, that due to strong radiation in the upper parts of the atmosphere, the combined oxygen has been dissociated into its atomic parts.

At an altitude of 500 km the amount of helium and hydrogen is prevalent. This is explained by the altitude and density of the atmosphere. As helium and hydrogen are the lightest gases they can easily reach the higher altitudes compared to heavier gases, even gaining kinetic energy due to the high temperature and interaction with charged particles, enabling escape velocity to leave Earth's atmosphere. Due to a lack of many heavier molecules low density ensues, and the constituents don't mix easily.

This knowledge should be new to the students, which makes it a good moment for the lecturer to emphasize the necessity for a deeper understanding of atomic and molecular physics. This way, the lecturer introduces the topic for the next unit.

Questions for participants concerning 4.12

1. "Can you detect the main constituent for each layer." Answer: N_2 in troposhere, O in thermosphere, He in thermospause.

2. "Which constituents are predominant in the layer in which humans live?" Answer: N_2 and O_2.

Wished outcome for Unit 3

The goal for unit 3 is to reach a basic knowledge of Earth's atmospheric layers starting at the troposphere and ending at the exosphere. A bonus is the explanation of the atmospheric chemical composition.

4.1.4 Unit 4: Physical building blocks: Atoms and Molecules

Guided tour 5

The fourth day starts in the physics lab. For this unit the lecturer uses a method mix between leading with questions, front-of-class lecture as well as work in group technique. This unit intends to foster a deeper understanding of the structures found in physical matter – especially on the atomic scale.

In relation with the chemical composition of Earth's atmosphere the fourth unit introduces the topic of chemical elements, atoms and molecular composition.

The lecturer begins with an explanation of the proper reading of the periodic table - as explained in 4.13.

Image description for participants: The figure shows a standard representation of the periodic table. Each chemical element is given with its abbreviation, atomic number and electron negativity - on the left, atomic mass and density - on the right. The color scheme denotes the chemical group blocks.

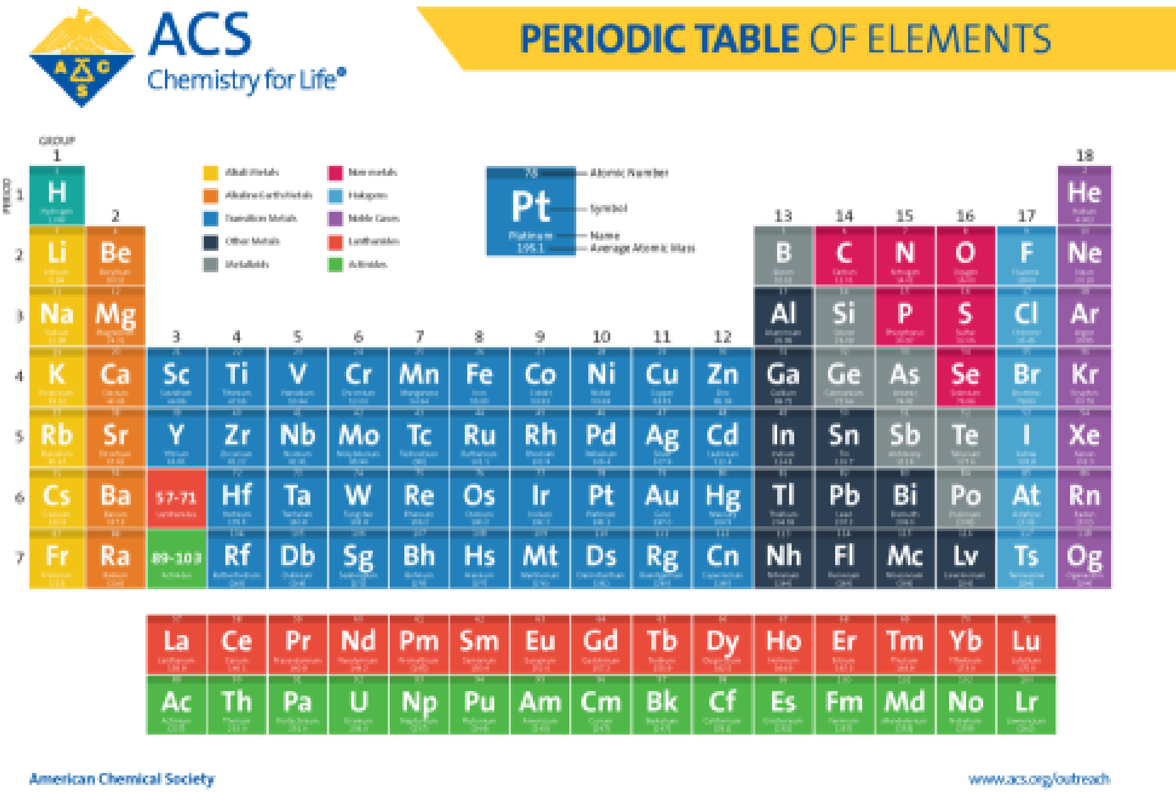


Figure 4.13: The Periodic Table (figure taken from per (last visited on 17/5/24))

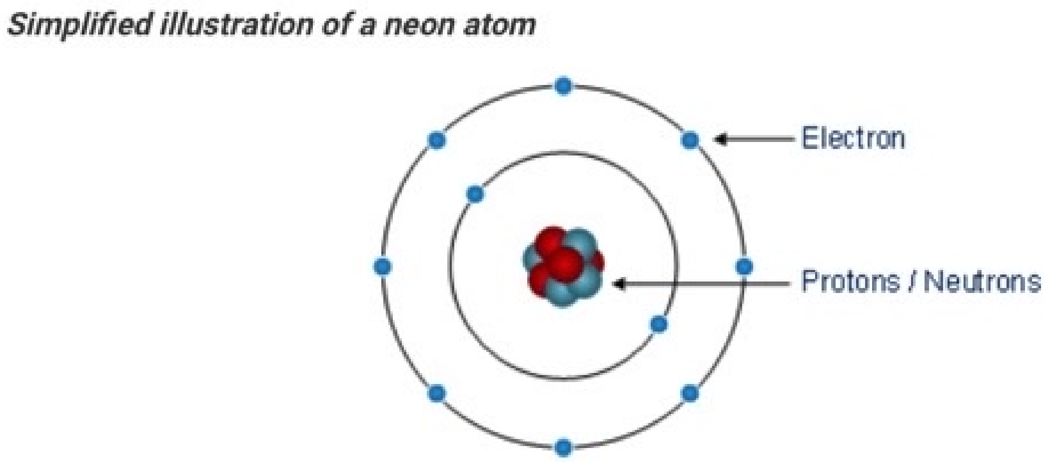


Figure 4.14: Simples Atommodell (figure taken from das (last visited on 17/5/24))

Image description for participants: The next figure is an artistic illustration of an atom. It is an easy introduction for the participants as it is a simplified representation.

The atomic model including protons and neutrons in the nucleus, and shells occupied by electrons must be explained in combination with the system of the periodic table, as it explains the given properties for each element.

The best way of tackling the subject with young learners is to paint a hydrogen atom on a black board, and explain how the atomic mass comes about using the ordinal number, and the deduction of the number of neutrons. Then repeat for a helium, and then a lithium atom.
Finding an interactive periodic table indicating the electron configuration for each element complements the process. Conveying that every shell can only hold a certain number of electrons, and that electrons all hold distinct energy states is important to transition into the topic of spectroscopy.
The lecturer should therefore stress that the most stable electron-shells are the inner shells, the ones nearest to the positive charge in the nucleus, but that electrons in the outer shells can be easier to strip away by interaction with other charges.
Looking at the chemical group blocks for very stable elements, such as noble gases, and less stable elements, such as alkali metals, can help participants to deduce the probability for the necessity of electron loss or capture by a chemical element.
Explaining that to reach a stable energetic ground state certain elements must make molecular compositions is the important conclusion to move on to the next unit. The lecturer then gives examples for molecular compositions on the blackboard for water H_2O and salt $NaCl$.

Work-in-group: Analyzing information from the periodic table

The participants are then divided into groups of two. Each group receives two or three elements from the periodic table to analyze. They get five minutes to come up with the number of protons and neutrons in the nuclei.

Once the time has passed, the group presents the results on the blackboard, and the participants discuss whether it is the right answer or not.

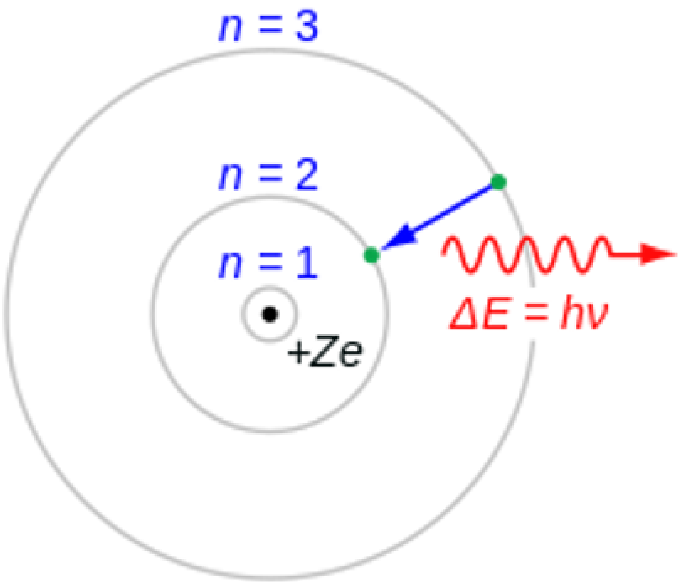


Figure 4.15: The Bohr atom model (figure taken from boh (last visited on 17/5/24))

Image description for participants: The next figure depicts the Bohr model as introduced earlier. The electrons - in green - move on circular orbits - shells for a distinct energy state.
A single electron jumps from the third to the second orbit. And a photon corresponding to the energy difference between the shells, n=3 and n=2, is emitted.
This model is vital for the understanding of spectral lines described in the next unit.

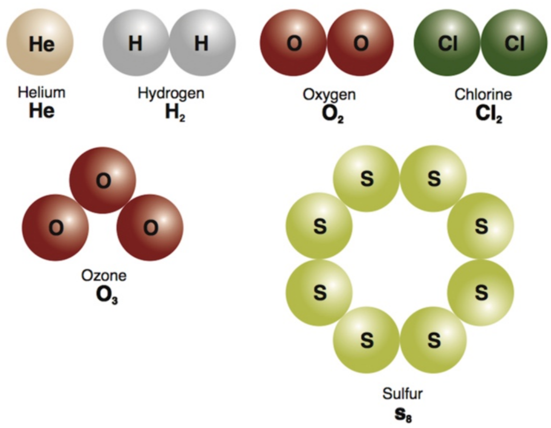


Figure 4.16: Molecules (figure taken from mol (last visited on 17/5/24))

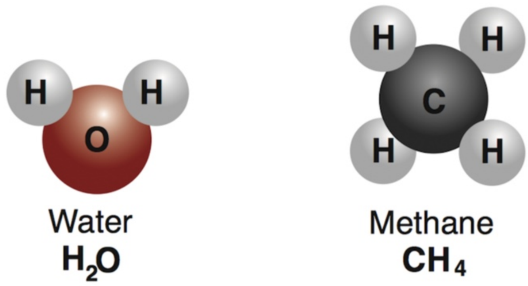


Figure 4.17: Molecular compounds (figure taken from mol (last visited on 17/5/24))

Image description for participants: The last figure for unit 4 intends to showcase different composite molecules.
It depicts molecules made of one kind of atom, like H_e, or be elemental molecules, such as hydrogen (H_2), oxygen (O_2), chlorine (Cl_2), ozone (O_3), and sulfur (S_8). The second figure depicts compounds made of two or more atoms of different elements, such as water (H_2O) and methane (CH_4). After the explanation the lecturer can ask the group to determine the ordinal number for CO_2.

Wished outcome for Unit 4

This unit's intention was to teach the fundamental structure of an atom, and how atoms can form molecular compositions.

4.1.5 Unit 5: Emission and Absorption

Guided tour 6

Starting the fifth day with Unit 5 the group assembles in the PC room to begin the unit in front of the projector screen. This unit intends to foster a deeper understanding of the light spectrum and the phenomena of emission and absorption. Considering the completely unknown subject matter for the young participants, the lecturer uses mainly front-of-class teaching.
Image description for participants: The figure above illustrate the excitation of an electron after absorbing a photon leading to a higher energy level of the electron, the figure below depicts the emission of a photon after the excited electron falls back into its initial ground state.

The processes of absorption and emission are best depicted as a step by step demonstration on a blackboard, and explained according to 4.18 and 4.19.

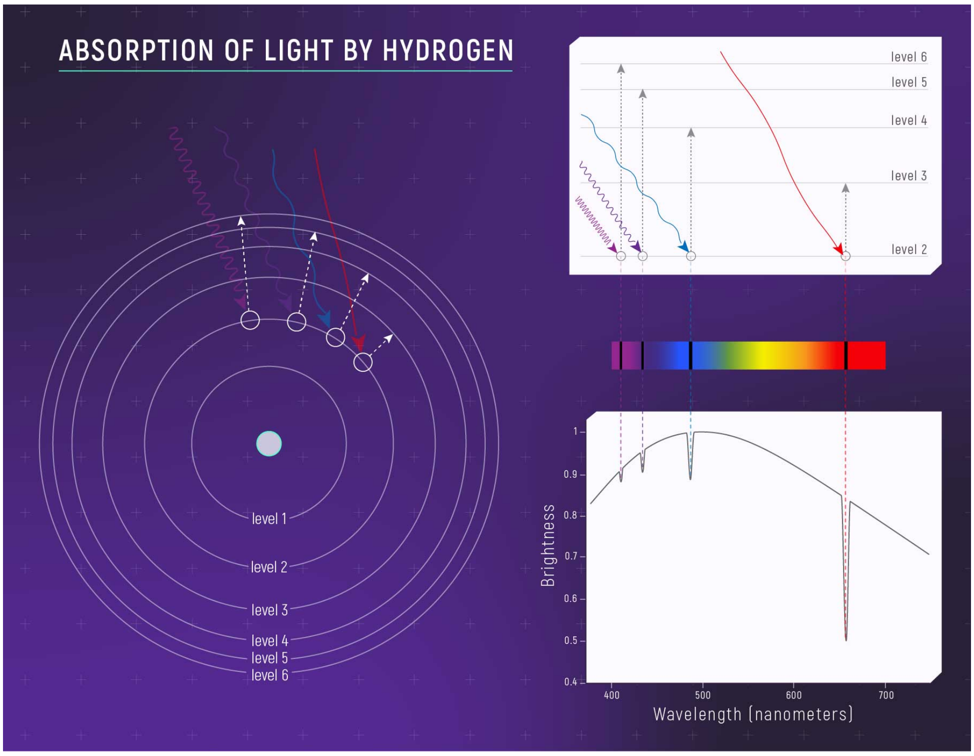


Figure 4.18: Absorption of light by hydrogen atom (figure taken from web (last visited on 17/5/24))

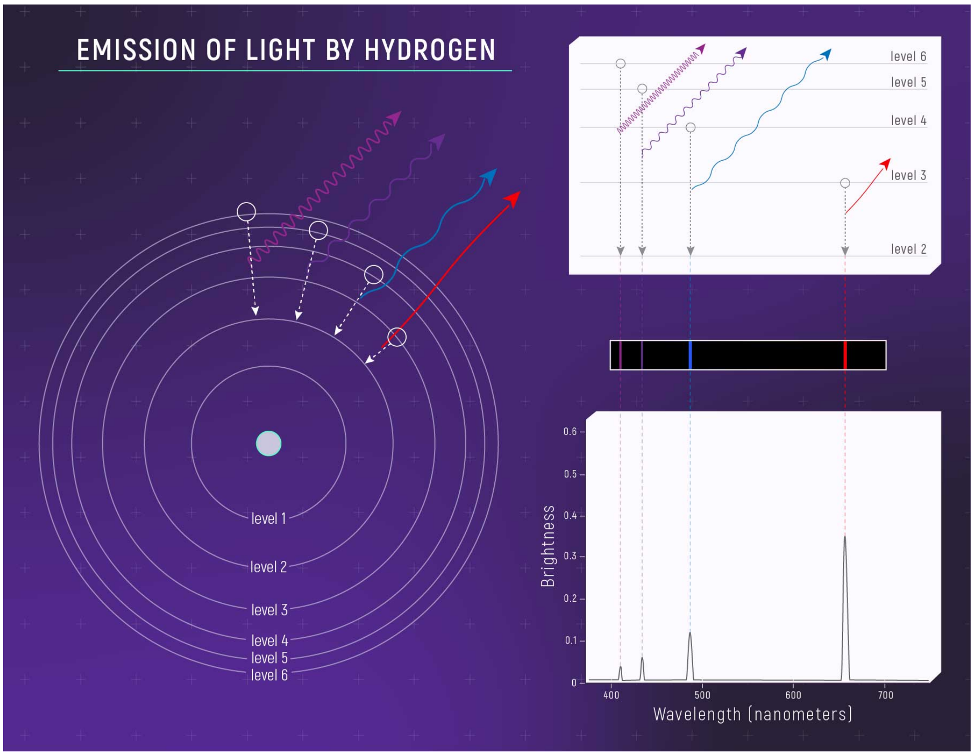


Figure 4.19: Emission of light by hydrogen atom (figure taken from web (last visited on 17/5/24))

Image description for participants: The figures on the right in 4.18 and 4.19 also depict absorption and emission line spectra for the hydrogen atom for discreet energy values specific to certain wavelength sections.

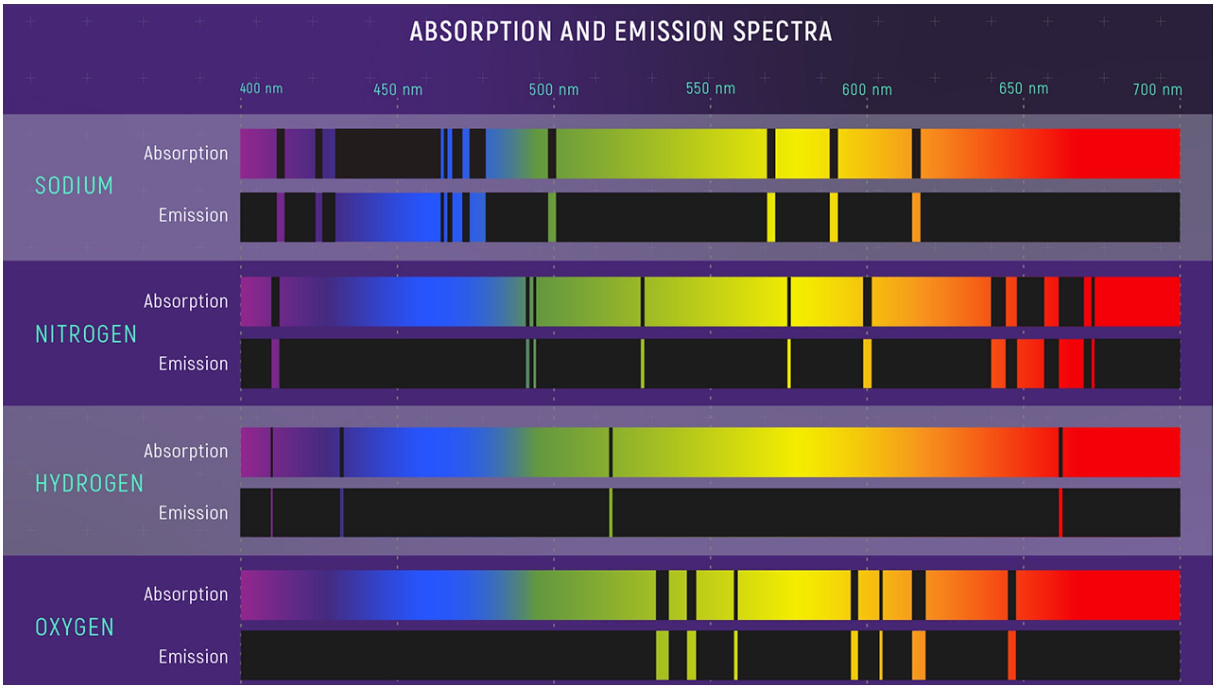


Figure 4.20: Line spectra (figure taken from lin (last visited on 17/5/24))

Image description for participants: The figure 4.20 shows four specific emission and absorption spectra for sodium, nitrogen, hydrogen, and oxygen. Each element has its own spectral line structure with distinct distances between the lines and a distinct number of lines, which allows for the identification of known chemical elements in an unknown object or gas composition.

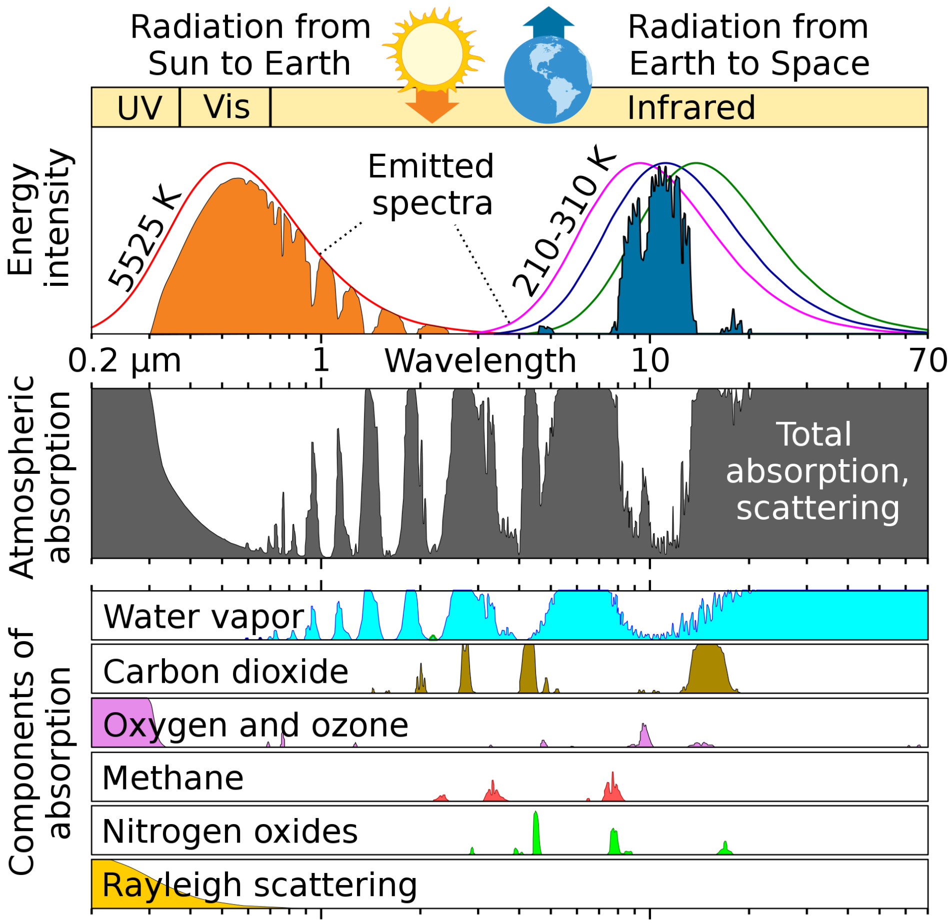


Figure 4.21: Atmospheric window (figure taken atm (last visited on 16/5/24b))

Image description for participants: The last figure in unit 5 deals with the phenomena of absorption. Figure 4.21 consists of three graphs each showing a different representation for the light spectrum on Earth.

The first graph depicts the received or emitted radiation versus the wavelength. It can be seen that the absorbed energy intensity from the sun is mainly in the visible range of the light spectrum, whereas the Earth's surface emits mainly in the infrared region of the spectrum.

Its second graph depicts the atmospheric absorption versus wavelength. It is shown that most of the Sun's UV radiation, parts of the near IR as well and microwave is absorbed by the Earth's atmosphere. At the same time, the visual and IR spectrum are transmitted.

The third graph shows the components of absorption, and the contribution of each to the overall absorption in the atmosphere: Water vapor is mainly responsible for the absorption of near IR and long-wavelength radio waves.

For the remaining components, carbon dioxide, oxygen and ozone, nitrogen oxides, and Rayleigh

scattering, it can be seen that they mainly contribute in blocking UV radiation and a small amount of the visual spectrum originating from the Sun. But, otherwise these components mainly absorb in the wavelength range in which Earth emits IR – heat radiation - back to space.
The figure helps deduce the fact that atmospheric components block the heat radiation on its way back to space.

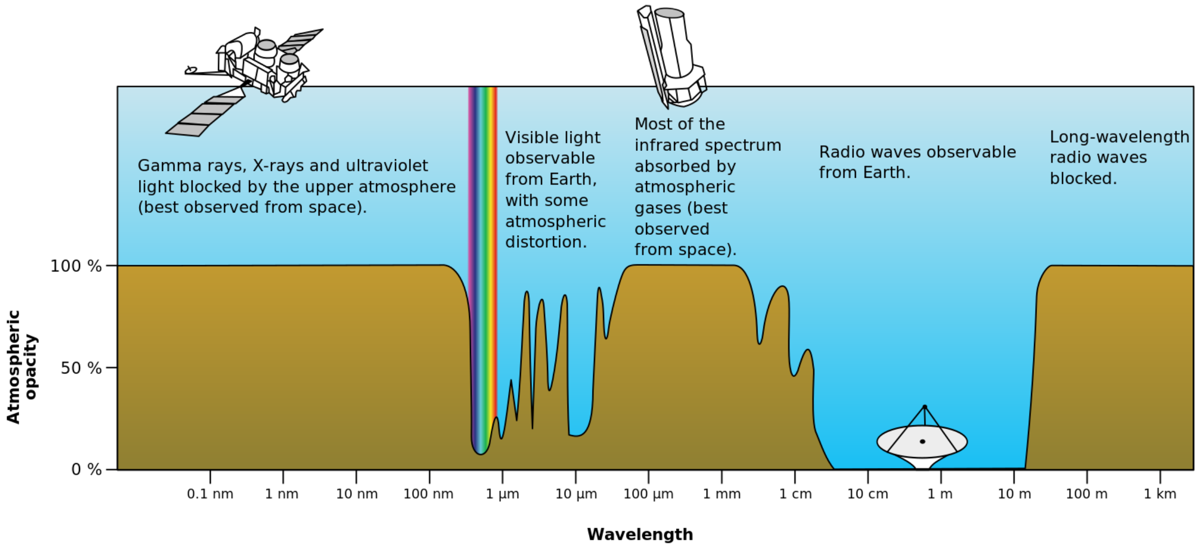


Figure 4.22: Electromagnetic transmittance, or opacity, of the Earth's atmosphere (figure taken atm (last visited on 16/5/24a))

Image description for participants: The figure 4.22 shows again the atmospheric absorption spectrum, only this time as atmospheric opacity as a function of the wavelength of incoming light. Telescope types used for observations are placed at the wavelengths for which they are generally operated.

Wished outcome for Unit 5

This unit's intention was to teach the origin of emission and absorption lines. Furthermore, the emission spectrum of the Sun and Earth, and the absorption spectra of Earth's atmosphere were introduced in order to transition to the topic of greenhouse gas absorption effects.

4.1.6 Unit 6: Greenhouse gas education

Guided tour 7

Starting the sixth day the group assembles in the PC room to begin the unit in front of the projector screen. The intention is to foster a deeper understanding of greenhouse gases and the phenomena of the greenhouse effect. Again, the lecturer uses mainly front-of-class presentation.

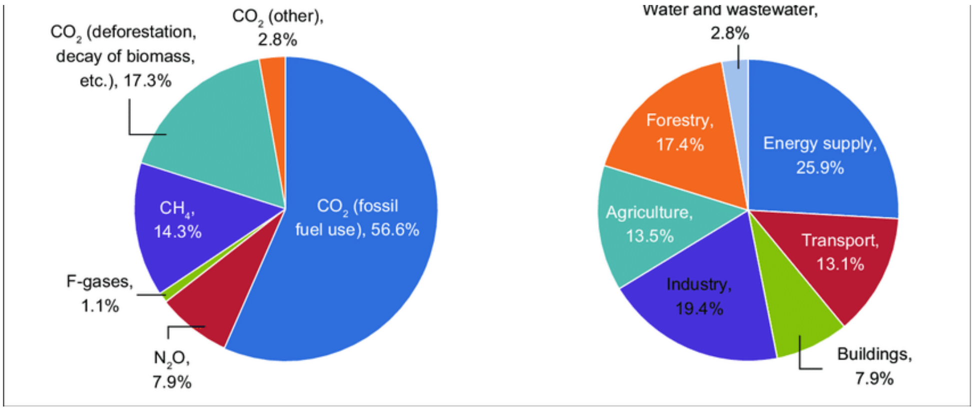


Figure 4.23: Proportion of anthropomorphic greenhouse gases (figure taken from ant (last visited on 17/5/24))

Image description for participants: Figure 4.23 depicts the ratios of anthropomorphic greenhouse gas types in Earth's atmosphere. The graph indicates that human civilization adds greenhouse gases to the atmosphere through different man-made sources.

The biggest contribution consists of 84% carbon dioxide, the other 16% are composed of the remaining greenhouse gases, methane, nitrous oxide, and fluorinated gases.

The important key point to take away from this figure is that human activities add a large share of greenhouse gases to Earth's atmosphere.

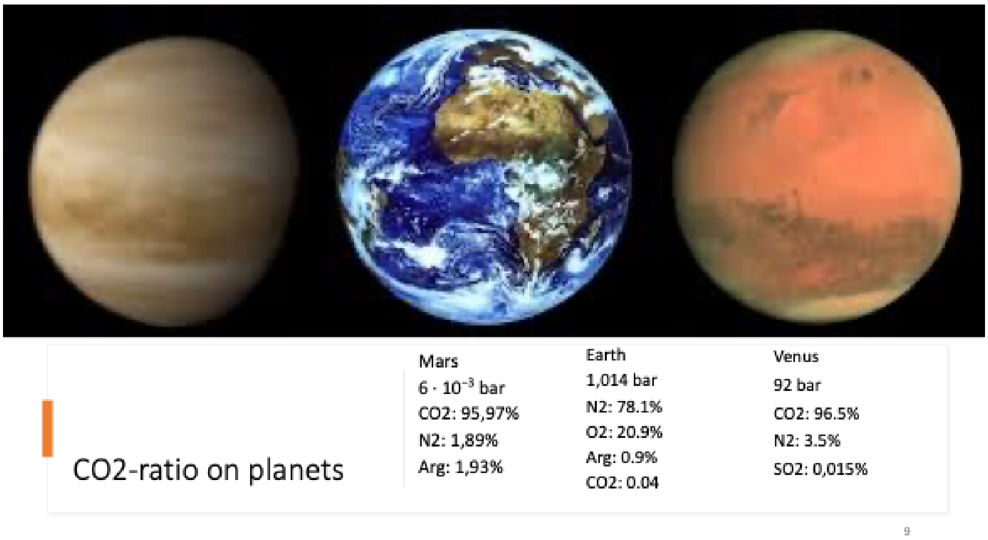


Figure 4.24: CO_2 ratio on planets Venus, Earth and Mars (figure taken from pla (last visited on 17/5/24))

Image description for participants: The figure 4.24 depicts the planets Venus, Earth and Mars, specifying their greenhouse gas and CO_2 ratio.

At this point it is essential to stress the role spectroscopic observations play in the determination of these planets' atmospheric compositions - as explained in 2.1.2.

It is seen that the planets have very different atmospheric pressures, varying surface temperatures, chemical compositions, and planetary gravitational pull on the atmospheres.

Earth's CO_2 share compared to the mass of atmosphere is at 0.05%, which is very small compared to Venus with 97%, and Mars' 95% CO_2 shares.

Venus with a surface temperature of more than 400° Celsius has a dense atmosphere consisting mainly of the greenhouse gas CO_2, which leads to a runaway greenhouse effect.

Mars has 95% of carbon dioxide in its atmosphere. Since the atmosphere is not well bound to the planet due to lower gravity, and is depleted by solar winds due to the lack of a global magnetic field, this leads to a surface temperature of minus 65° Celsius.

Compared to non-habitable temperatures on Mars and Venus, Earth has a moderate average temperature surface of 15° Celsius, which is due to its more moderate greenhouse effect, a consequence of the smaller amount of greenhouse gas concentration in its atmosphere.

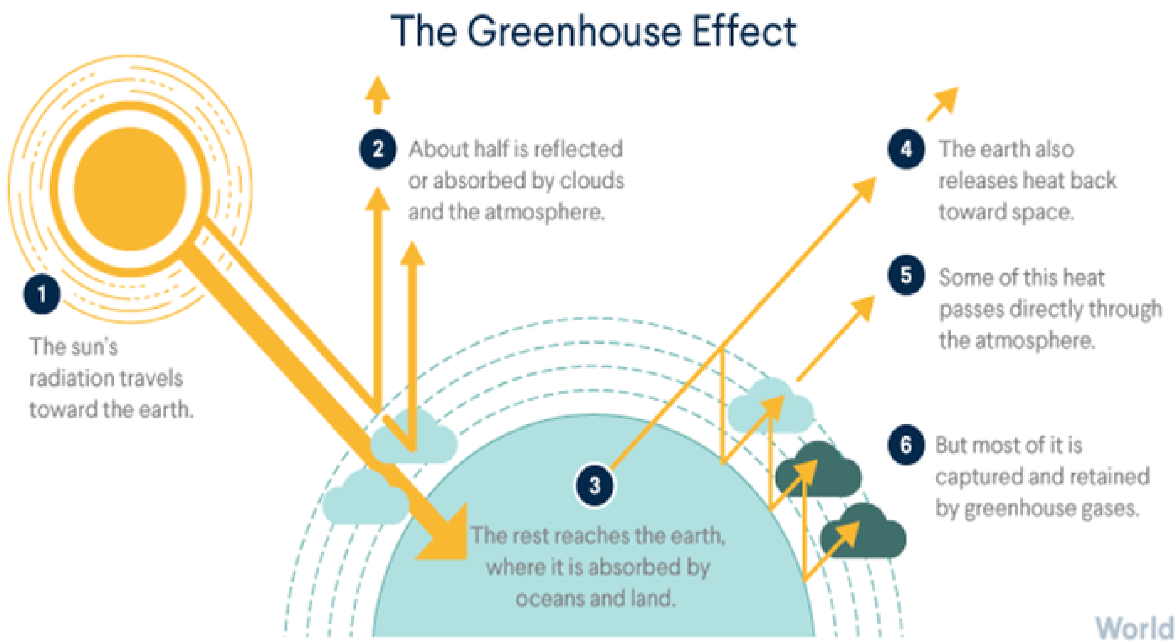


Figure 4.25: The natural greenhouse effect(figure taken from gre (last visited on 16/5/24))

Image description for participants: The greenhouse effect is described in figure 4.25. It illustrates the six main stages for the greenhouse gas effect, as depicted in the paragraph below: *"The greenhouse effect is a natural process responsible for keeping the earth at the temperature needed to sustain life. Acting just like the glass walls of a greenhouse, gases like carbon dioxide, methane, and nitrous oxide trap the sun's heat in the atmosphere and prevent it from escaping into space. About half of the sun's radiation that travels toward the earth never makes it to the earth's surface. Clouds and the atmosphere reflect about one-third of the radiation back toward the sun, and they also absorb another 20 percent. The rest of the radiation—about 50 percent—reaches the earth, where it is absorbed by oceans and land. This keeps the earth warm and sustains plant, animal, and human life. The earth also releases heat back toward space. Some of this heat passes through the atmosphere, but most of it is captured and retained by greenhouse gases before it can escape. This is the mechanism that keeps the earth warm.*
Normally, the greenhouse effect keeps the earth just warm enough to sustain life. Scientists say that without the greenhouse effect, the average temperature of the earth would drop to as low as -18 ° C (0 ° F), compared to the twentieth-century average of 14 ° C (57 ° F).
The greenhouse effect has supported life on the earth for millions of years." The (last visited on 09/17/23)

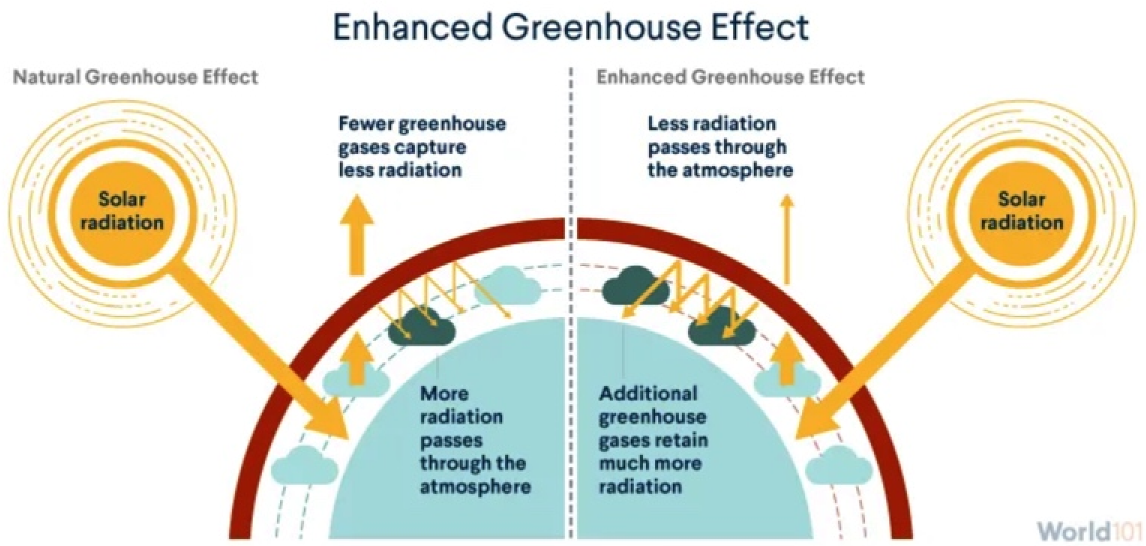


Figure 4.26: The enhanced greenhouse effect(figure taken from gre (last visited on 16/5/24))

"Today, however, the greenhouse effect is growing stronger as human activities such as deforestation and fossil fuel use release more and more greenhouse gases into the atmosphere. This traps greater amounts of the sun's radiation, which contributes to rising temperatures, also known as global warming." The (last visited on 09/17/23)

Citing the United States Environmental Protection Agency it is to be noted, that the greenhouse gas methane contributes to the anthropomorphic greenhouse effect to the extent of approximately 20% due to its high potency (25 times more effective than CO_2). Its atmospheric lifetime is significantly shorter than that of CO_2, ranging from 9 to 15 years, with an average atmospheric residence time of 12 years. Nitrous oxide N_2O is a greenhouse gas with a greenhouse potency that is 298 times greater than that of CO_2 and with an average atmospheric residence of 114 years. CO_2, on the other hand, has an average atmospheric residence time of approximately 120 years.

Even though all three greenhouse gases are very problematic, the longevity of CO_2 coupled with its abundance in the atmosphere makes it the main culprit concerning increased global warming.

Wished outcome for Unit 6

This unit's intention is to explain the greenhouse gas effect on planets, and how it entails a warming effect in a planet's intact atmosphere due to the surface's re-emission and the atmosphere's re-absorption of infrared radiation.

4.1.7 Unit 7: Consequences of the Greenhouse Effect

Open discussion

In the seventh unit the three hours are spend on a discussion about the consequences of global warming (Masson-Delmotte et al., 2021; Hayden, 2004). The inducement of droughts, floods, the rising sea levels, hurricanes, and ensuing effects on human and societal life are to be discussed (Jones, 2019; Solomon, 2007). One subject that should be stressed are the human, but also economic costs of natural disasters for every society (Storksdieck and Stylinski, 2010).
In conclusion to this subject, it can be discussed, that developing countries often pay a comparatively high price for global warming, since their infrastructure does not have the necessary quality to withstand most disasters nor are the funds for proper repairs accessible.
The next discussed subject is on jobs located in the academic and industrial fields tackling the effects of the greenhouse effect. Scientific research on environmental conditions made by chemists, biologists, geologist, mathematicians, meteorologists, and physicists should be talked through. Also the necessary networking on this serious subject done by activists and non governmental institutions should be considered (Edwards, 2013; Burroughs, 2007).
The attention should be placed on an open discussion between participants and the lecturer, recaping the past units and their conclusions, addressing personal reflections on what was learned and asking remaining, unanswered questions.

Wished outcome for Unit 7

The important message to take away for everyone is the connection between research questions on planetary parameters such as atmospheric compositions, and how to derive consequences for the habitability of a planet from this information.

4.1.8 Unit 8: Collective Brainstorming

The proper time for a feedback

The 8th unit is meant to give the participants time to fill in the feedback form on the program's impact. Also, the discussion on the forthcoming excursions set for the following two days is scheduled. In this context the students are informed of the planned activities - described in the next units. Especially, the collectively prepared questions for an hour long talk with astronomy researchers are to be formulated in groups, and then presented and discussed together.

Wished outcome for Unit 8

As this unit 8 is the last one held in school, it is time to prepare the end of the program and clean the used locations, such as the PC room and the physics lab. The participants should leave the class room with anticipation for the prospective excursions.

4.1.9 Unit 9: Group excursion 1

Deep Sky Show at the Planetarium Wien

On the 9th day of the astronomy program the group visits the Viennese Planetarium in the capital's former imperial hunting area called "Der grüne Prater". The planetarium is financed and led by the Community college of the Austrian state of Vienna. It contains a 3D dome representing animations of planets, stars and other cosmic phenomena. While the animated show is running on an electronic system simulating the night sky, scientists specializing on science communication give narrated tours for visitors. It is a very special experience to make with younger participants. The show viewed by the group is on the subject: "About the Life of Stars". It is intended for visitors starting at the age of 14 years and up, and has a duration of 50 minutes.

The next paragraph cites a translation of the shows description given by the Vienna Planetarium: "Stars are the sources of light in the universe! They produce energy within their core, illuminating the darkness of the cosmos. On a clear night, we see thousands of twinkling points of light in the sky. However, when we look deeper into the universe's darkness, a myriad of bizarre shapes and structures reveal themselves: the Deep Sky Objects. Many of these cosmic jewels bear witness to the birth, life, and death of stars. We visit the most beautiful examples and explore the question of what happens to a star throughout its life. - A production of the Vienna Planetarium."

Figure 4.27: Planetarium der Stadt Wien - Zeiss Planetarium (figure taken zei (last visited on 17/5/24))

Wished outcome for Unit 9

As unit 9 is held in a location for science communication on astronomy, its goal is the increase of knowledge on astronomical subjects.

4.1.10 Unit 10: Group excursion 2

Guided Tour at the Institute for Astrophysics and Telescopic Dome at the Sternwarte Park

The 10th, and last day of the program, was spent at the Sternwarte Park (Observatory Park) at the outskirts of Vienna. In the centre of this park is situated the beautiful building of the observatory which from the beginning accommodates the university's Institute for Astronomy with its many observatory towers.

Figure 4.28: Universitätssternwarte Wien - Institut für Astrophysik (figure taken from Uni (last visited on 17/5/24))

The extensive tour was organized by the institute's science communication team leader. This paragraph cites the institute's public relations mission: "The science communication team at the Institute for Astrophysics is responsible for making astronomical knowledge accessible to a broader audience. Its main objectives are the communication of new results and projects being conducted by the various research groups, carrying out projects to bring astronomical research closer to people, and promoting the participation of children and disadvantaged groups in STEM fields." (Taken from the homepage of the Astrophysics Institute of Vienna)

Meet and Greet with astronomers

The excursion was set for two hours. At first, the group visited a guided tour through the historical building and its ancient observatory dome led by a scientist from the institute. After that, took place the meet-and-greet with two astronomy researchers ready to answer every question the young participants threw at them.
The participants were given the opportunity to ask questions they had thought up themselves.

For this occasion a question catalogue was prepared in a group preparation, see 7.1. The questions reflect a real interest for astronomical research.
As could be observed by the lecturer, some of the questions regard topics that were touched on lightly in the units, but many arose from the curiosity of the participants.
The participants used the meet-and-greet to connect their cognitive maps: creating a red thread for the new knowledge they had recently acquired and connecting it to prior existing believe systems or information they had already been exposed to.
The next paragraph shows the participants' questions - translated into English. To view the original hand-written catalogue please refer to the appendix 7.1.

Hand-written question catalogue for the meet-and-greet with astronomers

- "How can one see dark matter?"
- "If there are many hot stars, why is the universe cold?"
- "Why is the universe constantly expanding?"
- "If you work a lot with stars, do you believe in astrology?"
- "Do cold stars exist?"
- "Do you believe we originated from nature or do you believe in the story of Adam and Eve?"
- "Do you know when and how the Earth will end?"
- "Is there extraterrestrial life?"
- "Have space rockets and Elon Musk changed anything?"
- "Is it possible to travel to other planets?"
- "Will humans fly to Mars by 2025?"
- "Is it possible for a new planet to form in our solar system?"
- "Is a moon landing possible?"
- "What is the significance of the cosmic microwave background radiation?"
- "What is the evidence for the Big Bang?"
- "Can nuclear energy destroy the Earth?"
- "Are there other universes besides ours?"

- "Can you fly away from Earth in all directions?"
- "Are there more Earth-like planets?"
- "What is the evidence for the existence of dark matter?"
- "Is it possible for humans to live on another planet?"
- "Do you believe there is a God in the universe?"

Wished outcome for Unit 10

As unit 10 is the grand finale for an intensive two week outreach program on astronomy, the goal is the rapprochement of the students to the source of this science, namely its scientists in their natural working environment. Thereby, promoting the participants inquiring mind and exploratory spirit.

5. Data Analysis

5.1 Analysis of quiz data and student feedback

5.1.1 Framework

Within the section the multiple choice quizzes (MCTs) are analyzed. Each quiz - meant to evaluate the participants knowledge on a distinct unit - was conducted once before the start of the respective lesson unit, and then once on the following day, approximately 24 hours after being exposed to the content.

For a review of the detailed design, quiz questions and answer options of the MCTs please refer to the Evaluation section 3.

MCT evaluation structure

In the following subsections the raw data gained from the MCTs is presented in table form. Each MCT consisted of ten questions with respectively three answers to select from. Each MCT contained approximately 15 possible correct or wrong answers - 30 in total. The green colored cells correspond to the correct answers for each question. The number given in the cells corresponds to the amount of ticked questions by participants. Important to note is that in the pre-lesson and post-lesson MCTs the number of present participants varied sometimes due to absentees.

Positive/Negative marking

The raw data of the MCTs was analyzed in two different ways.

The first was the positive marking method, which consists of counting each correct answer with a point. Unanswered questions and wrong answers do not score anything.

The second was the negative marking method, which consists of only counting wrong answers. This principle is called correction for guessing.

The corresponding graphs depict the sum of all correct/wrong answers given in the MCTs, which were conducted once before and once after each unit.

The horizontal axis corresponds to the ID for each correct/wrong answer. The vertical axis corresponds to the number of correct/wrong answers. The blue line depicts the answers given before being exposed to the outreach programs' content. The red line indicates the answers given the next day after being exposed to the content.

At the end of each unit, the fraction of correct and wrong answers is given, and the absolute change thereof. The fraction of correct answers was calculated as follows:

$$fraction\,of\,correct\,answers = \frac{\sum correct\,answers\,given}{number\,of\,participants * number\,of\,correct\,answers} \tag{5.1}$$

Likewise the fraction of wrong answers was calculated with the sum of all wrong answers given, and divided by the total number of wrong answers possible.

The graph depicting the amount of right answers has a white background, whereas the graph showing the amount of wrong answers has a black background.

5.1.2 Results

Unit 1

Unfortunately, due to human error the printed form of the pre- and post-lesson MCTs were not identical. Therefore, no data can be analyzed for unit 1.

Unit 2

Number of participants before lesson: 12; after lesson:10

Answers for Unit 2							
Questions	answer1_before	answer2_before	answer3_before	Questions	answer1_after	answer2_after	answer3_after
q1	7	6	6	q1	1	1	8
q2	7	5	0	q2	0	10	0
q3	2	5	5	q3	5	6	2
q4	7	0	8	q4	7	0	7
q5	7	4	2	q5	3	0	9
q6	6	0	6	q6	6	1	5
q7	6	4	5	q7	6	0	3
q8	2	10	0	q8	5	8	3
q9	3	2	9	q9	6	1	9
q10	1	5	7	q10	0	7	9

Figure 5.1: Unit 2 raw data

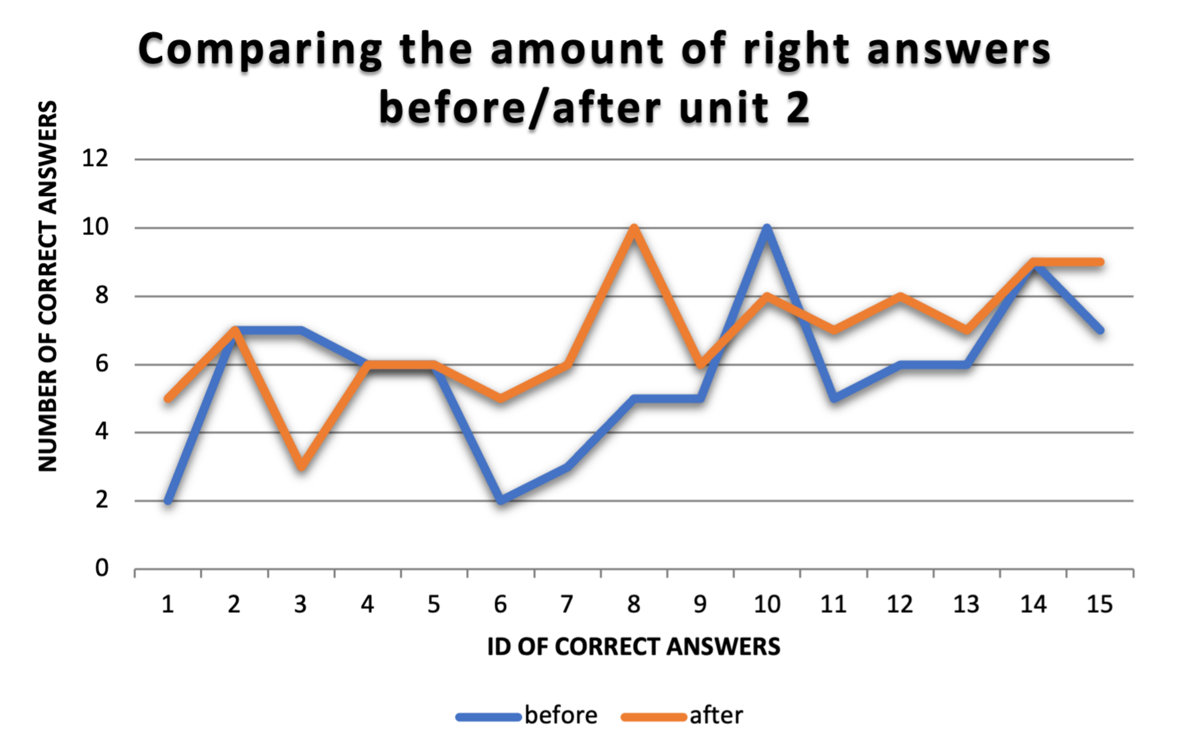


Figure 5.2: Right answers for unit 2 before and after

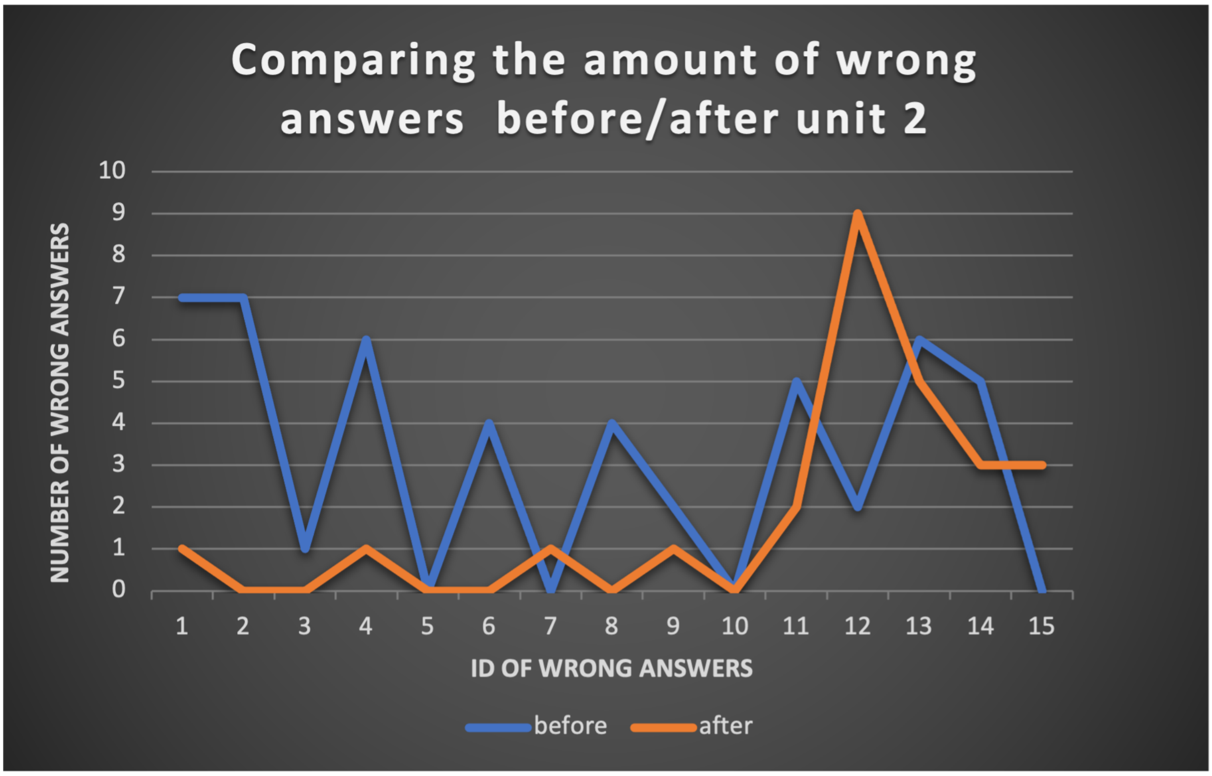


Figure 5.3: Wrong answers for unit 2 before and after

The fraction of correct answers before was 48,9%, and after 68%, respectively. This corresponds to an absolute gain in correct answers of 19,1%. The fraction of wrong answers before was 27.2%, and after 17,3%, respectively. This corresponds to an absolute reduction in wrong answers of 9,9%.

Unit 3

Number of participants before: 10; after:8

Answers for Unit 3							
Questions	answer1_before	answer2_b	answer3_before	Questions	answer1_after	answer2_after	answer3_after
q1	0	8	2	q1	0	8	0
q2	7	5	0	q2	7	6	5
q3	1	0	7	q3	0	0	8
q4	3	5	2	q4	8	1	0
q5	7	1	1	q5	8	0	0
q6	4	1	4	q6	8	3	0
q7	1	4	4	q7	0	0	8
q8	5	4	1	q8	8	0	0
q9	0	5	4	q9	0	1	7
q10	2	1	6	q10	1	1	7

Figure 5.4: Unit 3 raw data

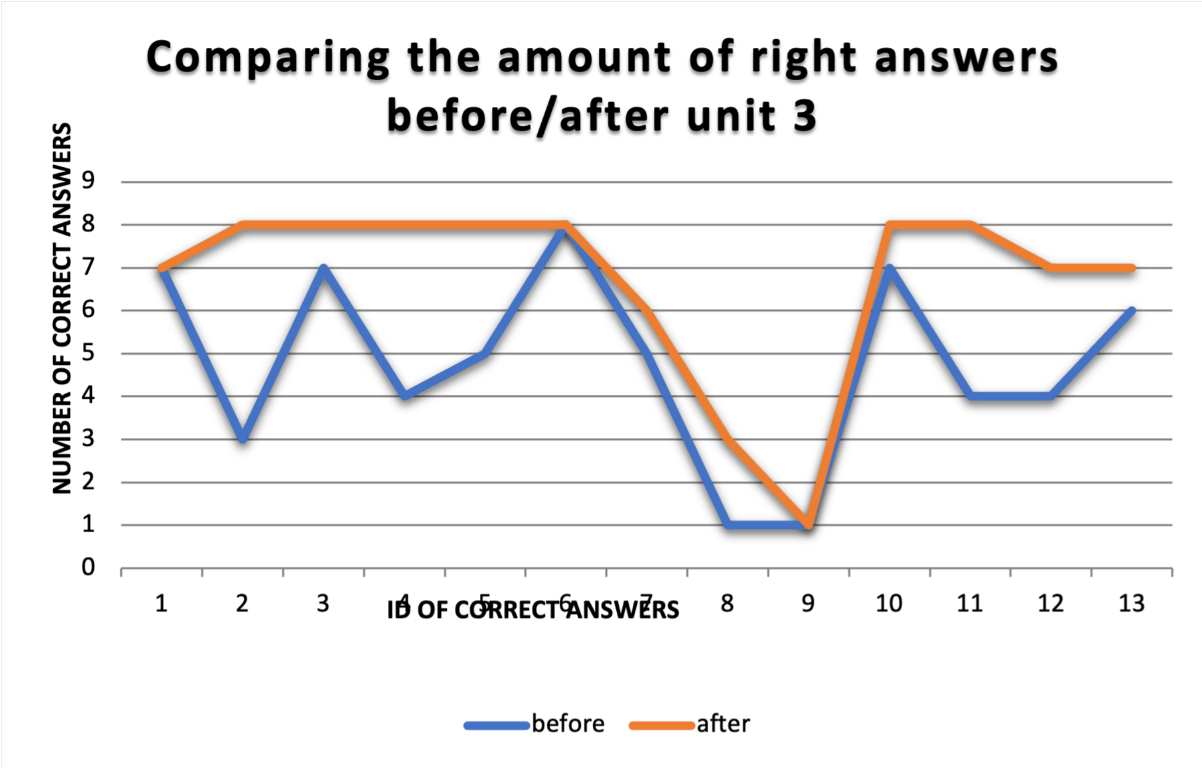


Figure 5.5: Right answers for unit 3 before and after

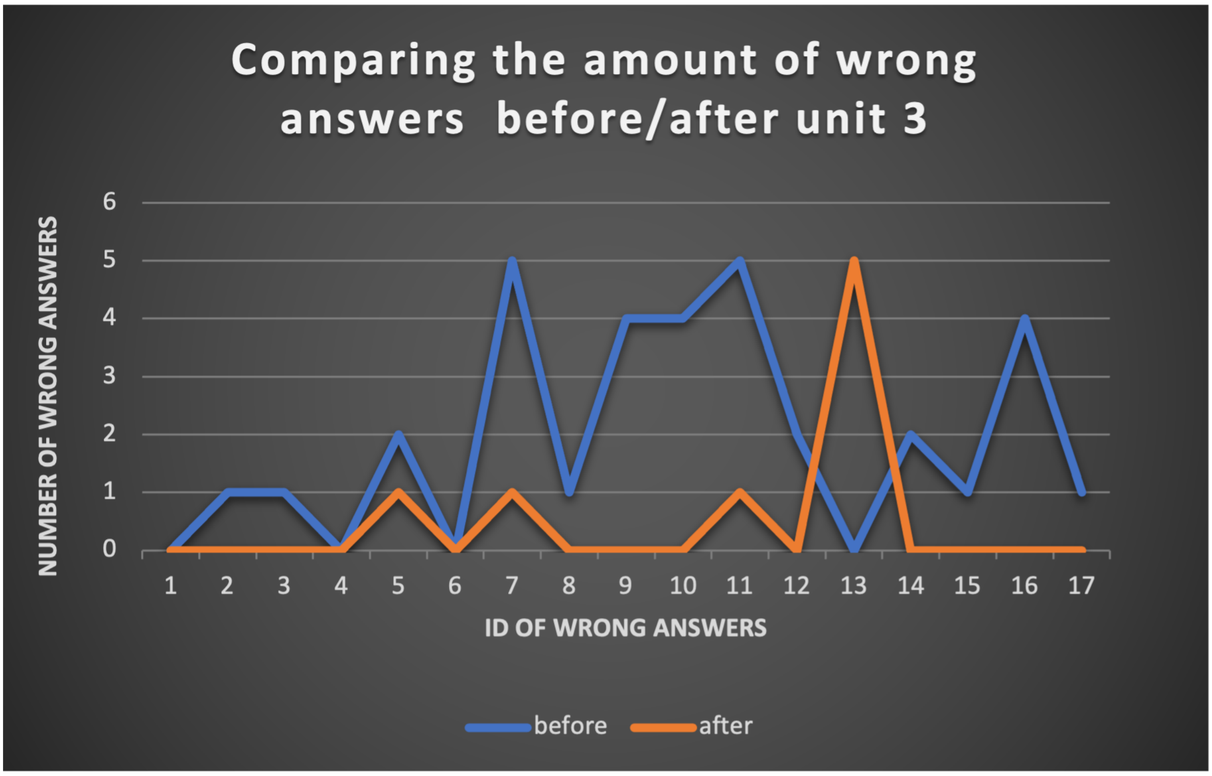


Figure 5.6: Wrong answers for unit 3 before and after

The fraction of correct answers before was 47,7%, and after 83,7%, respectively. This corresponds to an absolute gain in correct answers of 36%. The fraction of wrong answers before was 19,4%, and after 5,9%, respectively. This corresponds to an absolute reduction in wrong answers of 13,5%.

Unit 4

Number of participants before: 10; after:10

Answers for Unit 4							
Questions	answer1_before	answer2_b	answer3_befor	Questions	answer1_after	answer2_after	answer3_after
q1	3	5	2	q1	0	10	0
q2	3	7	0	q2	0	10	0
q3	5	5	3	q3	8	10	2
q4	3	5	4	q4	0	0	10
q5	6	3	1	q5	9	1	0
q6	3	5	1	q6	0	1	8
q7	5	3	3	q7	0	10	0
q8	6	4	2	q8	1	9	0
q9	6	5	1	q9	2	2	6
q10	2	4	4	q10	0	0	10

Figure 5.7: Unit 4 raw data

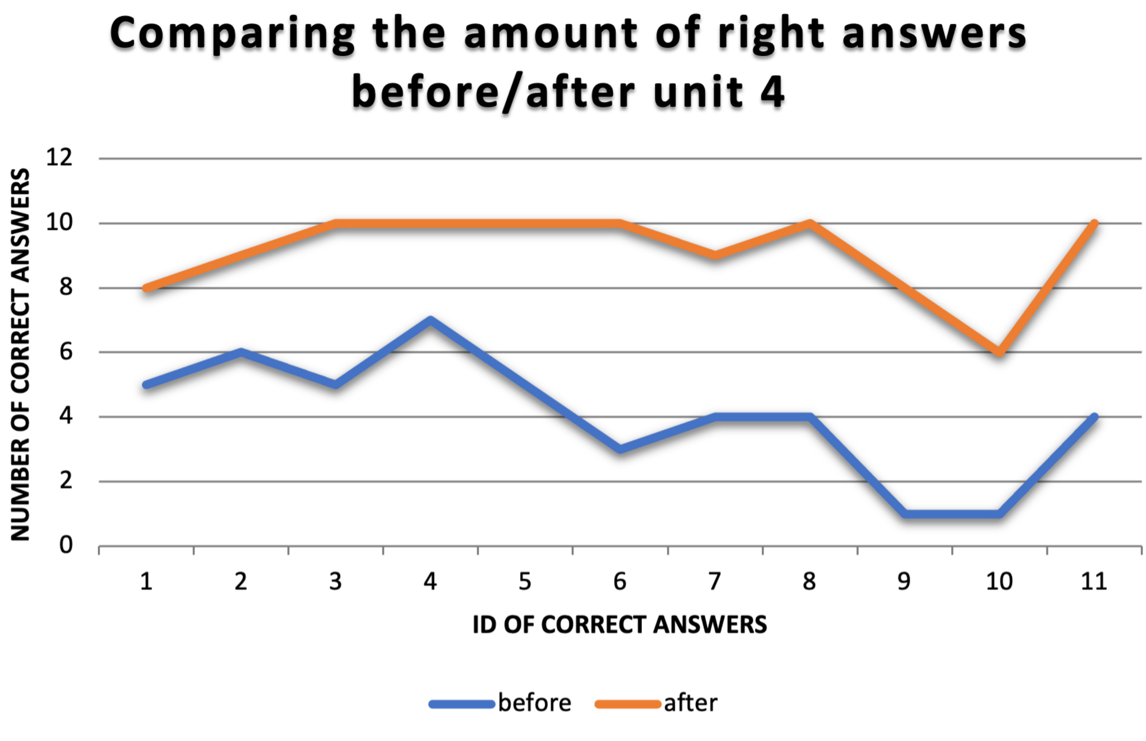


Figure 5.8: Right answers for unit 4 before and after

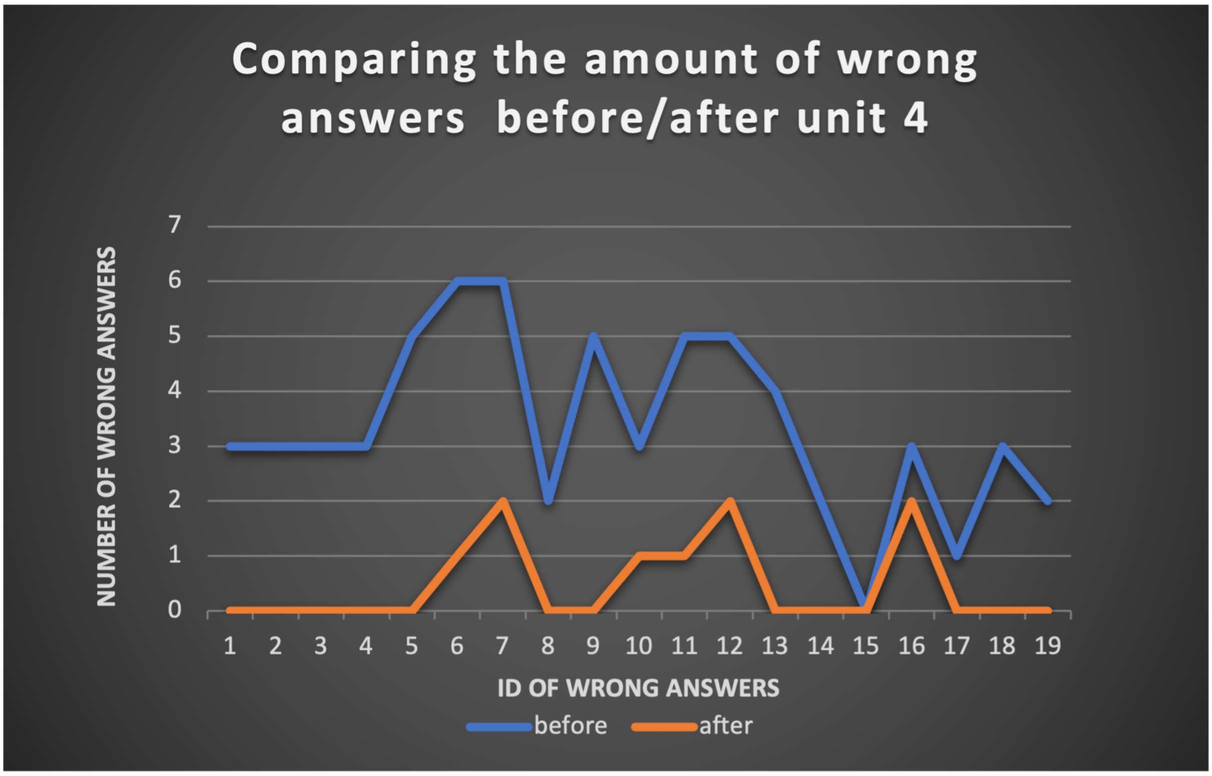


Figure 5.9: Wrong answers for unit 4 before and after

The fraction of correct answers before was 40,9%, and after 90,9%, respectively. This corresponds to an absolute gain in correct answers of 50%. The fraction of wrong answers before was 33,7%, and after 4,7%, respectively. This corresponds to an absolute reduction in wrong answers of 28,9%.

Unit 5

Number of participants before: 10; after:10

Answers for Unit 5							
Questions	answer1_before	answer2_before	answer3_before	Questions	answer1_after	answer2_after	answer3_after
q1	7	1	2	q1	10	0	0
q2	3	7	1	q2	0	9	1
q3	3	2	5	q3	0	10	0
q4	5	3	2	q4	0	0	10
q5	4	5	1	q5	8	1	1
q6	5	4	1	q6	1	1	9
q7	6	4	1	q7	0	6	9
q8	2	3	6	q8	5	7	7
q9	5	3	2	q9	2	1	6
q10	1	5	4	q10	6	1	7

Figure 5.10: Unit 5 raw data

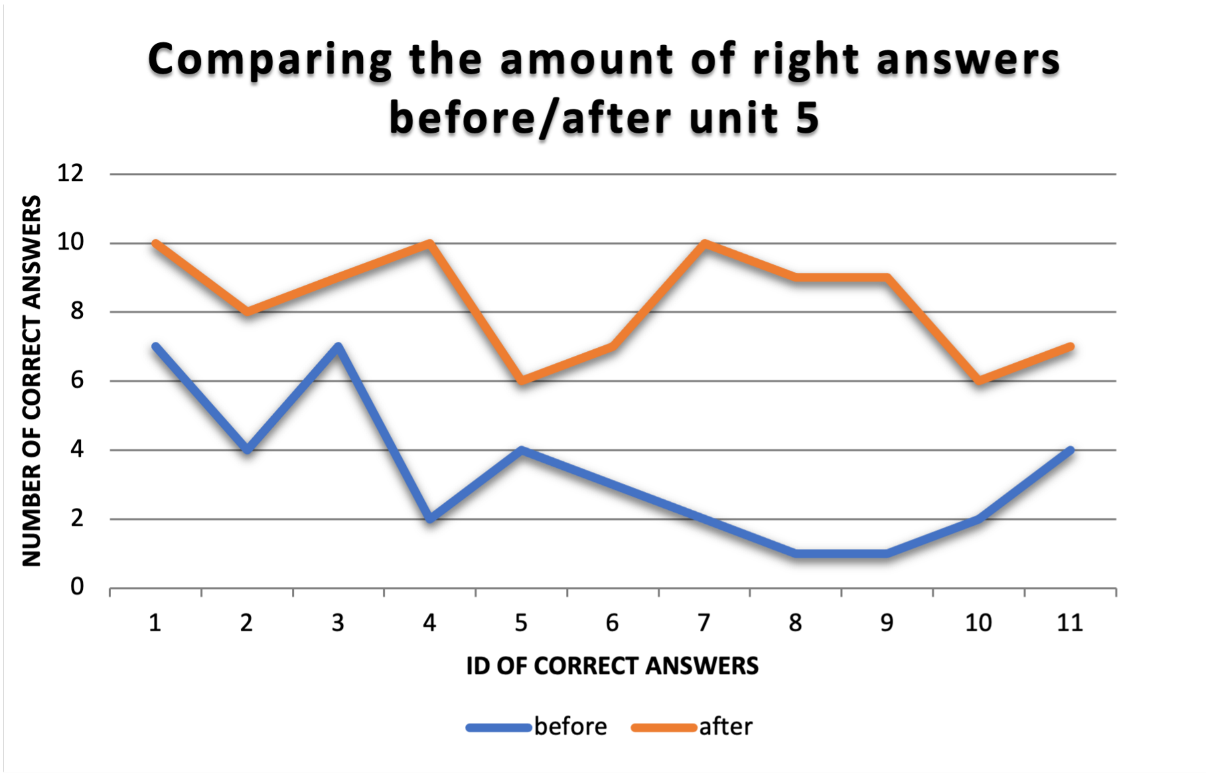


Figure 5.11: Right answers for unit 5 before and after

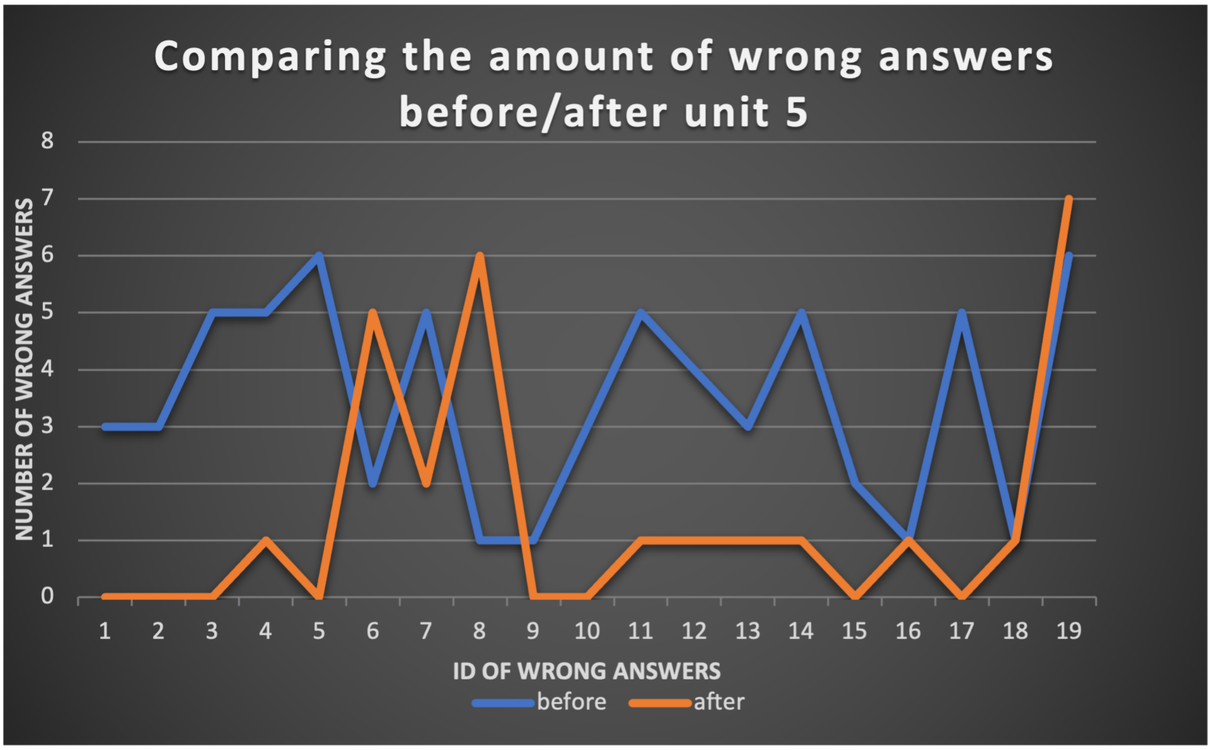


Figure 5.12: Wrong answers for unit 5 before and after

The fraction of correct answers before was 33,6%, and after 82,7%, respectively. This corresponds to an absolute gain in correct answers of 49,1%. The fraction of wrong answers before was 34,7%, and after 14,2%, respectively. This corresponds to an absolute reduction in wrong answers of 20,5%.

Unit 6

Number of participants before: 11; after:9

Answers for Unit 6							
Questions	answer1_before	answer2_before	answer3_bef	Questions	answer1_after	answer2_after	answer3_after
q1	5	1	5	q1	0	0	9
q2	3	9	1	q2	7	6	5
q3	2	4	6	q3	0	0	9
q4	2	5	4	q4	7	3	1
q5	8	3	0	q5	0	2	7
q6	3	4	3	q6	1	2	6
q7	6	2	2	q7	7	3	0
q8	3	7	0	q8	0	8	1
q9	6	3	1	q9	6	3	6
q10	4	3	5	q10	0	9	0

Figure 5.13: Unit 6 raw data

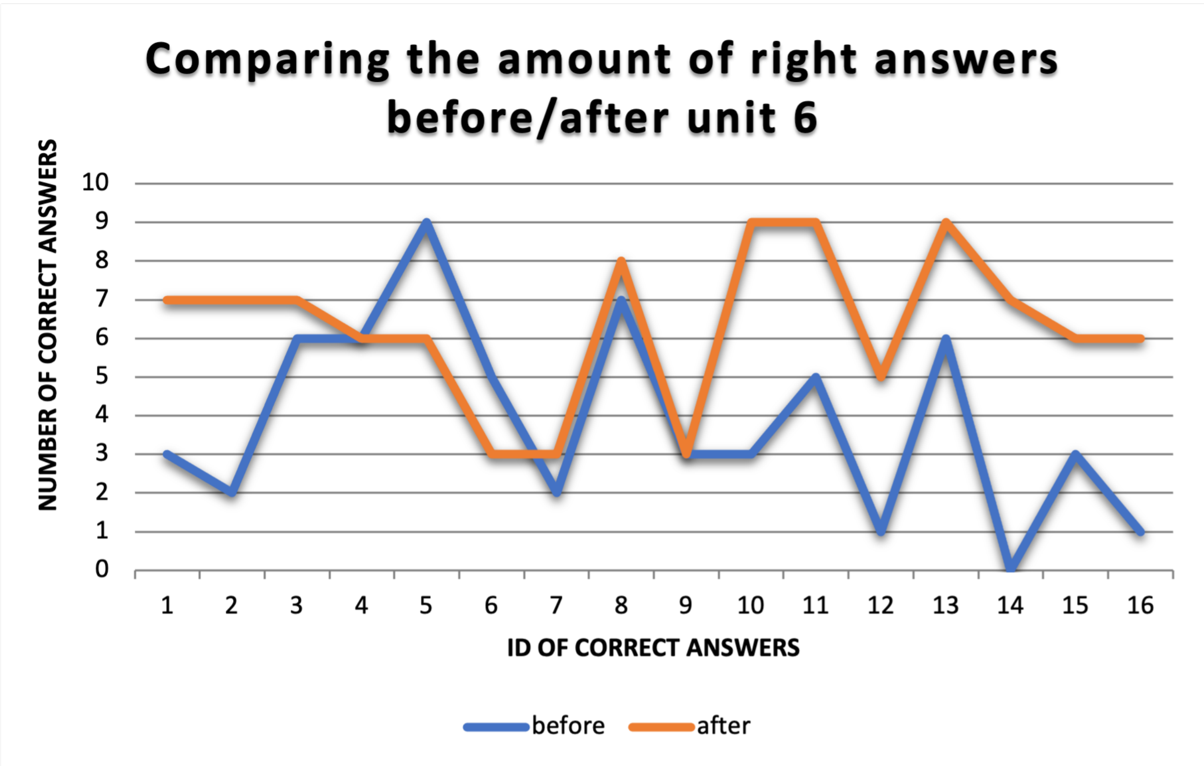


Figure 5.14: Right answers for unit 6 before and after

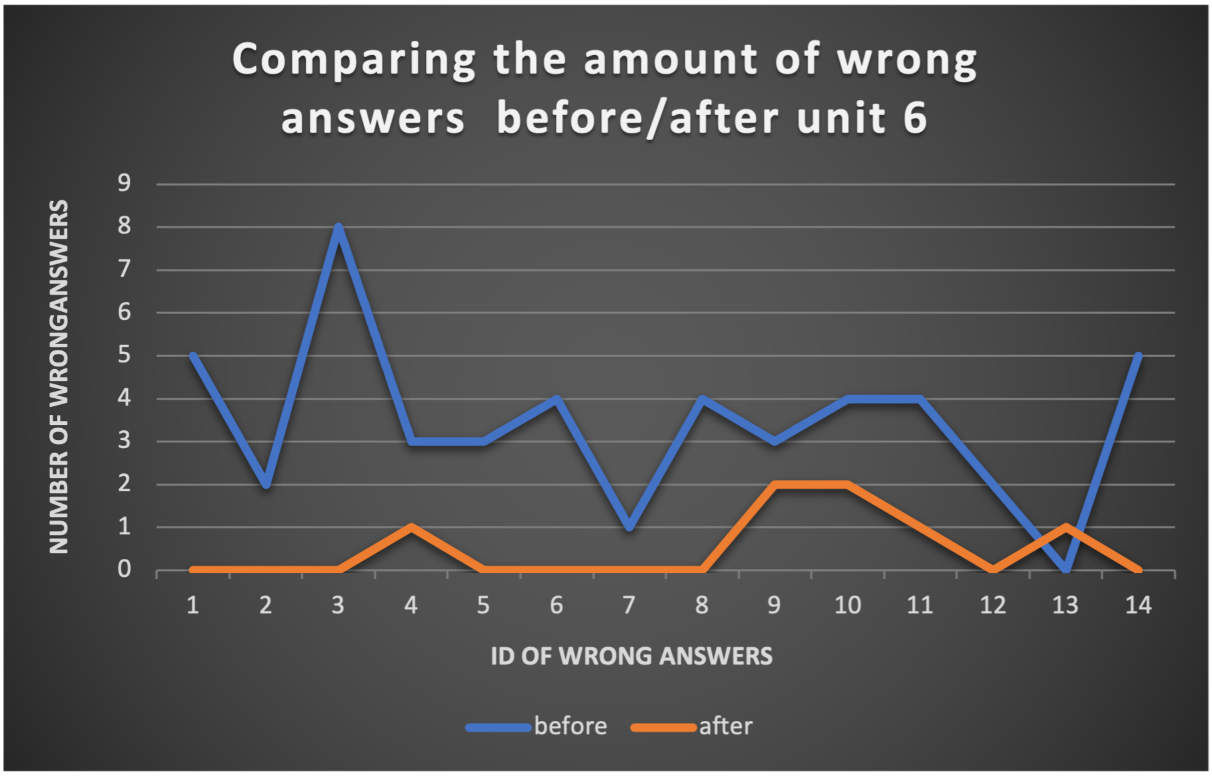


Figure 5.15: Wrong answers for unit 6 before and after

The fraction of correct answers before was 35,2%, and after 70,1%, respectively. This corresponds to an absolute gain in correct answers of 34,9%. The fraction of wrong answers before was 31,2%, and after 5,6%, respectively. This corresponds to an absolute reduction in wrong answers of 25,6%.

Thematic analysis of student feedback

The student feedback form contained 25 questions with a mix of ranking system questions and open questions. The feedback questions as well as the participants answering-behavior can be viewed in the tables below 5.16 and 5.17.

Most questions were given three possible answers to chose from, except for question 1 and question 17, which had a fourth possible answer. This explains all the empty gaps in the column for 'Answer 4' in 5.17.

Question number	Participant Feedback Questions
q1	Would you like to conduct more experiments or participate in scientific projects?
q2	Did you become even more interested in the universe, stars, and planets after the course?
q3	Is there a scientific topic from the course that you would like to learn more about in your free time?
q4	Could you imagine having a career related to natural sciences in the future? If so, which one? Why or why not?
q5	Did you enjoy the astronomy project?
q6	Do you feel more informed about natural sciences after the project?
q7	Did you learn something new and interesting during the project?
q8	Do you feel like you were able to understand the content well?
q9	How well was the course instructor able to answer your questions?
q10	How likable and competent did you find the course instructor?
q11	Did the course motivate you to learn more about natural sciences?
q12	How did you like the atmosphere during the course?
q13	How did you like the practical experiments and activities in the project?
q14	Can you apply what you've learned in your future life?
q15	Would you recommend the course to your friends?
q16	Would you recommend the course to adults in your life?
q17	Did you find the course schedule and duration suitable?
q18	Were modern technologies (such as computers, apps, online platforms) used effectively in the course?
q19	Were there enough opportunities to interact and collaborate with other course participants?
q20	Would you like to attend another natural science course on a different topic?
q21	What did you like most about the course?
q22	What do you think could be improved in the course?
q23	Did the course help you gain a better understanding of scientific topics?
q24	Did the course open up new perspectives or interests in the field of natural sciences?
q25	How satisfied are you overall with the astronomy project?

Figure 5.16: Questions from feedback form

Participant Feedback				
Questions	Answer 1	Answer 2	Answer 3	Answer 4
q1	46,2%	23,1%	30,8%	0,0%
q2	76,9%	0,0%	23,1%	
q5	92,3%	7,7%	0,0%	
q6	69,2%	0,0%	30,8%	
q7	100,0%	0,0%	0,0%	
q8	92,3%	0,0%	7,7%	
q9	61,5%	38,5%	0,0%	
q10	100,0%	0,0%	0,0%	
q11	69,2%	0,0%	30,8%	
q12	92,3%	7,7%	0,0%	
q13	92,3%	0,0%	7,7%	
q14	92,3%	0,0%	7,7%	
q15	100,0%	0,0%	0,0%	
q16	84,6%	7,7%	7,7%	
q17	69,2%	0,0%	15,4%	15,4%
q18	92,3%	0,0%	7,7%	
q19	92,3%	0,0%	7,7%	
q20	38,5%	0,0%	61,5%	
q23	92,3%	0,0%	7,7%	
q24	61,5%	7,7%	30,8%	
q25	92,3%	7,7%	0,0%	
note: q3,q4,q21,q22 were answered by text (information not in table)				

Figure 5.17: Feedback evaluation

Noticeably, there is a general tendency for a favourable perception of the two weeks outreach program. Certain questions stand out by the unanimously positive feedback - yellow colored. Question 7 and question 15 got a 100% evaluation, representing the participants high interest for the project topic and a readiness to recommend the outreach project to peer-friends.

A little drop of bitterness was the general answer to question 20 - orange colored - , which asks about the students willingness to participate in another natural science course on a different topic. To this question more than 60% gave the third answer, stating that they did not know whether they wanted to or not. On the other hand, 0% chose the second answer to the same question, which would have been a decisive no.

Overall, the very positive feedback to questions 5, 8, 12, 13, 14, 18, 19, 23 and 25 - dark green colored - give the impression that the young participants enjoyed the project all together, found themselves in a good environment, where they were exposed to sensible and practical knowledge, also applicable to their further life choices.

The methods were generally felt to be engaging, and the self-assessment of their improved scientific literacy was satisfactory 5.17.

The four questions not represented in the statistical evaluation are questions 3, 4, 21 and 22 in 5.16, since they were open questions for written text answers. Associated results are presented next.

In this context, topics of further interest to the participants were dark matter, stars, exoplanets, planets in general, galaxies, natural sciences, renewable energies and engineering.

The few participants who had a wish for later work-experience in a scientific field wrote that medicine, physics, biology and engineering were of interest to them.

The best thing about the project to the participants were the topics on stars, planets, and astronomy in general.

Recommendations for improvement included the wish for a more extended duration of the project, time for more detailed explanations, as well as the note that the repeated use of Power Point presentations in a darkened room made some students feel sleepy.

Beside these helpful remarks, the overall entries were stating that the two weeks project had been a good experience for the participants.

5.1.3 Findings and Discussion

Interpretation of findings in relation to the aims of the project

Overall, the evaluation shows very positive results.

The average over all units of correct answers increased from 41,3% before to 79,1% after, corresponding to an absolute increase of 37,8%.

The average of the wrong answers decreased from 29,2% before to 9,5% after, corresponding to an absolute decrease of 19,7%.

Concerning some outliers detected in the graphs tracking the progress of correct/wrong answers, it could be observed by examining the raw data that they were due to either badly phrased or more complex questions put in the evaluation forms.

The aim of this project was to create an engaging outreach program that would help improve the participants scientific literacy in astronomical areas, but without the necessity to study any content. This aim seems to have succeeded. Especially, the question catalogue drawn up by the participants shows a strong interest for astronomy associated questions.

Suggestions for further improvements in the outreach program

The data results and their processing give insights for improvement. Suggestions for an improved outreach program follow next.

The data analysis included a gigantic amount of paperwork for only one researcher. As all forms were filled in by hand, it was time consuming to read and evaluate the paperwork. It necessitated an high amount of concentration and correction-time to prevent mistakes in the putting together of the data afterwards. The existence of well functioning computer programs to do this kind of work accompanies the suggestion to implement online evaluation during the project. It is advisable not only to hold the project - when necessary - in the school's PC room, but also to use the computers available for evaluation activities.

A second suggestion concerns the findings from the participants feedback. A repeated recommendation was the extension of the duration for the outreach program. Since the units contained a lot of new information for the participants, especially towards the last units, it would be advisable to extent the program by at least one week to enable an even more relaxed contact with the new subject matter for the participants.

A third suggestion concerns a recommendation to the number of participants advisable for a smooth course. Initially, the project had foreseen to allow up to 30 participants. Luckily, this did not come to pass, as many interested students were prevented from attending for different reasons. The group consisted of about 13 students, which enabled an agreeable teaching as well as organizational setting.

A participant number above 15 should be questioned, as it might prevent the implementation of this open method experience due to unrest. Especially, school children are often difficult to lead when their group becomes too high in numbers.

On the other hand, reducing the amount of conveyed information might allow for a higher number of participants. Especially, with a shift to more excursions and less presentations. It must be noted, that an increased amount of activities requires more money, more time when dealing with the organizational framework of a school, and more adults for the duty of supervision, but then again, it offers more fun experiences for the young people.

A further observation by the lecturer leads to the next suggestion.

The group of students highly enjoyed the excursions to the two places of science. Particularly, the visit to the observatory and one of its telescopes was perceived as an exciting experience. Therefore, a third excursion to a place of applied science could further improve the participants engagement with the subject matter. Also, the use of more experiments during the project - especially in the last two units - is recommended to ease the cognitive access to more complex subjects of the outreach program.

Comparison of findings with the literature

In this short paragraph, the findings from this outreach program will be compared to statements or observations from the literature review in section 3.

As the outreach program used similar tactics to Neil de Grasse's book - "Astrophysics for Young People in a Hurry" - for the transmission of astronomical knowledge, it can be noted that using pictures and images to initiate the reflection process on science topics is a golden rule.

Also using connections to everyday life when explaining scientific content, private anecdotes or general stories helps participants with making a personal connection to the subject and memorizing what was learned.

Further, the implementation of the recommendation from "The Hands-On-Guide for Science Communicators" to properly prepare the project's material matching the target group's abilities was important. The outreach program was well received by the young participants and its contents mostly retained, which led to an overall improvement in the students' scientific literacy and interest in astronomy.

6. Conclusion and Outlook

6.1 Project outcomes

The project's success was to be determined by the effective design and implementation of an engaging astronomy outreach program for middle school students. This was realized as depicted in the section on findings and discussion. Further, the lecturer could observe positive changes in the participants knowledge and attitude towards astronomy, as evidenced by the multiple choice quiz data and the viewed feedback.

6.2 Astronomy in middle school education

A future-oriented idea that emerged during the implementation of this hybrid outreach program was the introduction of astronomy as a choice school subject for middle school students. Since astronomy conveys important knowledge on modern scientific findings it should be considered as an essential subject in contemporary school curricula. The outreach program encompassed a lot of research findings that are useful to fill in gaps in knowledge on atmospheric science. Learning about natural phenomena outside of Earth, and connecting mind-maps from physics, chemistry, biology and engineering within its cosmic framework as described in astronomy should be part of every humans general knowledge.

6.3 Future research

For further research purposes it would be desirable to repeat the outreach program in different settings, particularly varying the school participants' age group. This way, more data could be gathered to deduce which age group most profits from this type of outreach program. Using this project to create a supplementary bridge between school education and university research can create a meaningful foundation for young participants scientific literacy, and their future educational path. In addition, thus implemented interdisciplinary outreach programs involving educational sciences with natural sciences help connect people, their research fields and foster attention and support for their respective causes.

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7. Title of Appendix A

7.1 Program materials

7.1.1 Question catalogue

Inserted below is a question catalogue composed by students for the occasion of a meet and greet with astronomers.

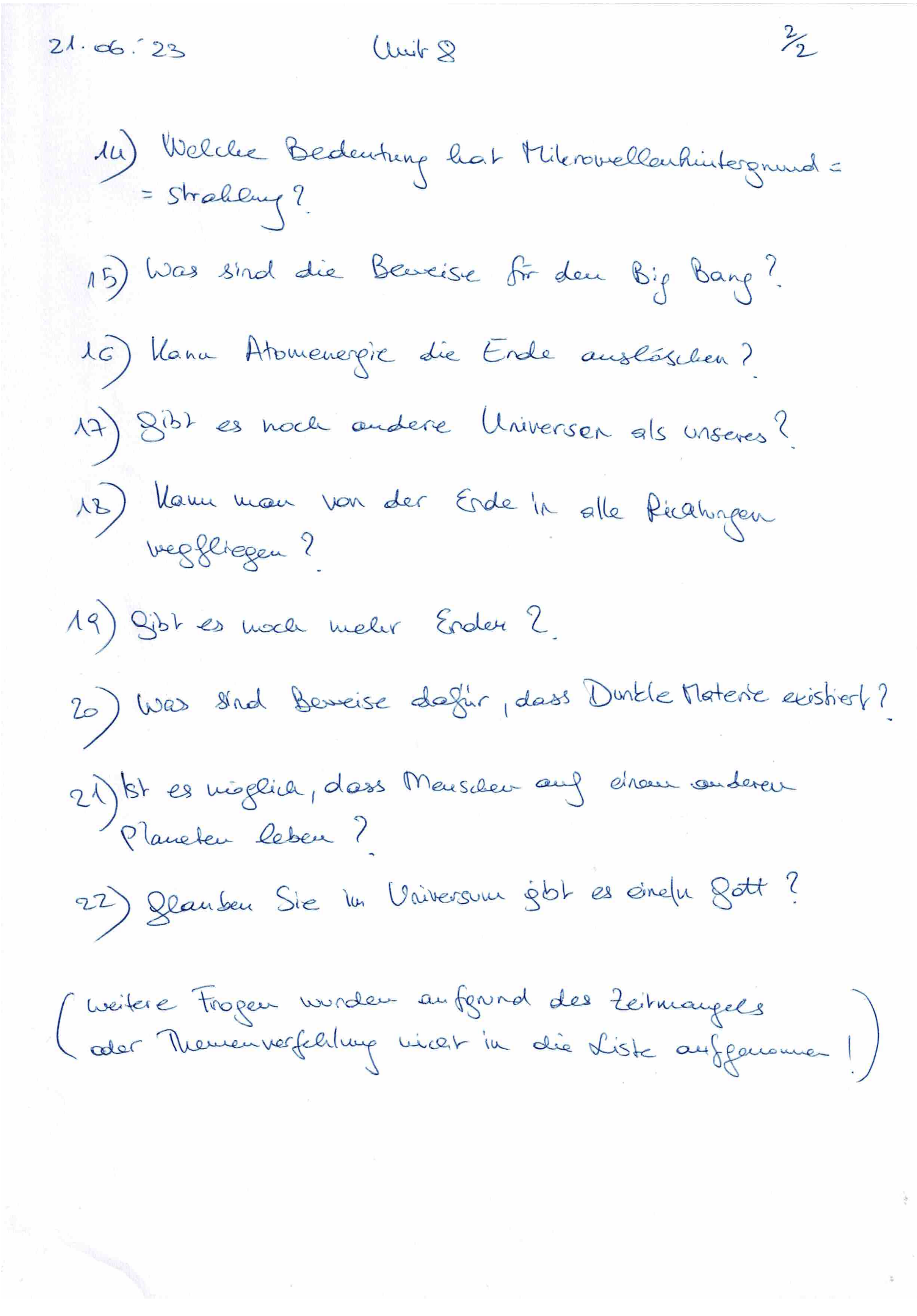
21.06.2023 Unit 8 1/2

(Von Schülern verfasste Fragen | Projektvortragende hat geschrieben)

Fragen fürs Meet & Greet mit AstronomInnen:

1) Wie kann man Dunkle Materie sehen?
2) Wenn es viele heiße Sterne gibt, warum ist das Universum kalt?
3) Warum wird das Universum immer größer?
4) Wenn Sie viel mit Sternen arbeiten, glauben Sie an Astrologie?
5) Gibt es kalte Sterne?
6) Glauben Sie stammen wir von der Natur ab oder stimmt die Erzählung von Adam und Eva?
7) Wissen Sie wann und wie die Erde untergeht?
8) Gibt es außerirdisches Leben?
9) Haben Weltraum=Raketen und Elon Musk etwas verändert?
10) Ist es möglich zu anderen Planeten zu fliegen?
11) Werden wir - Menschen - noch bis 2025 zum Mars fliegen?
12) Wäre es möglich, dass in unserem Sonnensystem ein neuer Planet entsteht?
13) Ist eine Mondlandung möglich?

Figure 7.1: Catalogue of questions from students to astronomers 2



21.06.23 Unit 8 2/2

14) Welche Bedeutung hat Mikrowellenhintergrund=
= Strahlung?

15) Was sind die Beweise für den Big Bang?

16) Kann Atomenergie die Erde auslöschen?

17) Gibt es noch andere Universen als unseres?

18) Kann man von der Erde in alle Richtungen
wegfliegen?

19) Gibt es noch mehr Erden?

20) Was sind Beweise dafür, dass Dunkle Materie existiert?

21) Ist es möglich, dass Menschen auf einem anderen
Planeten leben?

22) Glauben Sie im Universum gibt es einen Gott?

(weitere Fragen wurden aufgrund des Zeitmangels
oder Themenverfehlung nicht in die Liste aufgenommen!)

Figure 7.2: Catalogue of questions from students to astronomers 1

7.1.2 Forms

Dein Wissen über Astronomie (Einheit 1)

Über deine Antworten erkennst du, was du noch nicht gelernt hast und was schon

* Erforderlich

* Dieses Formular wird Ihren Namen aufzeichnen. Bitte tragen Sie Ihren Namen ein.

1. Was für Objekte werden im Weltraum beobachtet?

- [ ] Schwarze Löcher
- [ ] Kometen
- [ ] Galaxien

2. Welche Instrumente benutzt man in der Astronomie?

- [ ] Mikroskpoe
- [ ] Teleskope
- [ ] Simulationen mit Computern

3. Wo entstehen Planeten? *

- ◯ auf einer großen Staubscheibe um einen jungen Stern
- ◯ im innere Asteroiden Gürtel zwischen Mars und Jupiter
- ◯ im äußeren Sonnensystem

4. Welche Planeten sind unsere nächsten Nachbarn?

- ◯ Venus und Mars
- ◯ Sonne und Merkus
- ◯ Uranus und Pluto

5. Wo werden Sterne geboren?

- ◯ in Riesen Sternen
- ◯ in einer Scheibe
- ◯ in kühlen Molekülwolken

6. Wenn Gas sehr heiß ist, welche Farbe hat es?

- ◯ braun
- ◯ gelb
- ◯ blau-weiss

7. Welche Farben haben ältere Sternpopulationen?

- ◯ blau-weiss
- ◯ gelb-orange-rot
- ◯ violett-grün

8. Was für eine Galaxie ist unsere Milchstraße?

- ◯ eine Ellipsengalaxie
- ◯ eine Spiralgalaxie
- ◯ eine Kugelgalaxie

9. Warum ist es um ein Schwarzes Loch so hell?

- ◯ Weil es hell leuchtet wie ein Stern
- ◯ Weil es Blitze produziert
- ◯ Weil es viele Sterne um sich herum anzieht, bevor diese hineingezogen werden

10. Was brauche ich, um etwas sehen zu können?

- ◯ Licht
- ◯ Dunkelheit
- ◯ gesunde Augen

Dein Wissen über Astronomie (Einheit 2)

Was weißt du schon, was noch nicht?

* Dieses Formular wird Ihren Namen aufzeichnen. Bitte tragen Sie Ihren Namen ein.

1. Welche Farben kommt in der Mitte vom sichtbaren Lichtspektrum vor?

- ◯ Blau
- ◯ Gelb
- ◯ Grün

2. Welcher Strahlung im Lichtspektrum zeigt Wärmequellen gut?

- ◯ ultraviolette Strahlung
- ◯ infrarote Strahlung
- ◯ Röntgen Strahlung

3. Welche Tiere können nicht sichtbares Licht wie Ultraviolett sehen?

- ◯ Vögel
- ◯ Bienen
- ◯ Mäuse

4. Was kann Haut machen, um sich vor UV-Strahlung zu schützen?

- ◯ viel Melanin produzieren, das UV-Licht absorbiert
- ◯ einen Sonnenbrand bekommen
- ◯ starke Sonnencreme tragen

5. Welche Teleskope können im längsten Wellenlängenbereich beobachten?

- ◯ Radioteleskope
- ◯ Optische Teleskope
- ◯ Infrarot Teleskope

6. Warum scheint Neptun im sichtbaren Licht blau zu sein?

- ◯ die Atmosphäre streut kurzwelliges Licht
- ◯ die Atmosphäre streut langwelliges Licht
- ◯ die Oberfläche ist voll mit hellblauem Eis

7. Was ist für die Streuung vom blauen Licht in der Erdatmosphäre verantwortlich?

- ◯ die Rayleigh Streuung
- ◯ die Planeten Streuung
- ◯ die Licht Streuung

8. Welcher Planet ist ein terrestrischer Planet?

- ◯ Erde
- ◯ Mars
- ◯ Saturn

9. Welcher Planet ist ein Eisriese?

- ◯ Uranus
- ◯ Jupiter
- ◯ Neptun

10. Welcher Planet ist ein Gasriese?

- ◯ Pluto
- ◯ Saturn
- ◯ Jupiter

Dein Wissen über Astronomie (Einheit 3)

Deine Lernkurve

* Dieses Formular wird Ihren Namen aufzeichnen. Bitte tragen Sie Ihren Namen ein.

1. Welche Funktion haben Schichten in der Natur?

- etwas sauber halten
- vor etwas Schutz bieten
- etwas größer machen

2. Wovor schützen mehrere Schichten besonders gut?

- vor starker Strahlung
- vor Temperaturextremen
- vor über die Haut übertragbare Krankheiten

3. Welche Bestandteile kommen in jeder Schicht in der Natur vor?

- ◯ Fett
- ◯ Fasern
- ◯ Moleküle

4. Wieso gehen Moleküle Bindungen ein?

- ◯ um einen stabileren Energiezustand zu erreichen
- ◯ es können neue Bindungen entstehen mit neuen Funktionen
- ◯ um immer größer zu werden

5. Welches Kinderspiel ist so ähnlich wie ein Molekülbaukasten?

- ◯ Lego
- ◯ Tetris
- ◯ Memory

6. Welche Erdkrusten gibt es?

- ◯ kontinentale Erdkruste
- ◯ ozeanische Erdkruste
- ◯ atmosphärische Erdkruste

7. Woraus besteht der innere Kern der Erde?

- ◯ Gas
- ◯ Gestein
- ◯ Eisen

8. Warum hat die Erde ein Magnetfeld?

- ◯ weil obere Schichten des Eisenkerns sich bewegen
- ◯ weil die Sonne ihr Magnetfeld mit der Erde teilt
- ◯ weil der Nordpol kalt ist und der Südpol warm

9. Wo beginnt die Erdatmosphäre?

- ◯ Am Himalaya
- ◯ Am Horizont
- ◯ Am Meeresspiegel

10. Kann man in jeder Schicht der Erdatmosphäre atmen?

- ◯ Ja
- ◯ Nein
- ◯ Ja, wenn man die passende Ausrüstung dabei hat

Dein Wissen über Astronomie (Einheit 4)

Was hast du schon gelernt?

* Dieses Formular wird Ihren Namen aufzeichnen. Bitte tragen Sie Ihren Namen ein.

1. Woraus besteht alle Materie auf unserem Planeten?

- ◯ aus Energie
- ◯ aus Atomen
- ◯ aus Licht

2. Was ist die richtige Abkürzung für Wasser in all seinen Formen?

- ◯ C2O
- ◯ H2O
- ◯ W2O

3. Was kommt in einem Atomkern vor?

- ◯ Neutronen
- ◯ Protonen
- ◯ Elektronen

4. Was bewegt sich um den Atomkern herum?

- ◯ Neutronen
- ◯ Protonen
- ◯ Elektronen

5. Wenn ich Atome miteinander verbinde, ergeben sich:

- ◯ Moleküle
- ◯ Atomkerne
- ◯ Licht

6. Vor welchem Licht schützt Sonnencreme oder dunkle Haut?

- ◯ infrarot
- ◯ blaulicht
- ◯ ultraviolett

7. Warum erscheint der Himmel blau?

- ◯ weil die Gasmoleküle im Himmel blaue Farbe hat
- ◯ weil die Gasmoleküle im Himmel viel blaues Licht streuen
- ◯ weil er den Ozean reflektiert

8. Wenn ich etwas warmes beobachten möchte, benutze ich welchen Teil vom Lichtspektrum?

- ◯ ultraviolett
- ◯ infrarot
- ◯ grünes

9. Welche Farbe ergibt sich aus allen Farben des Lichtspektrums?

- ◯ blau
- ◯ rot
- ◯ weiss

10. Wie nennt man ein Lichtteilchen?

- ◯ Proton
- ◯ Neutron
- ◯ Photon

Dein Wissen über Astronomie (Einheit 5)

Was hast du schon gelernt?

* Dieses Formular wird Ihren Namen aufzeichnen. Bitte tragen Sie Ihren Namen ein.

1. Warum stehen Teleskope immer allein irgendwo am Berg, weit weg von Städten?

   - ◯ weil die Lichtverschmutzung von Städten das Sternenlicht dimmt
   - ◯ weil Astronomen gerne in Ruhe arbeiten
   - ◯ weil Teleskope nur am Berg funktionieren

2. Warum benutzt man auch Weltraumteleskope?

   - ◯ weil es so weniger kostet
   - ◯ weil so die Atmosphäre nicht dazwischen ist und stört
   - ◯ weil es nicht genug passend hohe Berge für Teleskope auf der Erde gibt

3. Was kann man mit einem Infrarot Teleskop gut beobachten?

- ◯ die kalten Regionen
- ◯ die wärmeren Regionen
- ◯ Asteroidengürtel

4. Was für eine Galaxie ist unsere Milchstraße?

- ◯ eine elliptische Galaxie
- ◯ eine kugelförmige Galaxie
- ◯ eine Spiralgalaxie

5. Was kann man von der Erde aus von der Milchstraße sehen?

- ◯ ihren Spiralarm
- ◯ die ganze Spiralgalaxie
- ◯ garnichts

6. Was schützt in der Natur sehr gut?

- ◯ Wasser
- ◯ Erde
- ◯ Viele Schichten von Materie

7. Was hat mehrere Schutzschichten?

- ◯ Blätter
- ◯ Haare
- ◯ Haut

8. Was schützt unseren Planeten Erde vor starker Strahlung?

- ◯ seine Form
- ◯ sein Magnetfeld
- ◯ seine Atmosphäre

9. Woher kommt das Magnetfeld der Erde?

- ◯ vom Magnetfeld der Sonne
- ◯ aus der Atmosphäre
- ◯ vom flüssigen Eisenkern

10. Warum können Menschen ab einer bestimmten Höhe in der Atmosphäre nicht atmen?

- ◯ wegen dem vielen Wasserdampf in der Lunge
- ◯ wegen der vielen Strahlung von der Sonne
- ◯ wegen dem niedrigen Druck

Dein Wissen über Astronomie (Einheit 6)

Was hast du schon gelernt?

* Dieses Formular wird Ihren Namen aufzeichnen. Bitte tragen Sie Ihren Namen ein.

1. Wo beginnt die Atmosphäre?

- ○ ab den Bergen
- ○ ab der Flughöhe von Vögeln
- ○ ab dem Meeresspiegel

2. Was befindet sich alles in der Atmosphäre?

- ○ Flugzeuge
- ○ Bäume
- ○ Satelliten

3. Wonach ist der Treibhauseffekt benannt?

- ◯ nach einem bekannten Physiker
- ◯ nach einem Gas
- ◯ nach einem Glashaus zur Pflanzenzucht

4. Wieso erwärmt sich unsere Atmosphäre immer mehr?

- ◯ weil aufgrund bestimmter Gase in der Atmosphäre Wärmestrahlung absorbiert wird
- ◯ weil nicht genug Wärmestrahlung zurück in den Weltraum emittiert werden kann
- ◯ weil die Sonne immer wärmer strahlt

5. Welches Treibhausgas produziert der Ozean, wenn er erwärmt wird?

- ◯ Helium
- ◯ Kohlenstoff
- ◯ Wasserdampf

6. Welches Treibhausgas produzieren Menschen durchs Autofahren, Fliegen und Fabriken?

- ◯ Ozon
- ◯ Sauerstoff
- ◯ Kohlenstoffdioxid

7. Was passiert, wenn mehr Wasserdampf in die Atmosphäre gelangt?

- ◯ es bilden sich mehr Wolken
- ◯ es können mehr Wirbelstürme entstehen
- ◯ die Atmosphäre kühlt ab

8. Warum steigt das Meer an vielen Küsten?

- ◯ weil das Meer von selbst wächst
- ◯ weil die Eiskappen am Nord- und Südpol schmelzen
- ◯ weil es so viel regnet

9. Was ist eine Folge von Dürren und regelmäßigen Umweltkatastrophen in ärmeren Ländern?

- ◯ Menschen haben weniger Wasser zu trinken
- ◯ Menschen haben weniger Essen
- ◯ Menschen verlieren ihr Zuhause und müssen als Klimaflüchtlinge fliehen

10. Sind die Konsequenzen vom Klimawandel für alle Menschen gleich ernst weltweit?

- ◯ das kann man nicht sagen
- ◯ es ist für bestimmte Länder schlimmer als andere
- ◯ es ist für alle Länder gleich schlimm

Wie war das Astronomie Projekt für dich?

Beantworte aus dem Bauch heraus, wie du darüber denkst

* Dieses Formular wird Ihren Namen aufzeichnen. Bitte tragen Sie Ihren Namen ein.

1. Würdest du gerne mehr Experimente durchführen oder an naturwissenschaftlichen Projekten teilnehmen?

   ○ Ja

   ○ Nein

   ○ Vielleicht

2. Interessierst du dich nach dem Kurs noch mehr für das Universum, Sterne und Planeten?

   ○ ja

   ○ Nein

   ○ Ich weiß es nicht

3. Gibt es ein naturwissenschaftliches Thema aus dem Kurs, über das du in deiner Freizeit mehr erfahren möchtest?

4. Könntest du dir vorstellen, später einen Beruf zu haben, der mit Naturwissenschaften zu tun hat? Wenn ja, welchen? Warum oder warum nicht?

5. Hat dir das Astronomie Projekt insgesamt Spaß gemacht?

- ◯ Ja
- ◯ Nein
- ◯ Ich weiß es nicht

6. Fühlst du dich nach dem Projekt besser über Naturwissenschaften informiert?

- ◯ Ja
- ◯ Nein
- ◯ Ich weiß es nicht

7. Konntest du in dem Projekt etwas Neues und Interessantes lernen?

- Ja
- Nein
- Ich weiß es nicht

8. Hast du das Gefühl, dass du die Inhalte gut verstehen konntest?

- Ja
- Nein
- Ich weiß es nicht

9. Wie gut konnte die Kursleiterin deine Fragen beantworten?

- sehr gut
- gut
- garnicht gut
- Ich weiß es nicht

10. Wie sympathisch und kompetent fandest du die Kursleiterin?

- ◯ sehr sympathisch und kompetent
- ◯ etwas sympathisch und kompetent
- ◯ garnicht sympathisch und kompetent
- ◯ Ich weiß es nicht

11. Hat der Kurs dich motiviert, mehr über Naturwissenschaften zu lernen?

- ◯ Ja
- ◯ Nein
- ◯ Ich weiß es nicht

12. Wie hat dir die Atmosphäre während des Kurses gefallen?

- ◯ Es war allgemein angenehm
- ◯ Es war allgemein unangenehm
- ◯ Ich weiß es nicht

13. Wie fandest du die praktischen Experimente und Aktivitäten (Ausflüge) im Projekt?

- ◯ interessant
- ◯ langweilig
- ◯ Ich weiß es nicht

14. Kannst du das Gelernte im weiteren Leben anwenden?

- ◯ Ja
- ◯ Nein
- ◯ Ich weiß es nicht

15. Würdest du den Kurs deinen Freunden empfehlen?

- ◯ Ja
- ◯ Nein
- ◯ Ich weiß es nicht

16. Würdest du den Kurs Erwachsenen in deinem Leben empfehlen?

- ◯ Ja
- ◯ Nein
- ◯ Ich weiß es nicht

17. Fandest du den Zeitplan und die Dauer des Kurses passend?

- ◯ Ja, es hat gepasst
- ◯ Nein, es war zu lange
- ◯ Nein, es war zu kurz
- ◯ Ich weiß es nicht

18. Wurden moderne Technologien (wie Computer, Apps, Online-Plattformen) sinnvoll im Kurs eingesetzt?

- ◯ Ja
- ◯ Nein
- ◯ Ich weiß es nicht

19. Gab es genug Möglichkeiten, dich mit anderen Kursteilnehmern auszutauschen und zusammenzuarbeiten?

- ◯ Ja
- ◯ Nein
- ◯ Ich weiß es nicht

20. Würdest du gerne einen anderen naturwissenschaftlichen Kurs zu einem neuen Thema besuchen?

- ◯ Ja
- ◯ Nein
- ◯ Ich weiß es nicht

21. Was hat dir am besten am Kurs gefallen?

22. Was fandest du, könnte man am Kurs verbessern?

23. Hast du durch den Kurs ein besseres Verständnis für naturwissenschaftliche Themen entwickelt?

- Ja
- Nein
- Ich weiß es nicht

24. Hat dir der Kurs neue Perspektiven oder Interessen im Bereich der Naturwissenschaften eröffnet?

- Ja
- Nein
- Ich weiß es nicht

25. Wie zufrieden bist du insgesamt mit dem Astronomie Projekt?

- sehr zufrieden
- etwas zufrieden
- garnicht zufrieden
- Ich weiß es nicht

Microsoft Forms

any supplementary material or data