KØBENHAVNS UNIVERSITET

Masters Thesis

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Creating and Testing Astronomy Teaching Packages for an Online Ressource

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Abstract

How do we create relevant and interesting astronomy teaching material and how do high school students solve the given astronomy problems? There are several challenges in teaching astronomy in elementary school and high school. Some of them are that the subject seems easy on the surface, but quickly becomes too complicated, and that the students often lack the mathematical skills needed. Also, the subject can be too abstract or too big compared to the available time for teaching it. Teaching material on exoplanet design has been developed for a high school level course based on different considerations for exoplanet observable and derivable properties, such as the orbital period, the planetary mass, size, atmospheric composition and equilibrium temperature, and other interesting considerations, that are not yet derivable with current technology, such as surface and weather of the planet and seasonal periods. The objective of the exercise was to combine the creative aspect of designing an exoplanet as a travel destination inspired by NASA's Travel Bureau posters, while taking different aspects into account and use physics to decide some of the properties with realistic values. Before testing the teaching material, a literature review was done on problem- and context-based learning with the focus on ill-structured problems, and using curiosity as motivation for learning, with the focus on science curiosity. The exoplanet design teaching material was then tested with a high school class. One group of three students was observed solving the exercise and the whole class was observed presenting their poster results from the exercise. Prior to the test, a study and research path has been created to map the expected flow of thoughts for solving the exercise, and after the observation an actual study- and research path was mapped based on the actual flow of thoughts during the exercise. After the exercise and presentations a survey was conducted for the whole class, to get an overall idea on what the students especially enjoyed about the exercise and which challenges they had. The result of the observation and the survey showed that the students especially liked the freedom of choice in the exercise, and the balance between the creative aspect and being able to connect the elements using reason based in physics. They were challenged by some of the equations and the time constrain. Based on the results and the study on ill-structured problems and curiosity, improved teaching material was created.

Acknowledgements

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I also would like to thank everyone in the Online Observatory project, with special thanks to Brorfelde Observatory for the opportunity, and the team at Faulkes Telescope Project for inspiring me with their Exoplanet Design package for middle school level.

Furthermore, I would like to thank Kristine Simone Nielsen for letting me use her high school astronomy class as a test subject, and the class itself for their inspiring poster presentations, with a special thanks to the three students, who bravely let me be a fly on their digital wall as part of my experiment.

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At last, I would like to thank Esben Hansen for being at the right place at the right time. I would never have gotten the crazy idea to start studying physics otherwise. My time machine worked!

Contents

Part I
Introduction

How do we create great astronomy teaching material for students? To answer this question, we need to consider the purpose of teaching astronomy. Why is it relevant or interesting and what should the focus of the teaching be? Which challenges are there in astronomy teaching and how can we overcome those challenges to fulfill the purpose of teaching? In this introductory part, I will introduce my thesis, its motivation and purpose, and a preliminary domain research on Danish astronomy education to get an idea of some of the challenges of teaching astronomy.

1 Background and motivation

Although this is a thesis in astrophysics, a great part of it is based on science education due to the didactic nature of creating and testing astronomy teaching packages.

1.1 Background and Online Observatory

The project started as a request for help from The Online Observatory (OO), which was under development as an online educational resource for teaching astronomy with activities targeted elementary school and high school. The project is a collaboration between several European observatories located in: Denmark (Brorfelde), Norway (Solobservatoriet), Finland, UK, and Latvia, and part of the EU Erasmus+ programme.

> Through OO, users can access a variety of educational classroom resources, free software, data archives and even make use of robotic and remotely controlled telescopes located around the world.[1]

There were a total of 8 topics planned for the OO, each with several teaching material developed as a collaboration between the observatories: 1) Observing the sky, 2) Virtual Tours, 3) Small Solar System Bodies, 4) Young Astronomers, 5) The Moon, 6) The Universe, 7) The Sun and Stars, and 8) Planets and Exoplanets.

I started my thesis project with trying to figure out the purpose and target group of the Online Observatory project. A Q&A (in Danish) is attached in appendix A. Basically, the teaching material is meant as free material for middle school and up. It is meant as a motivation and inspiration for teachers to include astronomy as part of the teaching. The packages will be developed in English and thereafter translated to Danish for the use in Denmark. The teaching material should be usable without visiting the observatory, but could include the use of data from the observatory.

1.2 Motivation and purpose

I have always been fascinated by our existence as part of something bigger, and hence the Universe has always been a curious interest of mine. Driven by the inconsistency in the common view on science as dull and many examples of the mainstream search for the truth about the Universe outside the domain of science, I feel motivated to learn not only the physics behind space, but also how we think, talk and teach about the subject.

I did not start a professional interest in astronomy until late in life because I never really thought of astronomy as something that could actually be useful as a choice of career. It was just a subject for a sense of personal wonder. To motivate a purpose of which material to test, with whom, how and why, I first needed to get better domain knowledge for how astronomy is being taught in school through the whole educational system, and also I needed a general sense of reasoning behind why astronomy education matters for other than personal existential reasons. It is my hope, that being

[1] From OO webpage, `https://onlineobservatory.eu` (November, 2020)

aware of a larger context for astronomy knowledge will be useful for designing teaching material with the purpose of inspiring students on the astronomy subject.

Hence, the main goal of this thesis is to create astronomy teaching material in one subject and test what happens when it meets the real world in a educational setting. How do the students react to the topics presented? What are they curious about, and what is challenging and discouraging? What can be improved in how the material is taught?

1.3 Structure of the thesis

The thesis consist of five main parts:

Part I is the introduction, including the background, motivation and purpose of the thesis and a second part of preliminary domain research of astronomy education in Denmark. In this part, I mainly look back at the "as is" situation and establish the background settings for the thesis.

In **part II**, I present the teaching material case, narrowed down to the subject of exoplanets. I will explore the physics behind various aspects of exoplanet observations and derivations of properties, which could be relevant up to high school level. Then I will present the first iteration of the teaching material, used in the following test, including justification for choices, based on the preliminary domain research.

Part III is a literature review of the science education field with main focus on motivating curiosity towards science and astronomy through problem-based learning and the improvement of the teaching material case.

In part IV, I will describe and justify the methodology used for the test and the following analysis of the results and then present the main result based on this methodology.

Part V includes an analysis and discussion of the results relating to the findings in the literature review, an implementation of improvements om the case material based on the discussion, and at last a perspective to further astronomy teaching.

At last, a wrap-up including conclusion of the main findings in the thesis relating to the purpose.

2 Preliminary domain research

For the purpose of the thesis, I did some preliminary research of the domain of astronomy education in Denmark, including the expected learning path and challenges and successes from teachers at various levels. The aim of this was to get an idea of issues and barriers, and find inspiration for upcoming topic and case for teaching material.

2.1 Danish astronomy education learning path

I have looked into the educational system at different levels, summarizing the main relevant learning objective for physics- and astronomy-related topics from middle to high school at the time of this thesis, based on the curriculum included in appendix B.1 to B.1.

2.1.1 Elementary (middle) school

For the elementary school, there are new requiments in 2nd, 4th, and 6th grade (Appendix B.1):

The closest to astronomy in **2nd grade** is learning about the sun, the night and day, and the seasons. Also, it is expected that the children at this age can distinguish between reality and a model.

In **4th grade**, the children will learn about the Earth, the Moon, and the planets in the solar system. They should be able to show the movements of the planets around the Sun, the Moon around Earth, and compare the planets in our solar system through a model. In general the children should be able to construct and understand simple models of the world.

In **6th grade**, there is not much new astronomy-relating teaching. Focus is more on nature itself, biology, energy and sustainability, and the geological properties of Earth. In this age, the students should be able to work with composite models to describe processes and be able to discuss the suitability of simple models.

To summarise, elementary school is all about getting familiar with Earth as a planet and in a greater context with the Moon, the Sun and the influence they have on our everyday life experience, such as day, night, seasons, tides, and other natural phenomena, including Earth sciences such as geology and biology. Also, the students are expected to be trained in modeling reality, from simple to composite models.

2.1.2 High school

In high school, there are three levels of physics, and one level of astronomy:

Physics C is an obligatory course for all 1st year high school students, and can thus be seen as almost a natural continuation and build-upon from elementary school. The main astronomy in this subject is: "The physics contribution to the scientific worldview"

- basic features of the current physical description of the Universe and its evolutionary history, including the expansion of the Universe.

- The Earth as the planet in the solar system as a basis for explaining easy observable natural phenomena

The second part might overlap and include some recap from elementary school, depending on the exact teachings in both, but certainly a repetition of something, that isn't studied otherwise, is usually a good idea in different contexts.

The two other topics that are part of the core material in this course is energy and light, both of which are relevant to the understanding of the Universe and observation of the Universe, although they do not necessarily relate to astronomical topics in the teaching. Light includes the electromagnetic spectrum and absorption and emission of a photon.

Physics B is the first extra level elective physics course, that builds upon Physics C. In "The physics contribution to the scientific worldview", there is an addition to the expansion of the Universe with knowledge of spectral redshift.

Teaching energy now includes the kinetic and potential energy in the gravitational field of Earth.

Teaching about photons is now specifically taught in the realm of quantum mechanics, and also includes the radioactive decay, which is an important process in stars, and therefore also extra relevant for astronomy teaching.

Another new topic is mechanics, which includes Newton's three laws in one dimension.

Physics A is the highest level of physics that the students can choose in high school. On this level, the mechanics that was taught in one dimension on level B, is now expanded to two dimensions and into the gravitational field around a central object.

There is also a "surprise" topic every year under the title "Physics in the 21st century". This changes about every 3rd year and is the same topic for every high school in Denmark. Previous topics have included:

- "Plasma physics and fusion energy" (2015),
- "The building blocks of the Universe" (2012),
- "The dynamical stars" (2009).

So it is quite often that it has been about astronomy. The latest in 2018 was about hospital physics, and the previous before 2006 was about laser physics.

Astronomy is an elective course, that does not require other physics than the obligatory level C and mathematics level C. The topics taught are:

- Our (physical) place in the Universe: The solar system, planets, exoplanets and the conditions for life, The Milky Way and other galaxies, the cosmic zoom and distance measurement.
- The evolution of the Universe: The Big Bang model, cosmological redshift, the age of the Universe, the Cosmic Background Radiation, and the creation of the first elements. Birth of stars and planets, evolution of stars, including the creation of elements. The fundamental elements of nature, including dark matter and black holes.

25% of the course will be supplementary subjects to expand on the core subjects described above. The students should have significant influence on the subjects, and the subjects can be interdisciplinary with other subjects.

The course should also include experimental and observational work, which could be: Own observations of the night sky with or without instruments, data processing of own or other data, analysis and interpretation of data, virtual experiments.

The students will be making a personal portfolio, collecting relevant astronomical material, which could include articles and reading material given by the teacher, own collected reading material, own collected observational material, own written material and any other products of thew course.

These are the formal plans, but real life is not always ideal, which is why I have also made a couple of surveys for middle and high school teacher and a few informal interviews with high school teachers, to get a more realistic understanding of the teaching situation and shed some light on the actual challenges in teaching astronomy in middle and high school. I have used a bottom up analysis to recognize patterns in the responses and get an overall idea of the situation. The results will be covered in the following section.

2.2 Teacher reported challenges

I have asked teachers in the middle school and high school to answer a few questions about their teaching astronomy practice, their challenges and successes. Some of the questions were demographic to establish which levels and subject the teacher was teaching, some where about the practice such as excursions with astronomical relevance and interdisciplinary work, but the most useful questions were about the experienced challenges in the teaching. Below are some key-findings from the survey.

Challenges in middle school

This survey[2] was shared in a Facebook group[3] for middle school science teachers. A total of 55 teachers replied. As bottom-up analysis of the survey showed that the challenges the teachers experienced fell into a few categories:

1. Teaching material:
   (a) Not enough teaching material
   (b) No practical exercises for this level
   (c) Practical exercises not possible in daytime/teaching time
2. Complexity:
   (a) Subject too abstract
   (b) Subject too big/not enough time
3. The why: Why is astronomy important / how to relate it to everyday life

[2] https://forms.gle/fxqcqiGSBrGe7RYx8
[3] https://www.facebook.com/groups/915402905185143/permalink/3365931250132284

Challenges in high school

This survey[4] was shared in a closed Facebook group[5] for physics high school teachers. 15 high teachers replied. There seemed to be a similar pattern of challenges:

1. Observations are hard or impossible, because weather cannot be planned and due to lack of darkness.
2. Complexity:
   (a) It quickly becomes more complicated, even though it seems easy on the surface.
   (b) The students lack mathematical skills
   (c) The more abstract subjects tend to be more explanatory and memorization, instead of based on physical explanations and calculations.

To get more information on high school teacher's experience with the curriculum, teaching practices, teaching material and any other comments d, I also made few informal semi-structured interviews, with teachers found through my network. One of the findings from these interviews was that astronomy was not a popular choice in high school (STX) and most classes only had a few students. Some years there were not enough students for the course to be created. One teacher mentioned, that she also often got the question "why should we learn about this?", which reinforces the idea that it is not easy to see the usefulness of astronomy.

In one interview, one teacher mentioned, that some students chose the optional subject Astronomy because they expected it to be "an easy course". This might at first glance not sound encouraging, but perhaps such mechanisms could be exploited to use astronomy as a fun entrance to physics or other subjects based on natural curiosity, especially if the "why" was covered as well, so that the students could see the relevance and "big picture" context.

2.3 Why teach astronomy?

> Astronomy is useful because it raises us above ourselves; it is useful because it is grand; .... It shows us how small is man's body, how great his mind, since his intelligence can embrace the whole of this dazzling immensity, where his body is only an obscure point, and enjoy its silent harmony[1] p. 84.
> — Henri Poincare, Physicist

It might be hard to find a reason for why observing far-away celestial objects or learning about the expansion of the Universe would be useful in everyday life. Beneath the surface, there lies deeper questions in astronomical research: Where did we come from, are we alone in the Universe, what is reality really? These are existential questions asked by humans since our very beginning. In my preliminary survey, teachers in middle school and high school have asked: "How can we make astronomy useful?"

[4] https://forms.gle/VsnJbvVvNPtMy75U7
[5] https://www.facebook.com/groups/fysiklaerer.i.gymnasiet

and ”How can it be connected to real life problems?”

Astronomy might be the perfect interdisciplinary subject, that brings cultures together, and inspires arts through its beauty and magnificence. A lot of great arguments are given in the paper [2], which I have collected and grouped below. This will hopefully serve as inspiration for placing astronomy in a larger context.

An interdisciplinary subject

Astronomy is one of the most cross-disciplinary subjects. It can be connected to most other natural sciences such as biology in the search for life and our origins, geology when considering Earth as a planet, chemistry as the elements originate in cosmological events, math and physics for obvious reasons, and humanities such as history, arts, religion, and philosophy.

Sciences

- Physics: Astronomy can be used to illustrate many concepts of physics, such as gravity, light, and light spectra.
- Mathematics: Historically, there has been a lot of mathematical development through astronomy, such as trigonometry, logarithms, and calculus, and hence astronomy can be used to illustrate those branches in mathematics.
- Geology: Astronomy has advanced the geological sciences by providing a variety of environments of other planets and moons.

Humanities

- History: In scientific revolutions, astronomy stands out. Astronomy has historically contributed to many practical applications.
- Philosophy: Astronomy reveals our cosmic root and place in space and times. It asks the most fundamental questions: What is the origin of the universe, galaxies, stars, planets, atoms, the molecules of life, what is the origin of us and life itself, and are we alone in the Universe?

Technology and applications

The interest and practice of astronomy have led to various kinds of discoveries and technological advancements.

- Timekeeping: One of the most important historical practical applications is timekeeping: Calendars, days, seasons, and years originate from the orbital movement and rotation of Earth around the Sun, and it should be part of general education to know about.
- Navigation: Astronomy has contributed to the development of the GPS and other satellite navigation systems. Einsteins relativity theory has made it possible to make exact corrections to the measurements.

- Natural phenomena: Astronomy explains tides and impacts of asteroids and comets with the Earth.
- Detectors and imaging: Astronomy has led to technological advances in low noise radio receivers and detectors for photography and electronic cameras. The image processing techniques for astronomy are also used in medicine.
- Computers: Astronomers use a large fraction of all the supercomputers in the world, driving the need for further development forward.

Bringing people together

Astronomy not only brings different subjects together but also different people across time, cultures, and borders.

- International: Astronomical observations require data from different latitudes and longitudes and thus foster international co-operation.
- Generations: Some observations require decades and centuries of time, thus linking generations of different times.
- Culture: Astronomy is deeply rooted in our culture because of its philosophical implications, and due to the time scales of observations, it also links cultures of different times.

Developing different kinds of thinking and attitudes

> When I think of science and scientists I think of kids who never lost their curiosity and wonder[6]
> — Neil deGrasse Tyson

- Curiosity: Astronomy harnesses our curiosity, imagination, and exploration. We have gone to the Moon and back, always pushing our geographical limits, ready to explore further in the Solar system.
- Abstract thinking: Due to the enormous distances and time scales, astronomy is great at training the sense of thinking more abstractly about scales of time, distance, and size.
- Rational thinking: If taught properly, astronomy can promote rational thinking and understanding the nature of science through observations and simulations.
- Environmental awareness: Astronomy explains and demonstrates long-term changes in the weather and the effect of solar radiation. Also, seeing our planet in a greater context from space can make us realize how special and fragile our planet is.

[6] https://thriveglobal.com/stories/neil-degrasse-tyson-on-the-power-of-curiosity/

Beauty and art

> Astronomy reveals a Universe which is vast, varied, and beautiful — the beauty of the night sky, the spectacle of an ecplipse, the excitement of a black hole.[2]
> - John R. Percy

Astronomy has not only scientific value, but emotional, aesthetic, and artistic values, inspiring artists, poets, stories, and movies. It can be the perfect combination of science and creativity.

The usefulness of astronomy is easier to see in a bigger and long-term context, while the usefulness of our education is often based on more short-term results. This can make it harder to see the context for astronomy, while on the other hand, it is important to keep on eye on the long term goals of developing human society. Astronomy can be abstract and not easy to teach or understand, because it deals with enormous scales and unfamiliar concepts. On the other hand, its strength is that is can be fun, inspiring and curiosity-driven. While it might take more effort to change the views to long-term goals and bigger picture, it might be easier to sneak the knowledge in disguised as curious fun. Therefore, curiosity-driven learning will be a big part of my thesis.

2.4 Summary of domain research

Regarding the successes that teachers had with teaching: Children and students of all ages find the topic exciting, so a lot of teachers find that that astronomy is "easy to teach", in the sense that the students are curious and motivated to learn about the subjects. This is also supported by the study on reasons for teaching astronomy: it helps developing curiosity, creativity and abstract thinking.

It seems to be consistent through the astronomy teaching path in our educational system, that the subjects seems to be exciting, but quickly turns hard to understand and complex to teach, if we go beyond the explanatory and focus on the physics behind. The right balance need to be found. It is also a problem, that most observational astronomy is best done in darkness and even for the experiments that can be done in daytime, the weather conditions are unpredictable.

Some of the challenges depend on which level we choose to focus on. The lack of useful teaching material seemed to be mostly a problem for middle school teachers, although the observational difficulties for astronomy follows though all levels. For high school level, the problems seems to lie mostly in the complexity, lack of mathematical skills, and the seemingly easy subject on the surface, which is often solved more by memorization and description than actual problem-solving through the use of physics.

A challenge for high school lies in how to combine something that is exciting, but at the same time makes student use physics and critical thinking for solving the problems.

Part II
Case: Exoplanet Design

In this part, I will present the case that I will be working on and testing in the thesis. As mentioned, I have chosen to focus on exoplanets and the search for life in the Universe. This is still a broad topic with many aspects, which I will narrow down eventually for the case of teaching material. My focus is on the physics and hence more on observing exoplanets and deriving properties rather than the biology behind possible life that could exist on such planets, but one almost cannot consider exoplanets without considering either the possibility of finding new life or the conditions that would be habitable for biological life as we know it on Earth. This is the context that makes the object that are light-years away from us relevant.

I have based my teaching material on an existing package called "Exoplanet Design" (appendix C), which was originally made by as a creative exercise for elementary school children by Faulkes Telescopes[7] for the Online Observatory (OO). I translated the package to Danish and planned to use this as test material for both middle school, and thereafter make appropriate changes, to develop it into a high school level. Unfortunately, I never got to test with the middle school due to COVID-19 lock-down at the day of the test.

This part of the thesis will be in two sections:

The physics of exoplanets, where I will lay out all the physics which can be used to derive a planetary properties such as their mass and size, atmosphere, temperature. I will also discuss other relevant properties to know, that we cannot quite derive from the current observations.

The "Exoplanet design" package, where I will narrow the various discussed physics in the previous section to a relevant level for high school students and put together to a teaching material package.

Hence, in the following section, I will explore the rich body of physics information that can be useful for working with exoplanets with students on a high school level, and thereafter narrow it down and prioritize for the specific case.

[7] http://www.faulkes-telescope.com/

3 The physics of exoplanets

To variety of exoplanets and their possible environments has continuously surprised us since the first discovery in 1995[3]. The methods and instruments for exoplanet observations are still being refined, and so far we have many interesting candidates for possible extraterrstrial life, but we have yet to be able to observe with enough resolution to derive implications about the planetary composition and atmosphere, especially when dealing with rocky planets. Those relatively tiny celestial objects are completely outshined by their nearby host stars, and any potential atmosphere of rocky bodies do not have enough height for current technology to resolve.

But let me start by a shortly introducing the package "Exoplanet Design" for middle school (appendix C), which inspired the subject here and a further development of teaching material for high school level. Since the target audience for this teaching material are young children, the focus is more on raising the awareness of the idea of planets outside the solar system rather than a detailed knowledge on derivation of their properties. Since the middle school students are just learning about the Earth, the Moon and the planets in the solar system and simple understanding of the models (section 2.1.1), eventual physics should be included as simple analogies based upon current knowledge of our solar system. Choosing an angle that will be based on their natural curiosity, the main focus on this teaching material for this age group is to see our planet and the planets in our Solar system as part of a bigger context and then use this as a creative exercise of considering the possibilities.

Upping up the game to high school level, an exercise of designing an exoplanet would can be expanded for students to include the use of physics equations. Designing an exoplanet with realistic values requires us to know about exoplanets. I wanted to develop teaching material based on physics, but also find the right level and balance between interesting information that is not too complex to implement. Therefore, I have explored the rich body of information we can observe and derive with some uncertainties about exoplanet, and the methods used for finding and deriving the information. This is what I present in this section, before narrowing the information down to an implementation for use in the test and analysis.

Our knowledge is based upon observations with our senses (mainly our vision) and technologies that can extend our observational abilities. The methods and uncertainty of observing will have an influence on the observable parameters. Therefore, I have split this section will be in three parts:

1. A description of methods used for discovery and observation of exoplanets, and which parameters it is possible to derivable from these methods

2. How we use physics and equations to derive the above mentioned parameters

3. Other considerations about exoplanets, not yet possible to measure or derive, but still relevant for the conditions of an exoplanet and its habitability

3.1 Discovering and observing exoplanets

Since the first confirmed discovery in 1995, over 4000 exoplanets have officially been discovered and confirmed[8], and there are thousands more candidates, which means planets that are likely to have been discovered by one instrument, but still needs to be verified by another.

There are different ways of discovering an exoplanet, but two main methods stand out: The transit method and the radial velocity. The radial velocity was the first method used for exoplanet discovery. In the period 2009-2018, the Kepler mission discovered more than 2000 confirmed exoplanets with the transit method.

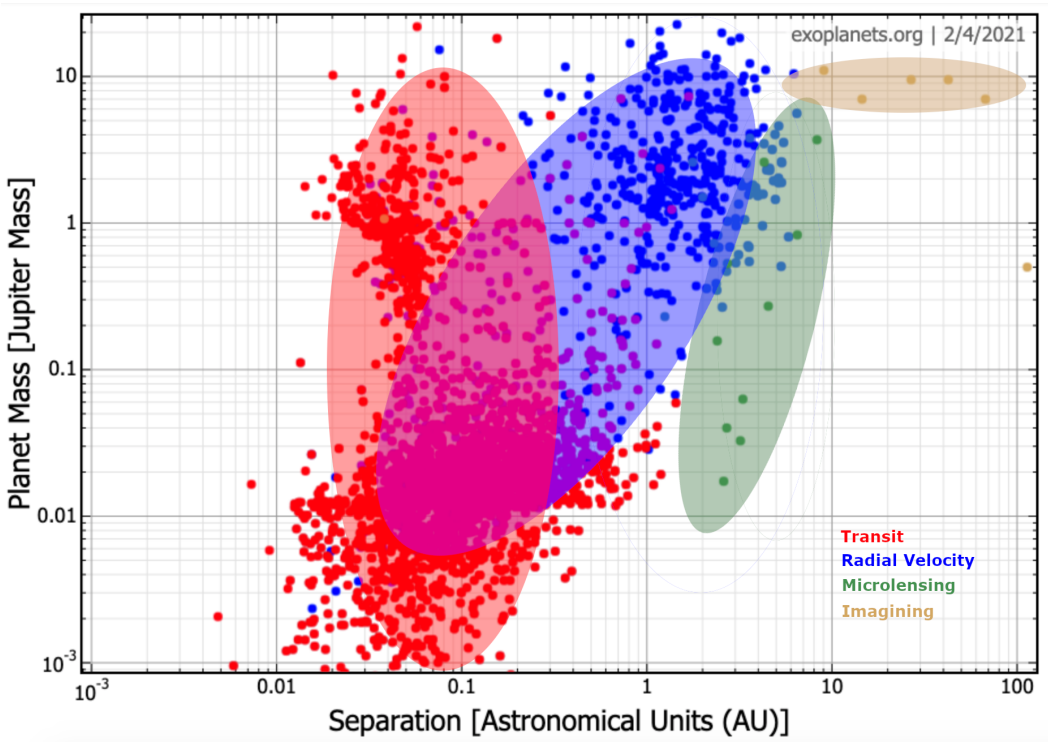


Figure 1: Planets discovered with different discovery methods. The transit methods mainly finds planets that are close to their host star (<1AU), radial velocity discovered planets are also fairly close to their star (<10AU) and typically with a higher mass. The microlensing and imagining methods both discover planets that are in the outskirts of their solar system, and specifically imagining needs massive planets with a higher luminosity. Data and graph by exoplanet.org, own markings of discovery methods.

3.1.1 The transit method

When a planet transits its host star from our point of view, it blocks a fraction of the stellar light. If the star-planet system is observed over a period of time and the flux is measured, then a periodical dip in the light curve will indicate something passing in front of it, and hence must be in orbit around the star. If its periodical and sufficiently small, it is most likely a planet. A visual explanation of this effect is shown in figure

[8] https://exoplanets.nasa.gov/

2.

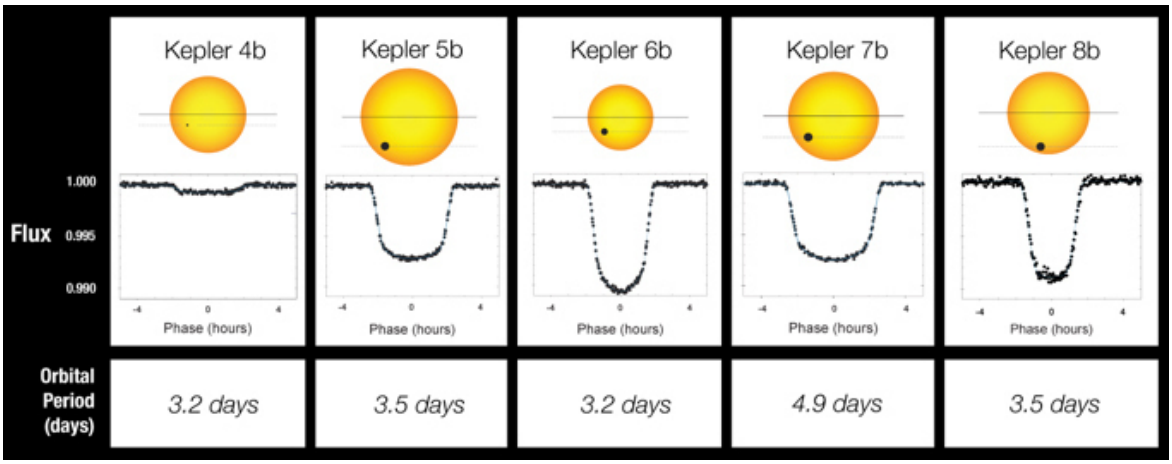
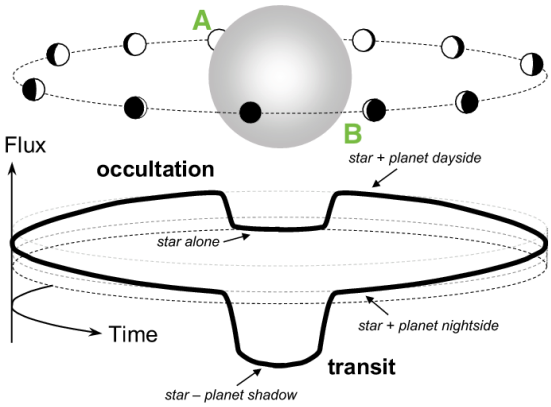


Figure 2: Transit light curves for Kepler's first five exoplanets. The depth of the curve depends on the planet-star radius ratio while the width of the curve depends on the star radius and the planet to star distance (a shorter distance will give a faster transit) and the angle we have on the orbital plane (the larger the angle is from 0°, the faster the transit). Image source: NASA, https://www.nasa.gov/mission_pages/kepler/multimedia/images/aas_conference.html

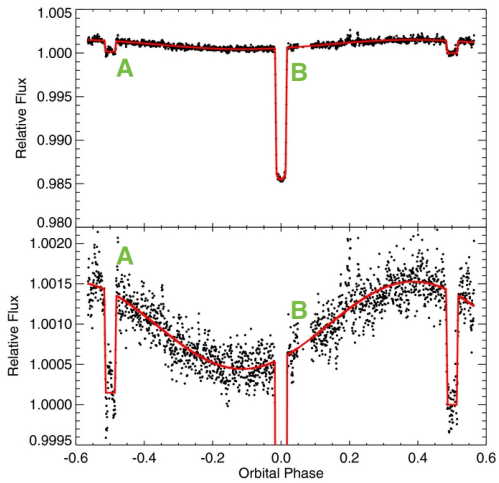
This dip is incredible small for transiting planets. As the scale in the figure indicates, the planet blocks less than 1% of the light from the star. What is not shown in the figure, is that the flux also varies when the planet is not in transit. This is due to the fact, that the light we measure is not only from the star, but also light that is reflected from the star by the planet. When in transit, we see the night side of the planet and hence total flux is at its absolute lowest. We should measure the highest value of the flux just before the eclipse of the planet behind the star. In the moments before, we see the full star flux and the full reflection of the day side of the planet. This can be seen in figure 3a.

The occultation depth is the flux difference between the star alone, when the planet is in occultation behind the star, and the star plus planet dayside as seen in figure 3a (A). By comparing the light spectra from the host star and the planet, we might find indications of the composition of the planetary atmosphere. More about that in the spectroscopy-section 3.1.5.

We might also compare the flux from the day side and the night side by comparing A and B. Large differences could imply a tidally locked planet, where the day-side is always facing the star and the night-side always away. Small difference could mean that the planet is rotating quicker and hence have "days" as Earth. Another important factor that could influence the day-night side difference in flux is the atmospheric circulation, which depend on the atmospheric composition and pressure variations. In the case where the flux from the star plus planet night-side (B) is roughly the same as the light from the star alone (occultation), this might suggest that there is no atmospheric circulation and that the planet is tidally locked to its host star.



(a) The measured flux for different positions of the planet compared to it is host star. The flux is highest for the visible part of the planets dayside since the reflected light is maximized here (A). The flux is lowest when the planet transits. The flux difference between just before and during the occultation, is called the occultation depth and gives us the day-time flux from the planet alone, which can be used to analyze planetary atmosphere composition. Image Source: Transits and Occultations[4]



(b) A full-phase $4.5\mu m$ light curve of the hot jupiter HD 209458b. Point A shows the highest flux rate from star + dayside of the planet. Point B shows the flux of star planet nightside. The A-B difference is the difference in the reflected flux in day- vs. nightside, and in this case it is predicted to be in synchronous rotation (tidally locked). Image source: Robert Zellem, CIT[5]

Figure 3: Transit method

The time between each transits or occultations is the orbital period of the planet. The orbital distance can then be derived from Kepler's third law:

$$P^2 = \left(\frac{4\pi^2}{GM_* m_p}\right) a^3 \Rightarrow a^3 = P^2 \left(\frac{G(M_* + m_p)}{4\pi^2}\right) \tag{1}$$

Using relative values of M_* in solar masses, and assuming the mass of the planet can be neglected in the mass of the star-planet system, we can find the relative orbital distance, a, in AU:

$$a^3 = P^2 M_* \tag{2}$$

We can calculate an estimated radius from the transit method and directly measure the orbital period.

The transit depth of the curve, as seen in figure 2, gives us an indication of the star to planet size ratio. It is given by:

$$d = \left(\frac{R_p}{R_*}\right)^2 \Rightarrow R_p = R_* \sqrt{d} \tag{3}$$

The exact radius of the planet would also depend on the orbital inclination, which we will define as the "impact parameter", as seen in figure 4.
The impact parameter is defined as:

$$b = \frac{a \cos i}{R_*} \tag{4}$$

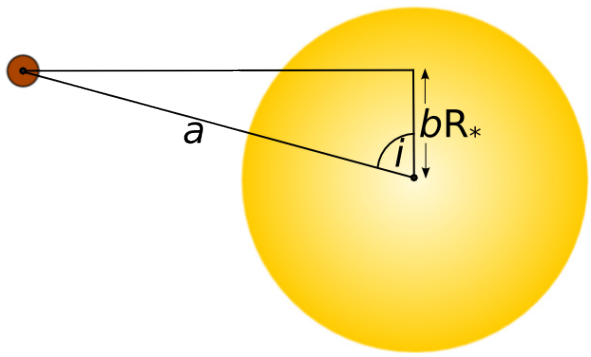


Figure 4: The impact parameter, b, is the one-dimensional sky projected distance from the center of the star to the center of the planet at conjuction.

b can vary from b=0 (the inclination of the planetary orbit is perpendicular to the sky projection) to b=1 (planet passes at the outer border of the star. Since the star is too far away to actually see the transit visually, we cannot know the impact parameter from the transit measurements alone and we will have great uncertainty on the radius calculations.

It is important to remember, that only planets with an orbital plane resulting in $0 \leq b \leq 1$, can be discovered with the transit method. Since all planets in a planetary system being born from the same protoplanetary disk have roughly the same inclination, we will miss all planets orbiting a star, if the orbital plane is perpendicular to our line of sight. Also, it is easier to discover larger planets, or at least larger planet to star size ratio, nearer their host star, because this is where most light will be blocked by the planet.

So, to summarise, the information that we can get om the planet from a transit light curves are:

- Orbital period (”year”), directly read from the flux plot
- Orbital distance, derived from period and Kepler’s third law
- Radius - derived from star radius and the transit depth
- An idea about atmosphere composition if combined with spectroscopy (section 3.1.5)
- Rough indication of possible atmospheric circulations
- Rough indication on planet rotation (”day”)

Only planets with an orbital inclinations towards our line of sight will be able to be observed, and the chances of discovering the planet are roughly proportional to their planet/star radius ratio (transit depth) and inverse proportional with the distance from the host star, a, and impact parameter, b. Therefore, the observation method might be biased towards finding larger planets orbiting closer around proportionally smaller stars.

3.1.2 Radial velocity

A planet orbiting a star is part of a (at least) two body system, where the bodies are revolving around a common center of mass. This means that it is not only the planet that's moving, but also the star. The center of mass of two objects is defined as $m_1 a_1 = m_2 a_2$, where m_1 and m_2 are the two masses and a_1 and a_2 are the distances to the center of mass for each object. If a is the total distance between the bodies $(a_1 + a_2)$, revolving around each other, the equation can be rewritten to

$$a_2 = \left(\frac{m_1}{m_1 + m_2} \right) a \tag{5}$$

If the star has mass m_1 then a_2 is the distance from the planet to the center of mass. The star being in the order of hundreds or thousands times more massive, the fraction goes toward 1 and the distance to the center of mass is almost the same as the distance to the center of the star. But not exactly. The small distance from the center of the star, means that the star is "wobbling" a bit round a center of mass either inside of it or a bit outside. It also means, that it will move slightly back and forth in our line of sight, making it possible to detect slight Doppler shifts in the wavelengths, from when it moves toward or away from us.

The measurement of the Doppler effect will result in a sine curve. The orbital period of the star itself is easily extracted directly from the measurement, since this will be the period of time where the movement pattern repeats (the wavelength of the sine curve in figure 5).

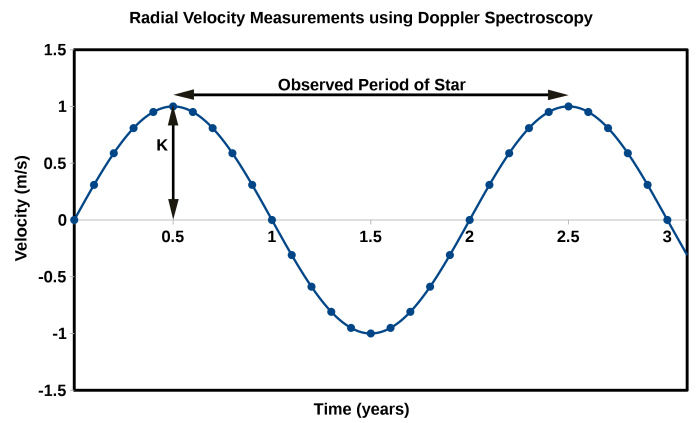


Figure 5: Radial velocity as a function of time. Image source: Cosmogoblin, Wikimedia commons

From radial velocity observation we can derive the mass of the planet. There are three steps involved. First, we use Kepler's third law to find the orbital distance of the planet:

$$a^3 = P_*^2 M_* \frac{G}{4\pi^2} \tag{6}$$

The orbital period of the star is the period of time that we can read from measurements.

Second, we derive the velocity of the planet from Newton's law of gravity which equals the centrifugal force on the planet, where we assume a circular orbit[9]:

$$F_g = G\left(\frac{M_* m_p}{a^2}\right) \quad , \quad F_c = \frac{m_p v_p^2}{a^2} \Rightarrow \frac{GM_* m_p}{a^2} = \frac{m_p v_p^2}{a^2} \Rightarrow v_p = \sqrt{GM_*} \tag{7}$$

Third, we find the mass by using the conservation of momentum for the two bodies in the system:

$$M_* v_* = M_p v_p \Rightarrow m_p = \frac{M_* v_*}{v_p} = \frac{M_* v_*}{v_p} \tag{8}$$

The velocity of the star can be found from the Doppler shifts in the light spectrum, $v = \frac{\Delta\lambda}{\lambda_{rest}} c$.

This is the minimum estimate of the mass of the planet, because we only measure the velocity in the line if sight. If the orbit is inclined from our line of sight, then the true wobbling velocity of the star will be higher than the one we have measured, and hence the resulting true mass of the planet will be higher[10].

If we want to calculate the true mass, we need to know the inclination angle i (as also seen and mentioned in transit section 3.1.1):

$$m_{p,true} = \frac{m_{p,min}}{\sin i} \tag{9}$$

There are many ways an orbit can be inclined from our sight of view. Not only can the orbit be inclined relative to our view, but it can also be inclined relative to the stellar axis of rotation. Such inclination can be implied by a Rossiter-McLaughlin effect[6], which is due to the fact, that the light from the star will be blueshifted on the side that rotates towards us and redshifted on the side that rotates away. This means, that the light curves will differ in spin-orbit alignment depending on the fraction of light that is blocked on either side of the star compared to is rotational axis.

Radial velocity is the method that has been used to discover most planets next to the transit method. Those two methods are also complimentary because one can find the radius and the other the mass of the planet. Both methods are best suited for big planets with high mass or radius and for planets orbiting close to their host star. The radial velocity is even more sensitive to the orbital distance than the transit method.

So, to summarise, these are the exoplanet properties, that can be determined from the radial velocity method:

- Orbital period
- Minimum mass
- An indication of the orbit inclination relative to the stellar axis of rotation

[9] Which might not be entirely correct, so the measured velocity might not be completely accurate for the whole orbit

[10] Note that the velocity of the planet will also be higher, but due to same momentum of star and planet and the hundreds or thousand time higher mass of the star, the error in the velocity of the planet will be a few orders less than the error in the star velocity

3.1.3 Gravitational microlensing

Observation of a star and exoplanet with gravitational microlensing, also called a binary-source event, is a one-time experience with the invloved objects. It occurs when the host star of a planet is passing in front of another bright star further away. The gravitational fields of the host star will bend the light of the background star and while it is passing directly in front, it will intensify it like a magnifying glass.

If the host star has a planet orbiting, the planet will also have a smaller impact on the light with it is its turn to pass directly in front. This required of course that the planet is not in transit or occultation while the system microlenses the background light (See figure 6). Microlensing is hard to measure, both because of it is one-time lucky coincidence, but also because of the time frame. If the timeframe for a star microlensing the background light is around a month, then the time for the effect of the planet will be only a few hours.

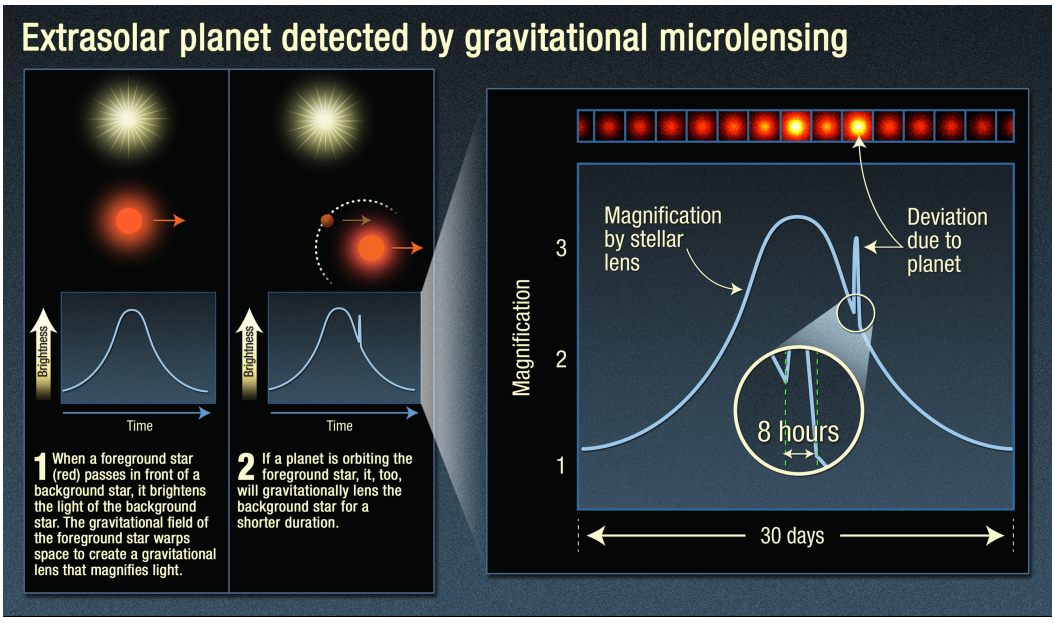


Figure 6: Exoplanet detection by gravitational microlensing. Image credits: NASA, ESA, and K. Sahu (STScI), https://exoplanets.nasa.gov/resources/53/extrasolar-planet-detected-by-gravitational-microlensing/

It might be a useful method for confirming exoplanets found through another method, in case the host star is in a lucky position to another background light. Also we might be able to estimate the mass ratio of the planet to the star and the planets orbital distance. This is done by comparison of the data to theoretical models. Since the mass is important for the gravitational effect, the more massive stars are easier to detect with this method.

Also, planets that orbit in large distance from their star, are also easier to discover, because the magnification of the light will be easier to distinguish from the magnification effect by the host star. The inclination of the planetary disk does not matter in this

method, and hence it is possible to detect planet candidates that would not be possible to discover through transit or radial velocity due to an inclination perpendicular to the sky projection.

3.1.4 Direct imaging and other methods

Direct imaging is also an option, alas for now only possible for large gas-planets in large orbital distance. This methods requires a large telescope with adaptive optic system and high angular resolution. Still, only planets that orbit in a large distance from their host star can be visually captured in an image. If the planet is too close, the star will outshine it a billion times in the optical part of the spectrum.

Direct imaging and gravitational microlensing is complimentary to both the transit and radial velocity method. While the latter are best suited for large planets near the host star, the imaging and microlensing method can be used to detect large bodies in the outskirts of a solar system.

3.1.5 Spectroscopy

Once a planet is discovered and confirmed, we can collect light curves from different positions of the exoplanet as seen in figure 3a, from the occultation, the transit or from a planet position in between. In the occultation position, we get flux from the star only. In transit we get flux from the star and thermal emission from the planet, minus the light blocked by the planet. In between we get flux from the star and the reflected flux and thermal emission from the visible part of the planet.

One way of collecting spectra data from the planet is by transmission spectroscopy. In transmission spectroscopy, we measure the flux from the star-planet-system, while the star is in transit and compare with the flux from the star itself when the planet is in occultation. By subtracting the stellar flux from the total star-planet flux when the planet is in transit we obtain a planet spectrum. Some of the stellar light will also pass through the upper levels of the atmosphere (if an atmosphere exists) of the exoplanet, probing it through a range of optical depths.

It is incredibly difficult to get detailed spectra of exoplanets atmosphere due to the tiny fraction of the light from the star that passes through a planet's atmosphere, because the atmospheric layer is very thin. We are able to obtain low resolution spectra with a few specific points for Hot Jupiters, where the atmosphere could be several hundreds of km, while we still have to wait for a better telescope, such as the long awaited James Webb Space Telescope (JWST)[11], which hopefully will be launched in 2021, to be able to study Earth-like and super-Earth planet atmospheres. Earth has a an atmosphere with a height of about 8 km.

3.2 Derivable exoplanet parameters

It is our eyes that look through the telescopes when we observe, but it is the brain that sees and our mind that interprets and draws conclusions. Our detectors, eyes

[11] https://www.jwst.nasa.gov/

or build in telescopes, receive electromagnetic signals, and our brain interprets the incoming signals based on both intuitive neurological processes as a result of our biological adaption to our experience living on planet Earth, while others are developed through science and the rational mind. From our assumptions of fundamental principles of space and time, we derive and draw conclusions about distances, periodical time, shapes and sizes with more or less certainty. What we think we know depends on those assumptions being true.

In the case of teaching exoplanets in high school, I would like to be able to include calculations that the students will be able to do to derive realistic values based on physical principles that they have been taught, balancing a creative imagination in the exoplanet design. In this section I will therefore focus on the derivable parameters, that I find relevant for the teaching package, based on what is possible to observe, as described in previous section 3.1. Which parameters I choose for the case in the end and why, will be described in the following section 4.

3.2.1 Orbital period and radius

The orbital period of the planet can be derived directly from both the transit and radial velocity method as described in the respective sections 3.1.1 and 3.1.2. The orbital distance (or separation) is derived using Kepler's third law, which is taught in high school in both first year physics and the astronomy elective course.

Kepler's third law in the general form using standard units in eq. 6, can be simplified by using star mass in sun-masses and orbital period in earth years, resulting in a relative orbital distance in AU:

$$\frac{a^3}{[1AU]} = \frac{T^2}{[1\text{Year}]}\frac{M_*}{[1M_{sun}]} \Rightarrow a^3[AU] = T^2 M_* \tag{10}$$

3.2.2 Mass, size, surface gravity and density

As we saw in the method section, a minimum mass can be derived from the radial velocity method (eq. 8 and eq. 9) while size can be derived from the transit method (eq. 3). Both the density and the surface gravity of the planet can be derived when the mass and radius are known, e.g. when combining observation with transit and radial velocity method.

Using Newtons law of gravitation $F_g = Gmm_p/R_p^2 = mg$, where m is the mass of an object on the surface of the planet of mass m_p and radius R_p and g is the gravitational acceleration at the surface, given in units $[N/kg] = [m/s^2]$, the mass of the object cancels out, resulting in:

$$g = \frac{M_p G}{R_p^2} \tag{11}$$

The surface gravity of a planet can have an effect on the atmosphere. If the surface gravity is small, such as the case with Mars, which has a surface gravity of about 1/3 of Earth, it will have a harder time holding on to a volatile atmosphere. Note: When dealing with gas giants, we define the radius as the total radius at which stellar light is absorbed from the planet and hence the surface is defined as the top layer of the

atmosphere.

The density of the planet is important for learning about the planet's physical structure and is found by dividing the found measured with the volume $V = \frac{4}{3}\pi R^3$:

$$\rho = \frac{m}{V} = \frac{4\pi m}{3R^3} \tag{12}$$

3.2.3 Elements in the atmosphere

By observing and comparing spectra of the host star and the planet, we might detect different elements in the planetary atmosphere. Due to the differences in atomic and molecular structure, different atoms, ions, and molecules absorb light from the host star at different wavelenghts, and hence there will be absorption lines in the transit spectrum, that cannot be seen in spectra from the star alone.

As already mentioned in section 3.1.5, it is difficult to obtain high enough resolution spectra for the planet atmosphere due to the massive amounts of flux coming from the star relative to the planet. For Hot Jupiters, where the planet has a larger amount of atmosphere close to the radiation, this can be done with current telescopes, but for smaller rocky planets, we need better tools.

Flux from a star can exceed the flux from a hot Jupiter by for example six orders of magnitude or more (figure 7), which makes measurement of the relative fluxes difficult. In longer infrared wavelength this difference in flux becomes smaller and measurements measurements can be more precise. The flux difference between a Sun-like star and an Earth-size planet will even in the infrared measurements be at least seven magnitudes. The above mentioned JWST will among other improvements have a larger angular resolution and longer wavelength coverage making it possible to create spectra of rocky planets atmospheres.

When observing atmospheres, it is especially interesting to look for biomarkers, which are elements that should not be found in an atmospheric equilibrium, which then could indicate something, that shifts the equilibrium, such s life or geological activities. For example, a combination of finding O_2 or O_3 with CH_4 would indicate an atmospheric disequilibrium, since this elements would naturally react into water and carbon dioxide. In the calculations, a planet is assumed in thermodynamic equilibrium. This is not necessarily the case, for example if the planet contains life.

3.2.4 Planet temperature

The temperature of a planet cannot be derived directly from our observation methods, but is one of the most important factors for whether a planet is habitable or not. We define the equilibrium temperature as the temperature at which absorbed power of the planet equals radiated power from the planet. We can use the equilibrium temperature as the starting point for the average temperature of a planet.

There are other factors that will influence the true temperature of the planet, such as the greenhouse effect (section 3.3.3) for the overall averages and the tilt (3.3.4)

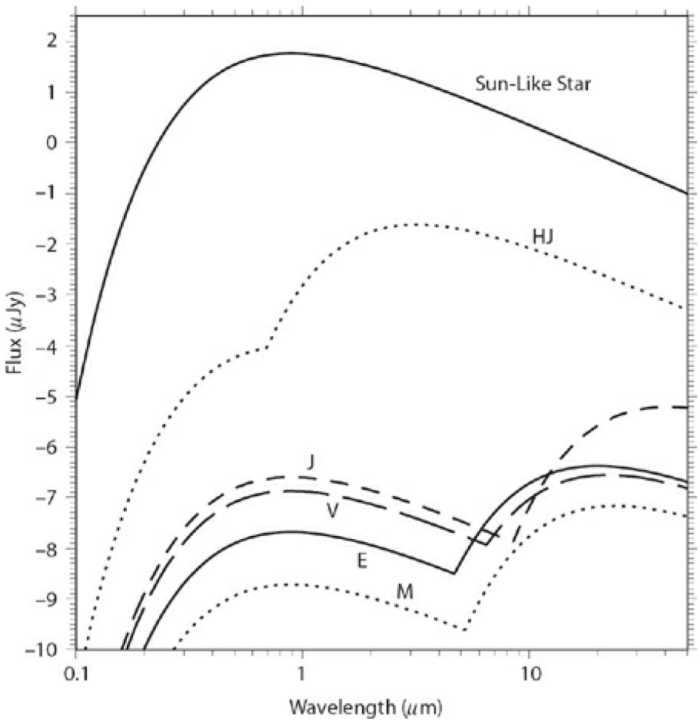


Figure 7: Approximations of star-planet distribution of reflected and emitted flux for planet-star flux ratio of a sun-like star, a hot jupiter and our solar system planets (Jupiter, Venus, Earth and Mars) [7]

and eccentricity (3.3.5) for local variations. For comparison, the calculated effective temperature of Earth would be 252 K (-21°C). The true average global temperature of Earth is 288 K (15°C). The greenhouse effects of some gasses in the atmosphere can increases the true surface temperature substantially.

The temperature also depends on the (bond) albedo[8] - the fraction of received light reflected by the planet surface. The albedo depends on the surface material of the planet, which again depends on the components that the planet consist of. This will be described in one of the following sections, 3.3.1.

Starting with the equations for absorbed power from the star and radiated power from the planet interior, and using the equation for the luminosity of a black body, $L_* = 4\pi R_*^2 \sigma T^4$, we can derive the equilibrium temperature:

$$\begin{aligned} P_{abs} &= P_{rad} && \Rightarrow \\ \frac{L_* R_p^2}{4a^2} \overbrace{(1 - A_B)}^{\text{Absorbed fraction}} &= \overbrace{4\pi R_p^2}^{\text{Surface Area}} \overbrace{\sigma T_{eq}^4}^{\text{Flux}} && \Rightarrow \\ T_{eq} &= \left(\frac{L_*}{16\pi\sigma a^2} (1 - A_B) \right)^{1/4} && \Rightarrow \\ T_{eq} &= T_*(1 - A_B)^{1/4} \sqrt{R_s/2a} \end{aligned} \tag{13}$$

Hence, we can derive the equilibrium temperature of a planet from the radius and temperature of the host star, the orbital distance and the bond albedo. For $A_B = 0$

all the energy gets absorbed while $A = 1$ means all the energy gets reflected. A planet with reflection albedo of zero will absorb the highest amount of energy, appearing darker and have the highest temperature for its parameters.

In this we assume that the planet does not have any intrinsic energy source in it self. While this might be negligible for ordinary rocky planets, it might not be for large-sized gaseous planets. The total effective temperature is then the sum of the radiation equilibrium temperature and the intrinsic temperature:

$$T_{\text{eff}} = T_{\text{eq}} + T_{\text{int}} \tag{14}$$

3.3 Other considerations for exoplanets

In this section, I will go through a few physical parameters, that are relevant to know about a planet, but that are not as easy to derive from the observables.

3.3.1 Albedo

As mentioned in the previous section, the albedo is a measure of the planet's ability to reflect light from the star. The reflectivity is the ratio of scattered light from the light received by the planet. There are different ways to define the albedo. Bond Albedo (A_B) is the ratio of total reflected stellar power to the total power radiated on the planet. This is the ratio that we use for calculation of the equilibrium temperature (section 3.2.4).

Bond albedo, which is used in determining the planetary equilibrium temperature, depends on the spectrum of the incident light from the host star[12] as well as the planetary surface and atmosphere, which partially can absorb some of the radiation. Since the planetary surface conditions are not easy to estimate, the albedo and hence the equilibrium temperature can only be rough guesstimates for an exoplanet. H_2O-vapor will for example absorb majority of the energy it receives and hence planets with more water molecules in the atmosphere will have a lower albedo and warmer temperatures. Liquid and solid water will on the other hand have a high reflectivity, which means that water or ice on the surface will reflect more light and lower the surface temperature.

3.3.2 Atmospheric pressure

The atmospheric pressure on the planetary surface is a direct result of the amount of atmosphere weighting down on it, hence it varies with the altitude. The pressure at the surface depends on how far up the atmosphere stretches.

The surface pressure will affect the temperature range at which water can stay liquid, which defines the planetary habitable zone. Therefore, we need to take the pressure into account, when considering the habitability of a planet. As seen in figure 8, the temperature range is ideally not enough to state whether can have liquid water. On a planet with low pressure such as Mars, there surface pressure is around the triple point and water will go directly from ice to vapor at temperatures around 0°C, while

[12] https://www.britannica.com/science/albedo (March 2021)

liquid water could exist on a high pressure planet like Venus, if the temperature was below 350°C.

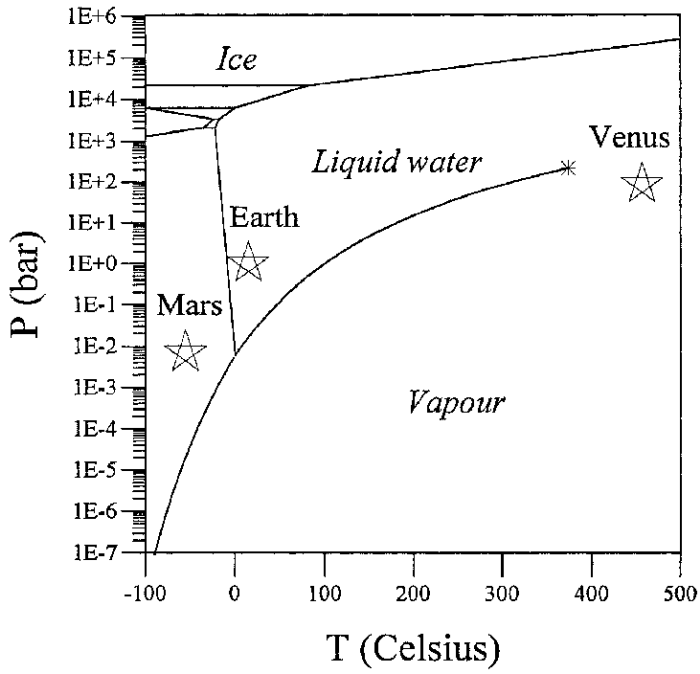


Figure 8: Pressure-Temperature phase diagram for water. Image credits: Bernd Lehmann, TUC, Department of Geology and Paleontology

The gravity of the planet will help holding on to an atmosphere, so the more massive the planet compared to its radius (squared), the higher the chance of being able to keep an atmosphere, especially with light elements with lower escape velocities in the atmosphere. A gas giant will always have a thicker atmosphere as part of it is gaseous whole. It might be harder to define the surface on such.

3.3.3 Surface and weather

We can roughly categorize planets in four different types: Terrestrial, Super-earths with a loosely defiend mass of 1-10 Earth masses, Neptune-like and Gas Giants, which can be up to 4000 Earth masses. A sub-category of the gas giants are the Hot Jupiters, which are Gas Giants that orbit close to their host stars.

The Terrestrial and Super-Earths are rocky planets, which have an easy defined solid surface and a perhaps a thin layer of atmosphere. The Neptune-like "ice giants" and the gas giants on the other hand, are thought to have a rocky and an interior of a fraction of metallic hydrogen[7]. Neptune-like planets have a layer of melted ices between the outer gas layer and the solid core.

The surface of a gas planet is harder to define, since most of the planet composition is gas. One common definition of the surface is where the pressure is 1 bar. Atmosphere at this altitude will remain fairly uniform in density and temperature because it is deep enough not to be influenced by external factors, such as solar wind. While the surface of a gas giant or Neptune like planet will be gaseous, the rocky planets can

have both solid and liquid surface.

The atmosphere of a gas giant is thought to originate from direct capture of gas form the protoplanetary disk, while the atmosphere for rocky planets are thought to come from planetary accretion. The atmosphere of a planet depends on both the original source of the gasses and the location of the planet in the protoplanetary disk during formation and on atmospheric escapes. Due to the atmospheric origin in gas giants and to their larger gravity, the atmospheric composition of the gas giants will more likely be unchanged during the solar system evolution, which means that their composition will be similar to the solar composition. This does not apply to rocky type planets.

The atmospheric compositions of exoplanets are still to be uncovered both theoretically and observationaly. When we look at exoplanet spectra (so far primarily for Hot Jupiters), we try to find absorption lines for elements and molecules. In addition to the chemical composition, we also need to take into account that some of the compounds will form clouds, depending on the temperature, pressure and condensation curve for the gasses.

We have a fair understanding of atmospheric compositions of the planets in our solar system. There are a few dominant molecules, such as CH_4, NH_3, H_2O and H_2 in gas giants while the Terrestrial planets are dominated by the CO_2 gas. The composition of Earth is dominated by 78% N_2 and 21% O_2. Only 0.04% of our current atmosphere is CO_2. The lack of CO_2 compared to the other Terrestrial planets in our solar system is due to the disequilibrium created by life. Although only a relative small amounts of gasses such as CO_2 and CH_4, they still have a great impact on our climate, functioning as strongly absorbing greenhouse gasses, unlike the homonuclear diatomic molecules, such as H_2 and O_2.

The atmosphere of a planet, regardless the planet type, can be either clear or cloudy, but most planets with equilibrium temperature less than 2400 K, will have dust, grain or liquid formation in the form of clouds[9], which is easily seen observing our own solar system, where clouds can be found in every planetary atmosphere. Clouds are important because of their contribution to the atmospheric energy balance[7]. Depending on the cloud composition, they might contribute to a higher albedo (such as water clouds), reflecting solar light and cooling down a planet. Other compositions are strong absorbers of short wavelength light. Clouds can change the planetary atmosphere, the temperature and the circulation. It is a whole field of study, which is outside the scope of this thesis, but it is important to note, that they will have a big influence on the planetary atmosphere. From the existence of clouds, one could continue and imagine the precipitation with liquid and solid compounds, both dependent on the components and their phase determined by temperature and pressure.

At last, it might be relevant to mention the importance of atmospheric circulation, which the spectra of dayside versus night side flux of a planet can partially reveal. A smaller temperature difference between day and night than expected (for example in tidally locked planets) might give a hint of large atmospheric circulation. The dynamics of this circulation requires complex and time consuming calculations, which I will not go into here, but in the context of exoplanet design, one could consider winds on

the planet surface and their significance for reducing the temperature gradients.

3.3.4 Axial tilt

The tilt of the Earth, which is about 23.5° is what makes up our seasons. But that is not the only importance of the tilt. The tilt of Earth is, unlike the tilt of Mars, very stable. The stability is what makes the seasons predictable and gives life on Earth predictable cycles, which is crucial for the development of advanced life[13].

Here, the Moon also play an important role. The gravitational effect of our Moon stabilizes the tilt, which might have otherwise have changed under the influence of the Sun or Jupiter. Likewise the tilt of an exoplanet can have great importance on the possibility of the development of life. This is part of the Rare Earth Hypothesis[10].

One could imagine which effect another tilt would have on life on the planet. A tilt close to 0°C like Mercury, would have most of its energy distributed at the equator and least on the poles, while the opposite would be the case in a 90° such as Uranus, or of the tilt was unstable because of the lack of a stabilizing moon or a closer distance to a more massive object in the solar system. The main thing here, is that the temperature differences would be very high in such case, and it would disturb an consistent evolution. Or a stable location for our travel destination, if that was to be the point of the planet.

No measurements can so far give us any indications of an exoplanetary axial tilt, although some observations of planetary resonances or the lack of such, might indicate large planetary axial tilts. This relates to Kozai mechanism[11], which also affects the eccentricity of the orbit. The effect is of time scales much larger than the orbital period.

3.3.5 Eccentricity

Just like the tilt of a planet, the eccentricity of the planetary orbit can have influences on the variations in temperature. Earth has an eccentricity near 0, which means that the orbital is practically spherical, and hence the seasons are only influenced by the tilt. Mars has a higher eccentricity, which gives it additional seasons.

The eccentricity can be derived from the radial velocity method if we have enough data points for a phase diagram, as seen in figure 9. Depending on the shape of the phases, we can deduce the eccentricity and the viewing angle. Many observed exoplanets have orbits with larger eccentricities than we see in our own solar system.

3.3.6 Other considerations

There are still more considerations for exoplanets. Rotation about own axis is what created the day and night periods on Earth. As living beings we, as many other living organisms, are highly adapted to this inner circadian rythm of our rotating planet.

Planets near the gravitational fields of the star can be tidally locked which means

[13] http://hyperphysics.phy-astr.gsu.edu/hbase/Astro/orbtilt.html (2020-12-11)

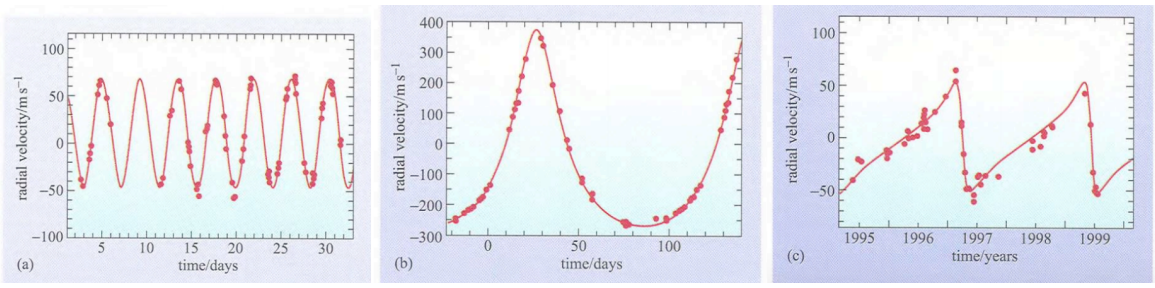


Figure 9: Phase diagrams of planets aroundsstars: a) 51 Pegasi with low eccentricity, b) 70 Virginis with and c) 16 Cygni B woth large eccntricity, Image Source: "An Introduction to Astrobiology"[12]

.

that they move (almost) in a synchronous rotation around their host planet. One such example is our inner most planet Mercury, which "day" is slightly longer than a year, because it rotates at the same time that it orbits the Sun. Another example is our Moon, which is tidally locked to Earth. Many discovered exoplanets are far closer to their host planet than Mercury and depending on the mass of their host star, they will most likely be tidally locked. We cannot derive the rotation from current observation methods, but it is interesting to consider if we were to imagine life on a different planet.

Magnetic fields around a planet, generated by liquid metals in the outer core, will also have impact on the planet habitability, for example by protecting the planet from solar winds and also by help keeping the atmosphere from escaping the planet surface gravity. Neither Mars or Venus has a magnetic field, but while Mars has almost no atmosphere, the opposite is the case on Venus. This is an example on how a magnetic field is not a necessary condition for an atmosphere, although it does help.

The frequency and strength of solar winds generated by the host star, is another parameter to consider, when considering the habitability. One example is our closet neighboring star, Proxima Centauri, which is a red dwarf with a planet orbiting. The planet experiences solar wind pressures that are thousands of times larger than we have on Earth, so although the planet might be in the habitable zone, it does not mean that it is habitable. This is an example of how habitability is not equal to, but a subset of the habitable zone.

3.4 Summary

While this section focused on the many aspects of observing planets and the possible derived properties of exoplanets, the next section will boil it down to a representation to be used in a high school level teaching material. Table 1 sums up the main possible derivations from the mentioned observation methods.

	Transit	RV	Spectroscopy
	Light curve	*Velocity curve*	*Spectrum*
Orbital period (year)	X	X	
Orbital Distance	X		
Planet Radius	X		
Atmospheric composition	(X)		X
Atmospheric circulations	(X)		
Planet rotation (day)	(X)		
Planet mass		X	
Orbital inclination / to stellar axis		(X)	
Albedo			
Atmospheric pressure	(X)		
Axial tilt			
Orbital eccentricity	(X)		

Table 1: Possible properties derived from observation methods

4 The package: Exoplanet Design

In the previous section, I presented observations and derivations of exoplanet properties. In this section I will narrow this down to a few equations for high school students to work with. Those should be relevant for properties that are important from an reverse engineering point of view. In real life, we don't "design" exoplanets, we observe and try to model the reality. In the exercise, the students start with an imaginary exoplanet of their choice, and thereafter reverse engineer the properties to make it realistic and pluasible. The purpose of this is to train the students in using physics in a creative and self-determined context.

As mentioned, I have used an existing package called "Exoplanet Design" for elementary school level as a starting point for a similar exercise for high school level. The original exercise is attached in appendix C, and is targeted for middle school students. It consists of student guide, a teacher guide and a presentation like all of the packages for Online Observatory. While the focus in the middle school level was on raising the awareness of diversity of planets outside our solar system and thereafter consider the possible life evolved in alien scenarios, at high school level a significant amount of relevant physics can be added to the creative aspects. This is where some of the physics from the previous section can be introduced. Both packages are based on NASA's Exoplanet Travel Bureau[14] for poster inspirations and use NASA's Eye on Exoplanet[15] for information and inspiration on discovered exoplanets and their host stars. I have included the material for the high school package as described in the following in appendix D.

In the presentation for teaching material for exoplanet design, the students are introduced to the relevant background and NASA's resources, and thereafter a walk-through of various properties for an exoplanet and the methods for calculating those properties if possible. The methods for observing exoplanets are shortly mentioned, but are expected to have been introduced in a previous session. A graphical overview of as seen in figure 10 is included to give a better sense the properties grouped in 4 categories: 1) The host star and its influence on the planet temperature, 2) The size and gravity of the planet, 3) The planet type, surface and weather, and 4) The "calendar" periods of the planet.

While there could be included many interesting factors to consider when imagining an alien world, time itself is not an unlimited resource for the class lecture and exercise. I wanted to have a balance between the creative parts and the calculations, therefore I chose only a few equations to include. Three of the above categories include calculations, while the surface and weather is mostly a creative exercise without numerical values. I chose a few relevant attributes, that I figured that the students could be expected to calculate, which at the same time were had a big influence on the design of an exoplanet as a travel destination.

- Equilibrium temperature (with a guesstimate of the albedo)
- Surface gravity

[14] https://exoplanets.nasa.gov/alien-worlds/exoplanet-travel-bureau/
[15] https://exoplanets.nasa.gov/eyes-on-exoplanets/

Figure 10: Introduction in the presentation to roughly four main exoplanet physics relevant to the exercise: 1) The host star and its influence on the planet temperature, 2) The size and gravity of the planet, 3) The planet type, surface and weather, 4) The calendar periods of the planet. Figure in presentation slides (appendix D). Images from NASA's webpage.

- Length of the year

These will be presented in the following sections.

4.1 Equilibrium Temperature

The temperature of a planet is important for the habitability for "life as we know it". The main heat source comes from the host star, which is why we can use the hypothetical equilibrium temperature as a base line for the expected temperature on the planet surface. The equation, as seen in equation 13 is dependent on the temperature and radius of the host star and the orbital distance. Hence it requires the students to think about not only the planet, but also the star that it orbits. In the students guide, the students therefore start with considering the properties of the host star.

The equilibrium temperature is also dependent on the albedo of the planet, which again is dependent on the surface. In the presentation, I made a note about leaving the albedo at 0 (all energy is absorbed by the planet) until they figured out the surface later. To make the exercise text short, I left it out in the student guide.

Considering that some of the students might have trouble using an unfamiliar equation, and I decided that an understanding of the implications of it was more important that calculating a specific number. After all, physics is more about understanding the physical implications than plotting numbers in a calculator. Therefore I added a "Too complicated, didn't calculate" note to give an idea of the overall influences on the equilibrium temperature:

- Higher star temperature and radius gives a hotter planet
- Higher distance from the star gives colder planet
- Higher albedo/reflection also gives colder planet

After the calculations of the equilibrium temperature, the final temperature would still depend on the surface material (albedo) and the atmosphere (greenhouse effect). In the end the purpose of this calculation was also that it could be used to get an idea on whether the planet was in a habitable zone with possible liquid water.

4.2 Surface Gravity

At this point, the students could have a idea on whether their planet could harbour life. Now it was time to consider the type and size of the planet and how a surface gravity could affect a possible life or human beings on a travel destination.

The calculations of the surface gravity is simpler than the previous, and requires only the size and mass of the planet, which the students are encouraged to consider before calculating the gravity. Classifying the type of planet could give a better idea of the metrics: Earth-like, Super-earth, Neptune-like or Gas Giant? (Fig. 11)

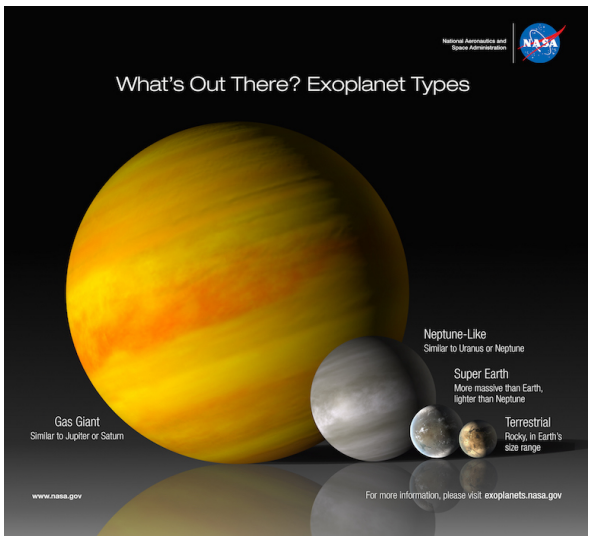


Figure 11: Infographics of the 4 planet types from NASA

After figuring out the size of the planet, the students can choose to calculate the objective gravity with the use of the total mass and radius of their planet and the gravity constant, and a relative surface gravity compared to the surface gravity of Earth, $9.82m/s^2$. The first option is given in equation 11, while the gravitational constant is not needed for the relative surface gravity, using the mass and size of the planet given in relative Earth mass and radius:

$$g_{rel} = \frac{M_p}{R_p^2} \tag{15}$$

It is up to the students which method they use, but the relative surface gravity might give a better contextual and intuitive understanding, plus they can skip the astronomical numbers including the gravitational constant. I have also included examples of specific exoplanet gravity calculations and a physical implication of the meaning of a relative high or low surface gravity in the context of weight.

4.3 Length of the year

The final calculation comes at the end of the exercise, following a section of mostly a use of their creative imagination, designing the atmosphere and it is components and pressure, the surface "look and feel" such as mountains, rivers, clouds and atmospheric

composition, which I will elaborate in the next subsection.

The assumption is that the students already had about planetary orbits and Kepler's laws, and therefore it seemed obvious to include their previous learned knowledge in the exercise. They have already been encouraged to consider the distance from the host star and the mass of the star in the section about properties of the star, before calculating the equilibrium temperature. These values could be used in Kepler's third law to calculate the orbital period with equation 2.

4.4 The creative guesstimates

As mentioned, there are several things about the planet, that cannot be derived from the observations we are able to make, but which are important for the overall planet with the qualities that make it a home for life - or a traveling destination. These are factors such as the atmosphere, if there is any. What does it consist of? Is it human breathable? And what is the atmospheric pressure at the surface? Although it could be possible to consider the pressure gradient, it is not a simple task even at University level, therefore, the students are encouraged to consider it in rough subjective numbers relative to Earth atmosphere.

The structure of surface is another subjectively important factor for the welfare of life. The students could consider whether the surface is solid, liquid or gaseous, which would be partially implied by the planet type, that they already though about, but for a rocky planet, the surface can be both solid and liquid in various degrees. Are there any mountains and does the surface change over time? Is it affected by the weather? Is it raining, and what could it be raining with acid or diamonds? Are there any winds, storms, or cloud? Is there a greenhouse effect? For once, speaking about the weather is not only for the purpose of small talk.

The last things to consider, that would be relevant for a life as we know it, are the recurring periods of time: The length of the day when the planet is rotating around itself, the length of the year when the planet it orbiting its star, and any seasons that might be affected by either the axial tilt of the planet, as here on Earth, or the eccentricity of the planetary orbit. As an example, unlike on Earth, the Martian seasons are not only influenced by the axial tilt of Mars, but also by the eccentricity of Martian orbit, because it is not as spherical as the orbit of Earth. Such considerations of the calendar implications is something that is also relevant in our own astronomy-related history, as mentioned in section 2.3, and it creates a context to something we take for granted living on Earth - the lengths and periodic occurrences of days, years and seasons.

All of these factors, except the year, is something that the students can think about creatively, without calculations, but they are still expected to use some logic. For example, when they consider the length of the day, I also suggest that they could consider a tidally locked planet with one locked day-side and night-side. This usually occurs for planets or moons close to their host. Also the implications would that the temperatures would have extremes on both sides instead of having an average equilibrium temperature.

This presentation and student guide is included in appendix D, and is meant as a first version for material that I will be using later as a test case as described in part IV, and improved upon in part V.

Part III
Literature review and theoretical framework

In this part, I present a literature study based on the topics, that I have identified as a possible challenge for teachers in astronomy in elementary school and high school in the preliminary domain research in section 2.

To recap, the topics identified in the pre-investigating interviews and surveys were:

- Astronomy can be abstract to teach, because it is often far away form our everyday life.
- It can be hard to find practical assignments to do, because of the nature of observations at night and also it is not always easy to find easy to use data.
- Students are easily excited by "exotic" topics (such as black holes and dark matter) in astronomy, but at the same time afraid of the complexity of those topics. It is a challenge to find the right balance for the level and to make it not too superficial (pure science fiction) and not too complex (death by math).

Various challenges has also been identified in previous research done on children's and adult's understanding of the Universe. A survey of 1120 adults on their contemporary cosmological beliefs in 1987[13] showed that misconceptions about space and astronomy carries on to the adult life. This might not be surprising, since astronomy is an abstract science and knowledge about celestial objects isn't required to function as a human in a modern society. Also, while learning new concepts might be hard enough, it is much harder to change an integrated misconception.

Concept about the world are mental models which can be[14]:

1. Intuitive models based on environmental stimuli
2. Correct scientific models
3. Synthetic models: A hybrid when the learner attempts to accommodate scientific models with own knowledge.

The synthetic model is the base of many misconceptions. Therefore, it is important to listen to the students questions and take them seriously, otherwise they might adopt wrong interpretations as part of their scientific view.

Other surveys on topics that included the nearest celestial objects and their influence on and perspective from Earth[15][16] compared with the previous surveys and concluded that some of the problems arise from misleading diagrams that are and not to scale[17] and that concepts need to be taught in suitable order - the students need to understand the reason first.[14]. This order might be both relevant to a teaching sequence in a course, as well as in building up an exercise, which is why I find it relevant to consider for this thesis.

5 Teaching vs. learning

Before I dig deeper into some of the above challenges, let me introduce a representation of a teaching situation by using the didactic triangle[18]. It is commonly used as a frame and consists of teachers, students and content and the interaction between the three parts, as seen in figure 12.

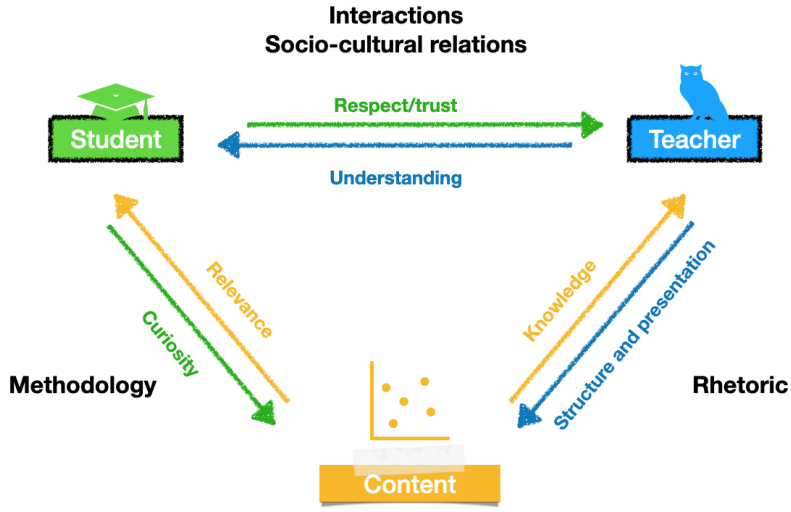


Figure 12: The three components of an teaching situation and the relations between: Teacher, student, and content, and their relation.

Besides the three aspects of the didactic triangle, there are also three axes - the relations. Those can be overall described as the teaching, teaching rhetoric and the students methodology[19], but have underlying many aspects.

The teaching covers the student-teacher-relation. The teaching situation will be influenced by the teacher's understanding of the students, such as their level, current knowledge and interest, and from the student's point of view it will be influenced by their trust and respect in their teacher.

The rhetoric is the teacher-content relation and refers to how the teacher presents, structures and communicates the content. It depends on the teachers knowledge on the subject taught, experience and an ability to present and structure the content to achieve a communication goal.

The methodology is described as the aspect between the students and the content. This deals with methods used for the students to acquire the knowledge in the best possible way, which could be influenced by how relevant the subject is (made) for the student and visa versa how curious the student is about it.

All of these factors influence the total learning experience and student engagement and are important to keep in mind when planning teaching material, but only aspects that are directly relevant to structuring and presenting the content, is relevant for this thesis. Hence, the relationship between the teacher and the students is out of scope here, but it is important to keep in mind that it is a factor in the teaching situation,

when examining the result of the teaching. Even with the same material (content), each teaching situation will be different, because both teachers and students vary.

The teaching material for the Online Observatory need to have a teaching guide and a student guide part as a standard structure. Although both should part of the final package, I have focused mainly on developing and testing the student guide (and presentation) as described in the previous part II.

This doesn't mean that I will skip the teacher guide for the final product, but I will argue that the teacher guide is most relevant when the level is elementary school, where many teachers do not have an education in and knowledge of astronomy. This can be seen as a lack in the teacher-content axis in the didactic triangle, and should be accounted for with a thorough guide. Astronomy high school teachers, on the other hand, will most likely have an education in astronomy or physics and hence the teacher-content axis will be stronger and they might even have their own idea on how to present the content. My focus on the teacher-content axis will be in the presentation and structuring of the teaching material in the student guide and the presenting slides, which is also material for the teacher.

What is the point of teaching, if not for students to learn? It is two coins of the same side, but there is a difference in the focus on teaching and the focus on learning. When we focus on the learning, we base the teaching on the students learning process. One could also ask further, what is the point of learning? For some students, it might be "passing the exam", and that would be an extrinsic motivation. Studies show that intrinsic motivation is far more effective for knowledge and memory retention[20] and that the intrinsic motivation is correlated with curiosity[21]. The exam-passing as an extrinsic motivation is more of a side effect of the evaluation process, and although it is sometimes the main motivation for students to participate in a course, this not a motivation I will investigate closer, as the intrinsic motivation is far more interesting and effective for the purpose of the thesis. More about that in section 7.2.

I have covered the "why" we should *teach* astronomy in section 1.2, but what's in it for the students? As some teachers mentioned in the interviews, the students are easily excited by the topic, and I would like to use that excitement and curiosity as a natural driver and enabler for learning and focus on learning process as opposed to the teaching methods[22], as illustrated in fig. 13.

In the following sections, I will review literature about problem- and context-based learning, since this fits the frame of most of the material presented in the Online Observatory. I will also take a closer look at curiosity as a learning driver and process to gain a better understanding on how to use the student's interest in astronomical topics as a context for relevant physics.

I will use this literature review and theory to help me design and improve an astronomy teaching package with the focus on the process of thinking and learning when the students interact with the teaching material. By problem solving assignments in a relevant context I hope to make astronomy less abstract and by using the student's curiosity in "exotic" topics, I hope to make it relevant to physics at various levels.

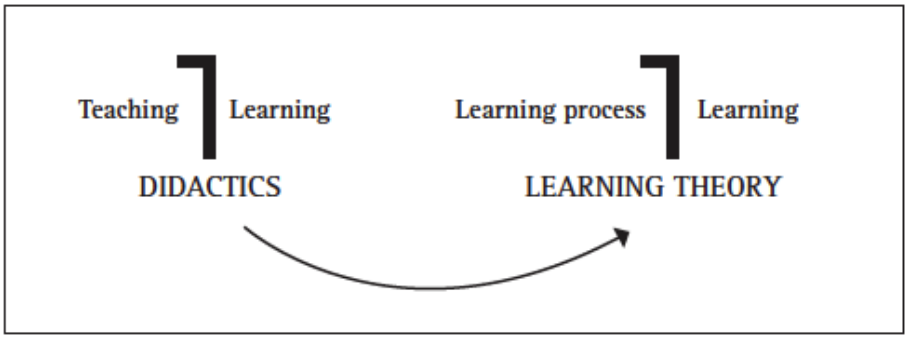


Figure 13: Transformation from didactics seen as teaching aiming to stimulate learning, into the learning process itself to stimulate learning.[22]

6 Problem- and context-based learning

The reason why science concepts might be abstract, is that a lot of those concepts cannot be directly experienced. Scientific concepts might be categorised into three categories: The macro (what we experience with our senses), the submicro (atoms, structures, forces - the "hidden"), and the representional (symbols, equations etc)[23][24]. These examples are from chemistry, but translating them into astronomy, the "submicro" would be more like "supermacro", way larger than our human size, but also incredibly far away, too far to experience (fig. 14).

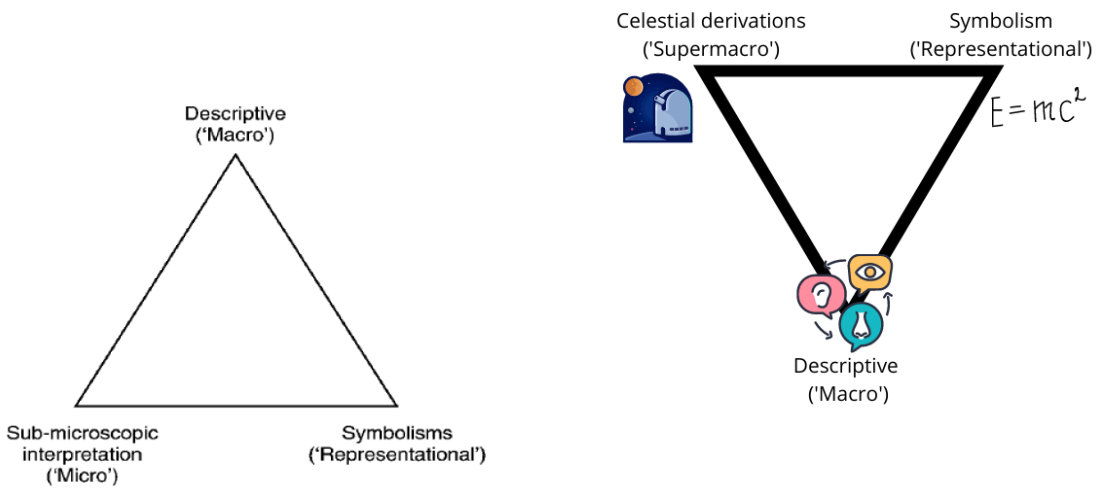


Figure 14: Left: The original tree levels of science concept representation working together as whole. Model credits: A. H. Johnstone. Right: My version as seen from an astronomy perspective.

Content based learning (CBL) starts with a real life context - something that can be known and experienced, hence a macro - before moving into whatever cannot be experienced by senses. It has been showed that a CBL can increase student engagement [24] as well as encourage critical thinking[25]. Prior mental models, which are cognitive

constructions which can describe a phenomena that cannot be experienced directly, that the students have already build in their mind about astronomy concepts, might also play for adapting new knowledge.[26].

Problem based learning (PBL) can be seen as a subset of Content based learning[27]. PBL was originally design to prepare medical students for solving problems in clinical settings in the 1950s. Later it has been adapted outside the medical field on various educational levels, including elementary school and high school, throughout the 1990s and with increasing popularity in the 2000s.

> [PBL is] an instructional method that initiates students' learning by creating a need to solve an authentic problem. During the problem-solving process, students construct content knowledge and develop problem-solving skills as well as self-directed learning skills while working toward a solution to the problem.[27][p. 486]

The problems are often open-ended, which improves the student's critical-thinking and general problem-solving skills, although is not about problem-solving in itself, but rather using the problems and the context as a way to increase knowledge and understanding. The point of creating a context to physics or astronomy problem solving is to anchor the new and maybe abstract knowledge into something that the student already knows and understands. This assumes a constructivist learning, where knowledge is individually constructed and anchored and co-constructed with the environment.[27] It would be relevant to consider the student's culture and environment, to identify relevant contexts is their learning process, such as what are their interests and current understanding of the world?

There are many ways of contextualising a problem. Some examples could be: Using analogies if the subject is abstract[28], using examples from everyday life if possible, using story telling, such as science fiction to set the frame outside Earth[29]. When dealing with exoplanets for example, we would use Earth as one very known example of a planet (and the evolution of the variety of life as the only example we know so far), planets in the Solar system as examples of other planetary objects with different properties, and perhaps the idea of traveling to unknown land with unfamiliar environment, if we want to connect the physics with human space exploration.

One such example is given in a publication where three scenarios of PBL in astrophysics were tested[30]. One scenario called "Alien environments" was used to illustrate unfamiliar environments in solar system physics. The problem given consisted of designing a mission to a moon of Jupiter, Europa, that would capture the imagination of private sponsors. The students are given various physical aspects to consider so that the mission is realistic, but need to balance the technical complexity with the some creative originality in their concept to attract independent sponsors. The above example illustrate how PBL is perfect for interdisciplinary subjects, since real life problems often consist of many aspects. It does, however, also require a substantial amount of preparations compared to ordinary teaching.

In another example in the same report, PBL was experimentally used as a teaching replacement for one group of students in astronomy. They received five problems

to work on together as a group during the course. The experiment showed that there was a surprise factor that work in physics might require more than just finding and following the right equation: "This encouraged some degree of inquisitiveness and understanding and some appreciation of the wonder of astrophysics."[30][p.7]

Such findings could indicate that using problem- and context based learning could go hand in hand with the encouraging curiosity and creativity in the learning process, which I will investigate in section 7.

Sometimes it is hard to find analogies for an abstract level, that breaks with our fundamental macro experience at subatomic sizes or near the speed of light. In those situation, we realize that the principles of our Universe are not always noticeable on our macro level, and we are left with symbolism for our understanding. These is where concepts become truly abstract. Since my test will be on exoplanets and not dark matter as I originally planned, this is left for the discussion and future perspective in section 15.

6.1 Ill-structured problems

PBL can deal with both well-structured and ill-structured problems[31]. Well-structured problems have a well-defined problem with all the elements presented and one correct and definitive answer. Ill-structured problems, on the other hand, are "life is messy" kind of problems. The problem is poorly defined and might be complex, there can be many possible answers and there is not necessarily one best or correct answer. Ill-structured problems require more cognitive skills to solve than the well-structured problems, as shown in a study comparing both types of problems in a astronomy study with 124 9th-grade high school students[32].

The above study showed that while both type of problems required domain knowledge and justification skills, ill-structured problems further require justification for needing to solve the problem (e.g. identify the problem), science attitudes, and regulation of cognition. For the science attitude variable, a TOSRA (Test of Science Related Attitudes) was used in the mentioned study, with 9 additional factors related to motivation towards astronomy. It was shown that for solving ill-structured problems, a general motivation towards astronomy was needed.

What could be the disadvantages if using PBL? As already mentioned, it can be sometimes time-consuming to create context- and real problem-based exercises, specially if they require interdisciplinary connections. On the other hand, all well thought out exercises require time to create. A critique could also be, that in the absence of good models for problem-solving, students might trial and error and on the way adapt ineffective strategies that might interfere with later learning[33]. It is therefore recommended that the students are will be able to see domain experts in action and learn from strategies solving the problems.

This is also supported by the instructional scaffolding pedagogy[34], where students learn with sufficient support from templates and guidelines in the development of skills. Problem-solving of ill-structured problems does not exclude guidance and instructional

scaffolding, but should be based upon already learned knowledge, which is why it is important to keep in mind the a priori level, knowledge and skills of students, when designing or choosing teaching material.

The problem-solving, especially for ill-structured problems, requires a higher level of cognition on the Bloom's taxonomy (fig. 15) Especially ill-structured problems require more understanding than simply remembering the right formula when needed. Critical thinking is needed for analyzing and evaluating and creativity for connecting the unknowns and combine knowledge on your own.

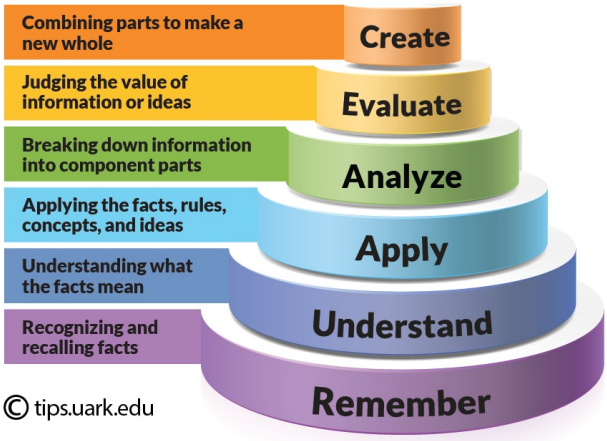


Figure 15: Bloom's Taxonomy, Image credits: Jessica Shabatura, https://tips.uark.edu/using-blooms-taxonomy/ Bloom B S (ed) 1956 Taxonomy of Educational Objectives: the Classification of Educational Goals: Handbook I, Cognitive Domain (New York: Longmans Green)

The levels are from the bottom:

- Simple knowledge: How well are the students able to recall facts, numbers of names taught to them?
- Understanding: Do the students understand the physical implications of what is being taught?
- Application: Can the students apply the knowledge to solve problems? Can they use given equations or numbers to do calculations to solve a problem?
- Analytical skills: Are they able to break a physical phenomena into smaller parts? Can they break a bigger problem into partial problems?
- Evaluation: Can they argue whether the results make sense? Are they able to see if they have made a mistake or argue that there could be other explanations for the problem?
- Creation: Are they able to combine different areas of physics in a novel context?

7 Using curiosity as motivation for learning

We saw in section 6 that a general interest in astronomy was especially important for ill-structured problems, that is problems that can be complex, where the problem is not entirely defined, and where there can be many answers and not one correct answer. We also saw in one of the examples of astronomy teaching, that using context- or problem-based learning often would require a different kind of creativity and critical thinking about the problems, instead of simply pattern matching formulae, because it is not always clear which formula to use and there is not always a clear answer. This means that the students need to understand the problem and the physics behind logically.

Learning science is about this kind of understanding. In a broad sense what all science have in common is the base of scientific thinking, which again means to be critical, to be able question information, use testable methods and to test ideas and assumptions. This is a skill to be learned, and it doesn't necessarily come naturally, also because much teaching does not focus on critical skills, but rather problem-solving algorithms and memorisation. Often the problem and the assumed facts are already given, and students are not trained in questioning the assumptions that are stated in a given problem. Problem-based learning might help develop this way of thinking, especially with ill-structured and context-based problems[25].

As mentioned, interest in the subject has a big influence on being able to solve those problems, but how does interest compare to general curiosity? In this section I will investigate interest and curiosity as a role in learning science and astronomy.

7.1 What is curiosity?

There are many attempts to define or describe curiosity, but no single widely accepted definition. Nevertheless, regardless of the definitions, people are better at learning information when curious[35], because curiosity is a great motivator for learning[36]. it is interesting to consider how curiosity motivates information-seeking, play and exploration, and helps in the learning process, and to have it in mind when designing problem-based teaching material, that requires an extra interest or curiosity, as we saw in the previous section.

It might be hard to distinguish a specific interest from curiosity, and not all study have this distinction. One study shows, that curiosity and situational or individual interest differ in many aspects such as the underlying triggers, biology and specificity of information search[37]. This study defines curiosity as wanting to satisfy an information gap, while an interest is more linked to the "liking" system in the brain.

7.1.1 The wanting and liking scale

Other studies use the term curiosity for both the "wanting" and the "liking", and define curiosity as interest-driven (I) or deprivation-driven (D)[38], which seems to be synonym with the "situational interest" and "curiosity" mentioned above. The I-type is looking for new information for the fun, internal motivation. They do not mind uncertainty and loose ends. The D-type is doing it out of need, they do not want

uncertainty, and need to close gaps. The I- and D-type curiosity are defined on a 2-dimensional liking and wanting scale, and can be visualised as a matrix (fig. 16).

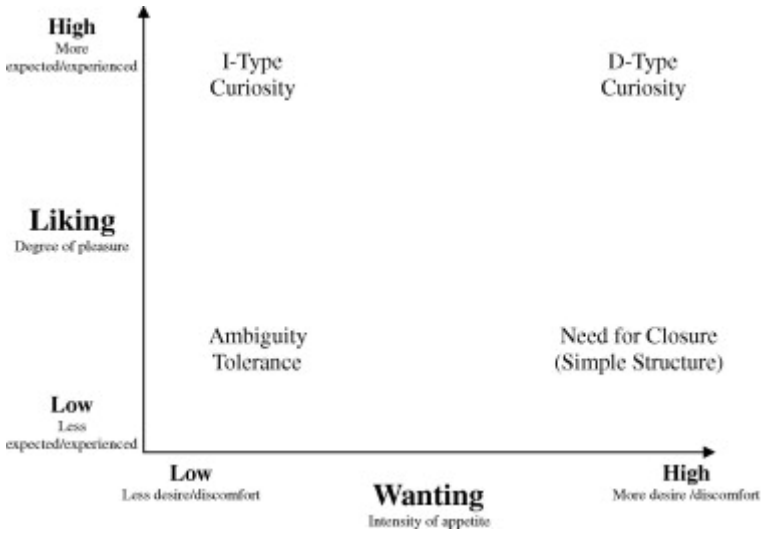


Figure 16: I- and D-type curiosity placed on the liking and the wanting scale. Image source [38]

For the I-type curiosity, the information seeking is associated with pleasure and higher dopamine levels, it is a "take it or leave it" knowledge seeking. The D-type on the other hand is associated with a need to close information gaps in current knowledge and hence a need for uncertainty deprivation. Both curiosity types are high on liking of information seeking, but the I-type does not need the information as such, as contrary to the D-type. Needing is the wanting-dimension.

7.1.2 Kinesthetic curiosity

Another interesting research-project, that can be connected to the I- and D-type curiosity is research done on how kinesthetic curiosity is used to gather knowledge in an open information space. The study deals with how we choose which information to search for, how we actually search for it and what we do with it afterwards.

> The busybody, the hunter, and the dancer: In a model called kinesthetic curiosity, we distill three major modes of potentially many functions described by movement embedded within information landscapes: the busybody scouts for loose threads of novelty, the hunter pursues specific answers in a projectile path, and the dancer leaps in creative breaks with tradition.[39][p.2]

Here I-curiosity could lead to a busybody or a dancer behaviour, while a D-curiosity would a hunter type, in the need of closing information. This distinction between curiosity-type might not simply be a question of personality, but also where we are in the information seeking process. While the busybody information seeking is more useful in the initial part of an open question or in a case with many unknowns and a diverging information gathering for defining the problem, the hunter gatherer is more useful at the middle of a project when specific questions need to be answered on a

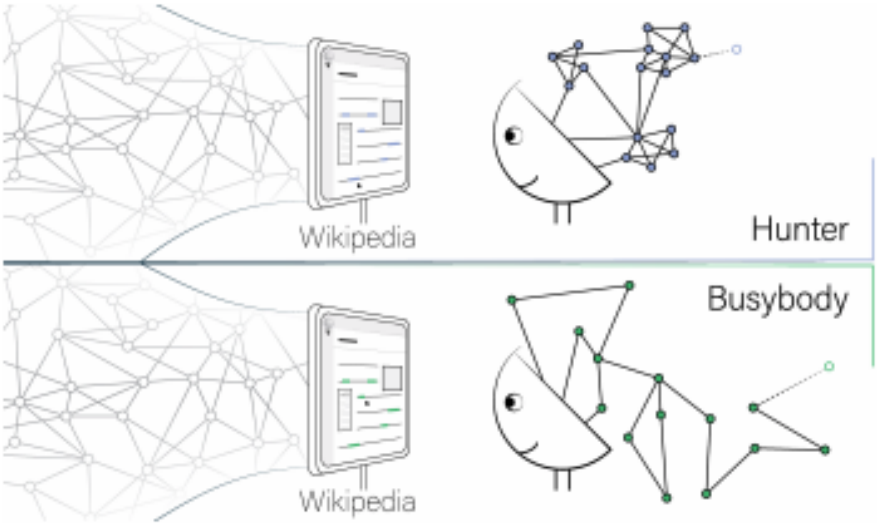


Figure 17: Hunter vs busdybody information search style. The nodes represent the unique Wikipedia pages visited, and edges represent the similarity between the text content of each page, Image source: [40]

deeper level or ends needs to be tied in a converging process at the end of a project.

The information dancer behaviour is where creativity is used connecting knowledge. Those will jump as I-types between various topics, but once an interest is sparked, they might exhibit D-type behaviour, wanting to close small gaps in various kind of knowledge or in knowledge connecting various areas.

While I have been highlighting curiosity as a good and important trait, there is also a backside to the medal. Curiosity share many behavioral and neural patterns with impulsivity, which is often associated with less desirable actions[41]. Impulsivity might be seen as a busybody or dancer kinesthetic behaviour, and hence it could also be closely related to creativity.

While there can be many complex patterns of information-seeking and curious behaviour, the key-point is that the curiosity can show in many forms, and while it is a great driver for learning, it can manifest in different way, each better suited for different purposes or stages in a problem-solving process. An ill-structured problem will often have many unknowns, which could lead to a busybody behaviour in the beginning to become familiar with different aspects of the problem, followed by more hunter-like information seeking when parts of the problem are identified and perhaps a dancer-like behaviour, when different areas of the problem, especially if interdisciplinary needs to be connected. Thus in the test of the teaching material, it could be interesting to note any difference of information searching behaviour during the phases of the exercise.

7.1.3 Science curiosity

When considering curiosity as an interest, it might be helpful to distinguish between an interest in a topic and *the reason for the interest*. The latter is more informative,

e.g. there is less information for a teacher knowing that a student is interested in astronomy or even more specifically exoplanets, than there is in knowing that the student want to know if there could be other life in The Universe, which planets it could live on, are other planets like Earth or could they be different, how could life differ or be similar than our own? Or even, what is a planet? [42]

We get a higher information value if we know the reasons of interest, because this can be used to create a better context for the students. Of course, reasons can vary, but the more we know why students are interested in a topic, the better we can create a context, a story or a real life connection around it in the presentation or problem-formulation.

When creating general teaching material, we cannot know beforehand what specific interest and the reasons for the interests that the students might have. Therefore, it might be practical to try to generalize what is behind a scientific curiosity. In a explorative study of a small sample of 19 students at about age 11, researchers explored what they called "Expressions of curiosity" which are students questions and statement of wonderment about scientific topics[42]. Their method was to have the children do a photojournal outside school, taking photographs and notes about anything in their daily life that made them think of science and made them wonder or become curious. Besides the photojournals, some of the children were interviewed about their photojournals.

The results were summarized according to six categories, based on science-relevant practices, and from multiple views of the data:

Mechanistic: How do things work or how does a process occur? Curious about the underlying mechanics.

Example: "I was wondering how sounds got through the little cords on them and came out the ends of the buds of the headphones."

Teleological: Why do things exist, or why do processes occur? Curious about the purpose or design of things.

Example: "I've always wondered why and how humans have those lines on their hands. Does it help us in any way or is it just there?"

Inconsistency: Curious about surprising or inconsistent observations vs. prior knowledge.

Example: Why does one tree have no leaves and the other has leaves when we're in the same season?"

Cause & effect: A what-if experimental curiosity about whether something does affect or will affect something else. Wanting to know what is the cause of an effect — without explicit mention of mechanism (how).

Example: "I was wondering what would make a tree grow crooked like that."

Engineering or medicine: Curiosity about how things are built, constructed or made.

Example: "I always wonder how they get all of the flavors (of jelly beans)."

General knowledge: Curiosity about facts, terms, classifications, or general information.

Example: "What kind of mountains are there?"

Based on this original research with 5th graders, a (Children) Science Curiosity Scale (SCS) has been developed.[16]

Science curiosity is not only relevant for science, but in general useful for all citizens in a democratic society:

> The reason why is relatively straightforward. Politically motivated reasoning generates a dismissive, identity-protective state of mind when individuals are confronted with scientific evidence that appears to undermine beliefs associated with their group identities. In contrast, when one is curious, one has an appetite to learn something surprising and unanticipated—a state of mind diametrically opposed to the identity-protective impulses that make up politically motivated reasoning.
>
> These features make science curiosity a primary virtue of democratic citizenship[17]

Fostering science curiosity does not only serve a better learning experience, but also seem to create a better society, according to the Science curiosity research program.

7.2 Intrinsic motivation and self-determination theory

As mentioned, curiosity can be an motivational factor. Self-determination theory (SDT)[43] is a theory on motivation and learning based on three psychological needs: Relatedness, competence and autonomy (fig. 18). When those three needs are fulfilled, the motivational scale can be enhanced from amotivation through stages of extrinsic to intrinsic motivaton which is about curiosity and enjoyment. We are then more able to get self-determination for learning. An environment that fosters self-determination for learning, will also encourage curiosity to its full potential.

Relatedness in the classroom could be about having a safe environment with other students that won't patronize. This could also be fostered by group work with a smaller amount like minded students. Competence could be about making sure, that the teaching material is build up gradually, so that exercises are neither too hard nor too easy and about encouraging feedback. Autonomy in the classroom could about being able to have influence on parts of the learning material, context or group members.

7.3 Engaging curiosity in learning

> Learning without curiosity is like eating without appetite.[37][p.866]

Regardless of the trigger of curiosity and whether it is based in an interest or deprivation of information and a need to close the gap, we cannot ignore the fact that curiosity

[16] Science Curiosity Scale (2016).

[17] The Science Curiosity Research Program, Part 2, 4th paragraph, last opened March 6th, 2021

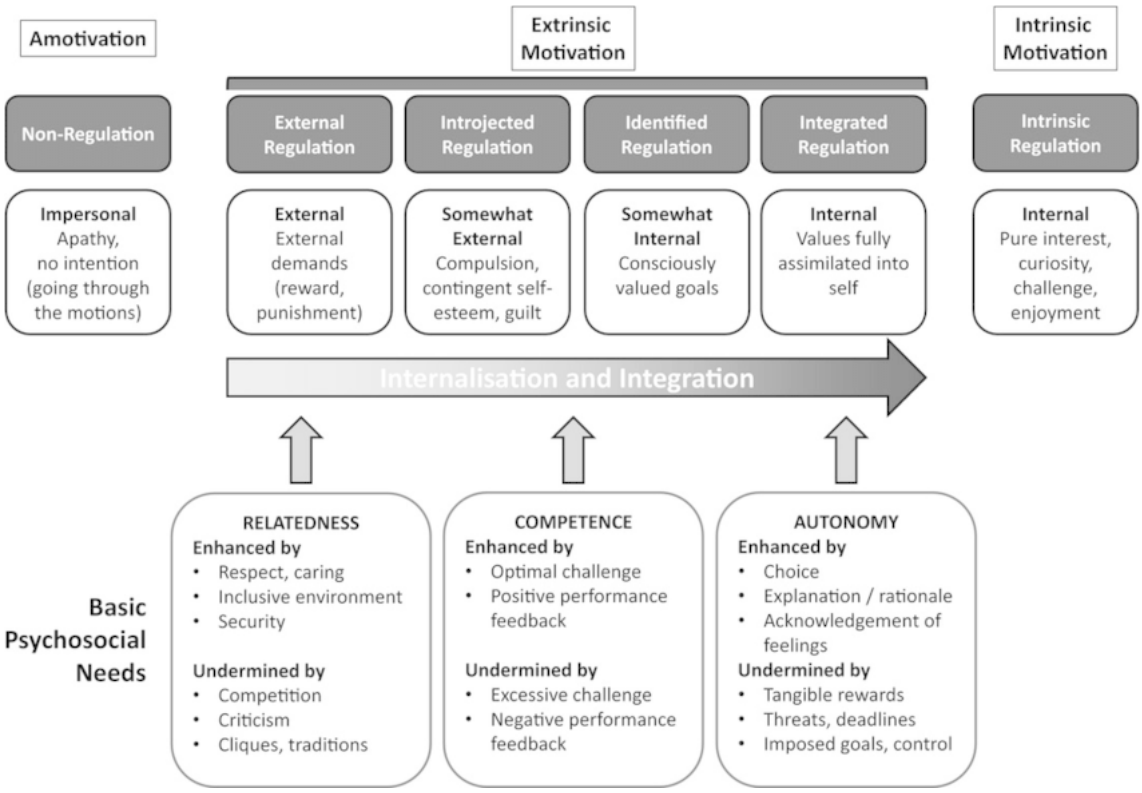


Figure 18: Self-determination theory, picturing three types of motivation: amotivation, extrinsic, and intristic motiovation, and three basic psychosocial needs: relatedness, competence and autonomy (Deci and Ryan, 1987)

is an important value for long life learning. It makes learning more enjoyable and less strained or forced. There are a few suggestions on how to include knowledge about curiosity in learning:

1. **Knowledge gap**

   > The first step to instigate curiosity is creating an optimal knowledge gap and helping students to be aware of it. A simple way to achieve this is to introduce cognitive incongruity immediately after providing students with basic knowledge in a particular subject. Presenting an exception that deviates from previously learned knowledge surprises learners and leads them to ask for further explanation.[37]

   This "element of surprise" matches the inconsistency curiosity that was described in the precious section and could serve as a natural driver to close a knowledge gap. In astronomy, this often comes naturally, since space environment is an alien environment, very different from what we are used to on Earth. This might be one of the many explanations, why so many students are extra interested in "exotic" topics such as black holes, dark matter and extraterrestrial life on alien planets - are truly mind blowing exception from what we know about our world!

2. **Ill-structured problems**
   The article also mentions ill-structured problems specifically as one way to generate the knowledge gap to trigger curiosity.

> Providing ill-defined problems or implementing problem-based learning are also effective strategies that can generate knowledge gap.[37][p.867]

3. **Gained value of information larger than the trouble pursuing it**
   For curiosity to be triggered via a knowledge gap, the gained value of the information needs to be larger than the trouble of pursuing the missing information. Hence giving the information a context that increases its value can give better results. This can for example be achieved by creating increasing "levels" of the value, if the information found in one step is needed for the next step and hence put in a larger context. We then cover the "why" the information is needed.

   > Questions which students can work on progressively can increase the value of the answers at each step. Students can learn to value the information gained more by successfully resolving each step of their curiosity.[37][p.867]

4. **Feedback including reasoning**
   Also, students should in general be encouraged to ask questions and receive prompt feedback on errors including the reason for the error, as opposed to delayed feedback in a yes or no format.

   > Prompt informative feedback on errors (as opposed to a delayed and simple indication of whether something is right or wrong), such as the timely identification of incongruity and the reasons for an error, can encourage reflexive perception of backward curiosity and lead to in-depth cognitive exploration to rectify their mistakes and to close the knowledge gap. [37][p. 868]

8 Summary of theoretical framework

To summarize, to foster better learning in science, based on more curiosity and inner motivation:

1. Create a context and an overall problem:
   - Use problem-based learning, preferably ill-structured problems, where the highest level of cognition is needed and student practice their creative and critical thinking.
   - Create contexts for the problem for a better understanding of abstract concepts, more interest-driven engagement and to encourage critical thinking.
2. Create the elements and connect them:
   - Use the element of surprise to create a knowledge gap, which will play on deprivation-driven curiosity. Note, that the excitement about "exotic" topics, might very well be explained by this inconsistency based knowledge gap.
   - Consider why the students are interested in a specific context, and use this knowledge for creating further context or connecting to other topics in the same "genre" of reason behind interest.
   - When constructing problems, consider the different kinds of curiosity: Mechanistic, teleological, inconsistency, cause-effect, engineering or general knowledge.
   - Create extra value for finding information by making progressive use of the answers found for use in following problems or questions.
3. Encourage more critical thinking:
   - Give prompt feedback on questions, including the reasons.

The teaching material from in part II will tested with students and the result analysed and related to above findings in IV.

Part IV
Test methodology and results

In this part, I will describe the methodology for testing and analysing the "exoplanet design" package and present the results. I have used Design-based research[44] for the overall process. Design-based research combines empirical educational research and theory-driven design of learning environments for a better understanding how educational implementations work in practice. My method consisted of the following steps:

Design: First, I researched the domain, that is middle and high school astronomy-related education including content and challenges in teaching, as described in the introduction in section 2. Then, I researched the content of physics related to exoplanet design, which would be the topic for the teaching material, which is described in section 3. Combining knowledge about the students level, the education system and the possible content, I designed a package for "exoplanet design", as described in section 4.

Implementation: Next, I implemented and tested the design in a teaching situation. My plan was to test both the original version of exoplanet design for middle school level (C) and the developed exoplanet design for high school level (D). Unfortunately the possibility for middle school was shot down, due to new COVID-19 restriction on the test day. I customized the developed high school package to online teaching and tested with a high school class, which will be described further in section 10.

Analysis: At last, by using the results from testing the package summarised in section 12, I analysed those in the theoretical framework that I have presented in part III (sections 6, 7). Based on that and a further discussion of the results in section 13, I designed a new and improved "Exoplanet Design" package for high school in section 14.

This is an iterative process, as illustrated in figure 19, because the improved package can once again be implemented and tested for further results. In stead, I will do a perspectivation at the end of the discussion in section 15.

As mentioned, the setting was changed from physical to virtual due to the COVID-19 situation. This meant that I was not able to do a pilot-test of the original package with middle school and that there was more focus on online tools in the observing method, but otherwise the methodology for the analysis has remained the same.

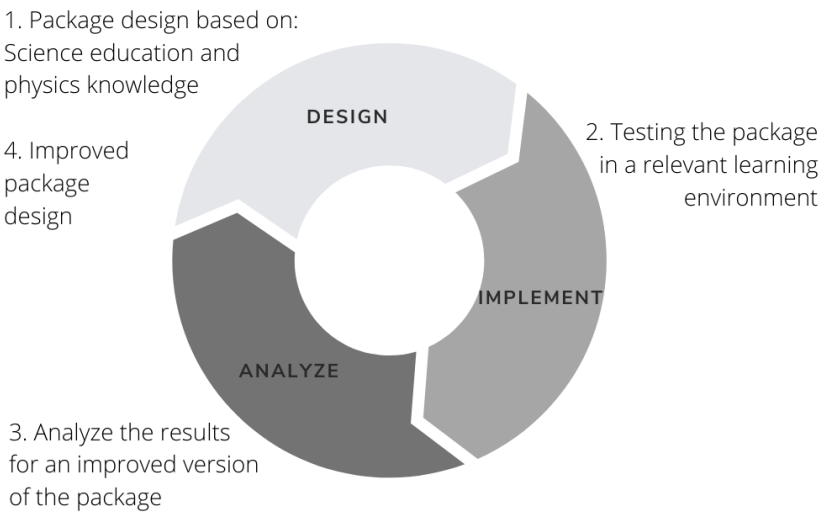


Figure 19: The design-based research implemented in this thesis

9 Philosophy of science

I have used an interpretivist research paradigme, meaning that my focus was on qualitative data collected in "classroom observations" and interviews [45]. This is different from the usual "hard science" (post-)positivism approach, where quantitative data is collected and categorized. When it comes to human beings as a test subject, the context of data has more influence and a pure quantitative data collection could mean that a lot of aspects will be lost.

The interpretivist approach is to "focus on the fact that people construct their understanding based on their experiences, culture, and context."[45][p.7] Relating this to the purpose of the thesis, this will only give one example on how a teaching situation can evolve and how one group will think about and solve a problem. Since every teacher may implement it differently, and every group may interpret their own way, this will not be used to generalize how everyone could would with the package, but act as an illustration of how a meeting of a physics teaching package *could* evolve.

Since I only succeeded with a full observation of one group, but was able to see the results of 8 other groups in the class, I have supplemented my observation with a more quantitative survey, to get a better understanding on differences and similarities between my test group and other groups working on the same problem.

10 Testing Scenario

The section describes my planning considerations for the testing scenarios and a description of the final setup.

10.1 Test planning

The test of the packages was planned to be done in two steps:

1. A pilot-test of the original exoplanet design package with middle school
2. A test with a developed exoplanet design package for high school students

For the middle school, i planned to do a pilot-test with a 5th grade in N Zahles Grundskole, a private school in Copenhagen, on December 9th, 2020. I had translated the package to Danish and decided on my own version of a presentation, since the original mainly included links to BBC videos that were not available in Denmark. Luckily I recently did another 20 min short presentation for another 5th grade class working on a project about life in the Universe, and I planned to use the same presentation with slight modifications. The presentation was in Danish and is attached in appendix C. Unfortunately the very same day that I planned for my pilot test, all 5th graders and older in Copenhagen switched to online education, and hence the test was not doable in the creative form that it had.

I continued to develop the package into a high school level without the pilot testing. Fortunately, the material could make more sense as an online exercise, since the focus would be more on creativity in discussing physics and attributes of the exoplanet and less on the drawing a poster. This package is attached in appendix D.

10.2 Choice of high school course and level

I had some considerations for which type of high school course and level to test with. Should I go with a physics course at level C, B or A? Or would Astronomy C be more suited? (see section 2.1 for the descriptions of the courses).

Physics at C-level seemed to be the least relevant, since the students here have a minimum astronomy and may not have learned about gravity, forces in general, and Kepler's law, which is a relevant prior knowledge for the package. Both Physics level B and A might be relevant and of course the astronomy-course. There are pros and cons for both choices.

Pros Physics A/B:

- Dedicated time for a higher level of physics and a more uniform level of physics and mathematics in the class
- A more popular course and hence a larger interface with students

Pros Astronomy C:

- Obligatory use of data

- Dedicated time for astronomy
- More time for qualitative discussions

It boils down to whether the focus should be physical knowledge, understanding and application as the primary goal, or rather an astronomical bigger picture based on some physics and a focus on qualitative discussions about astronomy. Dealing with a real live scenario, the choice was also restricted by logistic practicalities and was highly dependent on the availability of resources, such as teachers, teaching structure and teaching schedules.

I found a teacher, who was teaching both physics and astronomy courses and had time to do the exercise. Although being an astrophysicist, she did not plan to teach any astrophysics in the physics classes this year because of time logistics. Hence, the choice on course was done for me, and the course would be in Astronomy C.

Likewise, due to same time logistics, I also restricted the thesis to exoplanet design only, although I originally also had considered testing dark matter teaching material. The teacher would not be teaching in this topic until after my thesis deadline. I have not mention my considerations on this teaching material before because the execution was made impossible, but it has been part of my considerations for the choice on topic and package to test. Such subject is especially interesting, because it deals with abstract concepts of the fundamentals of space and something that we do not actually know what is. It is hence also something that has the opportunity to ask deeper existential questions, such as what is mass and matter in general. Instead, I will include this topic as part of my perspective discussion in section 15.

The high school teacher had planned her teaching progression starting with the physical closer objects; the planets in the Solar system, then stars and their life cycle, exoplanets and moving on to galaxies, cosmology and the more abstract topics later. This teaching sequence is similar to what I could understand from other teachers, that I interviewed in the beginning of the thesis, which also builds upon an intuitive level of abstraction with distances from our macroworld.

10.3 Final setup

The test was made with an Astronomy C elective class of 30 students in the Technical High School (HTX), Sukkertoppen in Copenhagen. The exercise was done during in January, each in a 1.5 hour time slot. Wednesday 20.02.2021 at 14:30-16:00 (Day 1) and Thursday 21.02.2021 at 8:30-10:00 (Day 2).

I wanted to test a realistic teaching situation, hence it was important that the teaching stayed as close to a natural situation as possible, with me as a ”fly on the wall”. To make the testing possible, I did need the work to be done in groups, so that I could observe and record 1-2 groups during their working process. For the sake of me getting permission to observe a group, we (the teacher and I) decided together that it would be best if the students could choose their own working group, because it might be harder for a random mixed group to reach consensus about giving me permissions to observe. Also, a group that the students have influence on themselves, would be more

”safe” for the students regarding openness and discussion of new, creative ideas.

My observations and recordings of the exercise process was made with a group of 3 boys in the age of 15-16 on day 1 and the first 30 minutes of day 2. I could also see the final poster presentations of 6 other groups, and also received the posters form two lasts groups, who did not make their presentation on day 2, due to lack of time.

Usually the online teaching is done on Microsoft Teams, but unfortunately I could not get access as an external person, so therefore the teaching environment was changed to Discord for those two days. This had a few other disadvantages, such as not being able to present screen sharing for more than 25 people at once, which made it harder to show a slideshow presentation.

I assumed that the knowledge of my presence and the need to get permission would most likely have an influence on the type of students that I will be observing, and would result in students average higher confidence or competence. The teacher confirmed my assumptions about the one group that gave me permission to observe. Although I had planned a setup that could record two group processes at once, only one group was willing to let me be a fly on their wall. Other than that, the teacher chose how she presented and controlled the teaching situation, so that it would resemble a real case, as if she downloaded the material herself with as little influence from me as possible.

11 Techniques used for testing and analysis

As mentioned in the previous section about the setup, I used online observation of one group and their work process. In this section, I will describe the techniques for observation (11.1), and the method for analyzing the results of the observation (11.2).

Since I have only been able to observe one group, which I knew would be in the higher end of interest and abilities, I also did a short survey for the whole class at the end, to get some more information about the exercise process and a little about all of the students "class-wise". The design of the survey is described in section 11.3

11.1 Observation

For recording the observation, I used Camtasia Screen recording software[18], which gave me the option of recording the internal computer sound, which gave a better quality of recording than recording form the build-in microphone, plus it was ready to record multiple groups at once with the sound off, although unfortunately, I did not get to need that feature.

I did the observations on mainly day 1 and some of day 2. Day 1 was spend on a short introduction to the case. Due to technical problems on the Discord platform, the presentation of the slides were skipped, stating that the students should go through the slides themselves, as it included useful and relevant information.

The student started the exercise about 20 minutes in class and I followed and observed one test group for the day. The last 5-10 minutes of day 1 was spend on checking the status of the groups. It was decided that they would spend the last 30 minutes of the next day to finish their exercise and the posters, before the presentation.

Day 2 started with half an hour for the groups to finish up their poster exercise, and once again I followed my test group. While the day before was mainly about the physical design and calculations, the half hour on day 2 was spend on making the poster from their description of the exoplanet. The rest of the day, I observed the presentations of the posters made by the other groups. Although I have not been able to follow their process, I was able to see their results (except for two groups, who did not get to present this day, because we ran our of time).

11.2 Using study and research paths for analysis

A Study and research path (SRP) is a technique mapping the flow of thoughts in students for solving a problem [46]. I start by mapping an a priori SRP, which will serve as a direct representation of the assignment, its questions and the dependencies needed to answer the questions.

The SRP is a tree structure of nodes, starting with the main node with the overall problem. In our case that is the node Q0: Design an exoplanet. This node will have several underlying main questions or sub problems, which becomes child nodes Q1, Q2,

[18] https://www.techsmith.com/video-editor.html, January 2021

..., Q3. Each child node, can again be broken into smaller sub problems or questions that needs to be answered in order to answer the parent question, until we have nodes with atomic sub problems. The sub problem of Q1 will be called Q1.1, Q.2, ... Q.n etc.

The a priori SRP for the exercise "Exoplanet Design" can be seen in figure 21. Further below is a description of all the nodes. The order of questions and the splitting into sub problems are based directly on the exercise in the student guide in D.2.

You may notice in the graph, that there are some dashed lines pointing in other and directions across the diagram. This is because there can be other dependencies to answering a question, which may be part of another question. For example, to calculate The equilibrium temperature, we need information about the star, that we calculated in a previous question. Likewise, to consider the greenhouse effect, you need to know about the atmospheric components, and to consider the planetary surface, you may need to know the planet type (surface). To calculate the gravity, you need to know the mass and radius, which are part of a previous sub problem - figuring out the size of the plane.

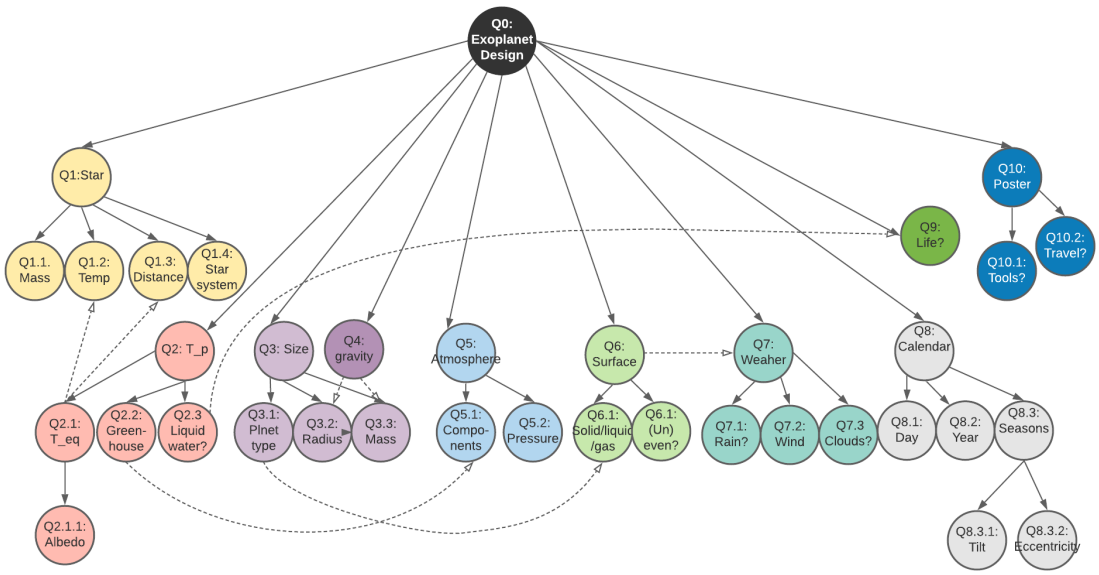


Figure 20: A priori Study and Research Path of Exoplanet Design Assignment, own figure.

Below is the full tree-structure of the research and study path of exercise:

Q0: Design an exoplanet

Q1: What kind of star does it orbit around?

- Q1.1: What is the mass of the star
- Q1.2: What is the surface temperature of the star?
- Q1.3: What is the distance from the star to the planet?
- Q1.4: Is it a single star or part of a double or triple system?

Q2: What is the temperature of the planet?

- Q2.1: What is the equilibrium temperature? (get data from Q1.2, Q1.3 (forgot Q1.6: radius of the star)
  - Q2.1.1: What is the albedo? (need answers from Q6, the surface)
- Q2.2: Is there a greenhouse effect?
- Q2.3: Is liquid water possible?

Q3: What is the size of the planet?

- Q3.1: Which type of planet is it?
- Q3.2: What is the radius of the planet?
- Q3.3: What is the mass of the planet?

Q4: What is surface gravity?

Q5: Is there an atmosphere?

- Q5.1: What does it consist of?
- Q5.2: What is the atmospheric pressure?

Q6: What does the surface look like?

- Q6.1: State/phase of surface (depends on planet type Q3.1)
- Q6.2: Even/uneven?
- Q6.3: Does the surface change?
- Q6.4: Is it affected by the weather? (dependent to Q7)

Q7: How is the weather?

- Q7.1 Raining? With?
- Q7.2: Wind?
- Q7.3: Clouds?
- Q7.4: Greenhouse-effect? (depends on Q5.1)

Q8: Recurring time factors

- Q8.1: Day length?
- Q8.2: Year length (depends on Q1.3)
- Q8.3: Seasons
  - Q8.3.1: Tilt
  - Q8.3.2: Eccentricity

After the observation of my test group I transcribed the whole discussion between the students, also noting relevant timestamps visible information search, longer pauses or sounds that indicates specific emotions such as laughing or a ”hmm” as an expression of thinking. I have then analyzed their work process according to the a priori nodes and any other relevant nodes that came up during the exercise. The analysis is a button-up analysis, where I identified nodes based on the results, since I did not know beforehand which new insights the students would come up with and which other information search they will go through in their process.

The nodes in the resulting Study and research path has been numbered chronologically as they turned up in the discussion, although there might be a few irregularities, since it has been an iterative process with many iterations. For easier comparison, I have colored the nodes, so that same main nodes in the a priori and the updated SRP have the same color.

11.3 Survey after the test and analysis method

After the exercise and the presentations by all groups, I decided to make a short survey for the whole class, hoping that it would give me some hints about weather my test-group were different from the other groups on a few points. For example, I was not sure whether my group used the presentation slides as a resource, and wanted to check whether this could have been a general thing. I also wanted to know about their general feelings about the exercise to get a better idea on how it was met and what could be improved. Therefore, I had questions on whether there was anything specific that they enjoyed and if there was anything specific hat they were missing (explanations, formulas, more time ...) or that they found hard to do.

I was curious about their calculations and physical considerations. My test-group seemed to have spend a lot of time on calculations, but especially by use of formulas and attributes that was not part of the exercise (considering luminosity of their star, trying to figure out the habitable zone). Therefore, I wanted to know whether the other groups had spend time on doing all of the listed calculations in the exercise or if maybe they skipped any, and whether they have been using other formulas or considerations, that were not mentioned in the exercise. They could add further comment on the calculations, optionally.

For the online technical part, I was curious which program they used for solving the exercise. This was mainly for me to get an idea about what there could be recommended, and is more about the online practicalities in general than physics, but still part of the exercise experience in the virtual circumstances of our time.

Another purpose of the survey was to figure out what could be improved as seen from the teachers perspective. She had already mentioned, that she would like to use this exercise again next year. So, I asked her whether she had any other questions to add and she added a question about weather the time spend on the exercise was appropriate.

A last bonus question was about their interests in science fiction. The purpose of

that was to feed my curiosity on the connection between astrophysics/astronomy interested students and an science fiction interest. This could be helpful on planning a relevant context for the improvement on the package, since already the package was partially sci-fi oriented with the planets as travel destination.

The questions and answers are attached in appendix H in they raw, Danish form. Since most of the questions are open, have done a button-up analysis of the results, once again looking for overall patterns in the answers and grouping them accordingly after similarity to find some key-points from the most occurring categories of answers. The results from the quantitative questions can be plotted directly as pie- or bar-charts.

To summarise, both the analysis of the results form the observation and the survey has been done as a bottom-up analysis, identifying patterns and key-points.

12 Results from the test

In this section, I will present the results of the test as described in the previous sections. I will start with the overall SRP result as described in the methodology chapter, followed by a more detailed description of the discussions in the observation and a split of the SRP in three phases to get a bit of a perspective on the work process through time. The analysis and discussion of the result will follow in part V.

12.1 Study and research path based on the observation

I have made a transcription of the observation (attached in appendix E). To summarize the work process, I have identified the topics in the test groups discussions as described in section 11.2 and numbered the questions in chronological order from the discussion (e.g. Q1 came before Q2, but it is not possible to see from the graph, whether Q1.1 came before Q2.1, because the order is only chronological on the same level). There might be some deviations from the order due to several iterations of the same process, while identifying and grouping categories for nodes. The colors for the main questions are the same as used in the a priori SRP in figure 21. The nodes are also marked in the attached transcription.

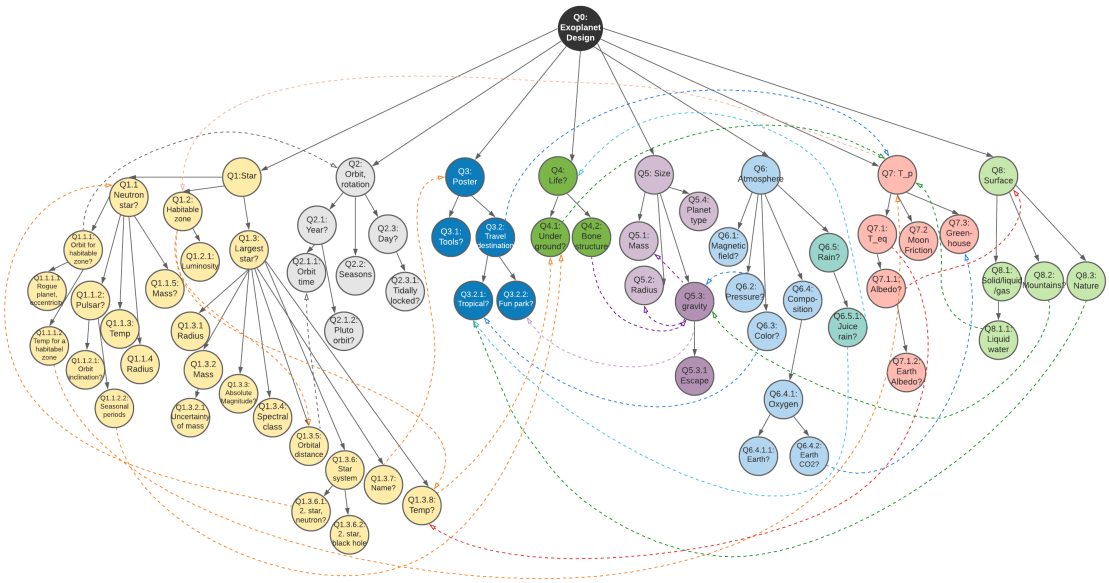


Figure 21: Study and Research Path of the group discussion and solution of the Exoplanet Design assignment. A larger version is attached in appendix F

Q1: The star

Q1.1: Can the star be a neutron star? (because it's cool)

Q1.1.1: Orbit for habitable Zone for a neutron star? (Cross reference orbit Time Q2.1.1)

Q1.1.1.1 Dead star -> rogue planet captured, eccentricity

Q1.1.1.2 Temperature range for a habitable zone (Cross reference to planet temperature)

Q1.1.2 Pulsar (”magnetizer”) Bursts

Q1.1.2.1 Orbital inclination to avoid bursts

Q1.1.2.2 Seasonal periods (Cross reference to living underground Q4.2)

Q1.1.3 Temperature of a neutron star

Q1.1.4 Radius of a neutron star (and cross reference to luminosity)

Q1.1.5 Mass of a neutron star

Q1.2 Habitable zone (Cross reference to temperature of star, Q1.3.8 and orbital distance Q1.3.5 for the found star)

Q1.2.1 Luminosity

Q1.3 Chose the largest star

Q1.3.1 Radius of largest star

Q1.3.2 Mass of star

Q1.3.2.1 Large uncertainty of mass found

Q1.3.3 Absolute magnitude?

Q1.3.4 Spectral class

Q1.3.5 Orbital distance

Q1.3.6 No. of stars in system?

Q1.3.6.1 Can the other star be a neutron star? (More cool)

Q1.3.6.2 Or a black hole (“Interstellar”)

Q1.3.7 Name of the star

Q1.3.8 Temperature of star? T_s

Q2: Orbit and rotation

Q2.1: How long is a year?

Q2.1.1 Orbit time, Kepler

Q2.1.2 What is the orbit time of Pluto?

Q2.2: Seasons

Q2.3: Day length

Q2.3.1: Tidally locked?

Q3: Poster

Q3.1: Tools?

Q3.2 Travel destination

Q3.2.1 Tropical Paradise?

Q3.2.2 Fun park?

Q4: Life

Q4.1: Underground

Q4.2: Human bone structure

Q5: Size of planet

Q5.1: Mass

Q5.2: Radius

Q5.3: Gravity (Cross reference to Bone structure Q 4.2, trampoline part Q3.2.2, planet mass Q5.1 and planet radius Q5.2)

Q5.3.1 Escaping planet

Q5.4: Planet type: Rocky, superearth, Neptune-like, Gas planet

Q6: Atmosphere:

Q6.1: Magnetic field

Q6.2 Pressure (thick atmosphere) (cross reference to surface gravity Q5.3)

Q6.3 Color (cross reference to tropical planet Q3.2.1)

Q6.4 Composition

Q6.4.1 Oxygen

Q6.4.1.1 Oxygen on Earth?

Q6.4.1.2 CO2 on Earth? Cross reference to greenhouse effect)

Q6.5: Does it rain? With what?

Q6.5.1: Juice rain (cross reference to biological creatures Q.4 and Tropical paradise Q.3.1)

Q7: Planet temperature (Cross reference to living underground Q4.1 and travel destination Q3.2)

Q7.1 T_{eq} (cross reference to Star temperature Q1.3.8 and star radius Q1.3.1)

Q7.1.1 Albedo (cross references to surface Q8)

Q7.2 If planet = Moon, friction influence on temperature

Q7.3 Greenhouse effect

Q8: Surface

Q8.1 Solid, liquid, gas?

Q8.1.1 Liquid water (best water in the world!) (cross reference to planet temperature Q7)

Q8.2 Mountains (cross reference to gravity Q5.3)

Q8.3 Nature, trees, plants

12.2 Observation of the test group

In this section, I will describe the progress of the test day, which resulted in the SRP in figure 21. For use in a following analysis, I have divided the observed group work in three phases: 1) Idea-phase, 2) Step by step, and 3) Tying up ends. This is a subjective division, decided by a feeling of a change of work state. The idea-phase to "step by step" division, is where the students decided that maybe they should try following the exercise guide instead of discussing everything at once. The last phase started when

the students had about 20 minutes left and had some troubles with the calculation of an equilibrium temperature while trying to get the last things done. The reason for this division, which was not planned, is to be able to see some kind of time progression in the SRP, which I have created separately for each phase.

1) Idea-phase (26 min)

The students had from the very beginning decided that they it would be cool to have a planet around a neutron star and spend the first 4-5 minutes discussion the possibilities, not regarding the wording of the exercise itself. They spend some time discussing whether equations for luminosity (eq. 16 and eq. 17), which they would use for the temperature and habitable zone calculations, were applicable for a neutron star.

$$L_* = 4\pi R^2 \sigma T^4 \tag{16}$$

$$L_* = 10^{\left[\frac{M_{bol,\odot} - M_{bol}}{-2.5}\right]} \cdot L_\odot \tag{17}$$

These equations were not mentioned in the exercise, but I found out later by asking the teacher, that they have been working with these recently in a larger hand-in assignment about stars.

After the first 5 minutes, they started reading the exercise, but continued mainly discussion and researching neutron stars and the possibility of planets around it. They discussed a possible large orbit and orbit time, an eccentric orbit and the possibility of this being a captured rogue planet, since the original planets around the star would have been destroyed during the supernova explosion forming the neutron star. They also discussed pulsars and the risk of bursts and the solution of having an orbital inclination away from the bursts or maybe that there could be seasons where life would hide under ground for periods of time.

They continued having a neutron star in mind, while they started to use NASA's Eyes on Exoplanets[19] from the resource links. They spend some times exploring other planets and their orbits and habitable zones, discussing the surface temperature and radius of an arbitrary neutron star and its luminosity for their own equation. They started a little on discussion the surface gravity of the planet from a point of view of what would be interesting for a travel destination, while also continuing to do the calculations with luminosity and their idea of habitable zone. They also had an idea that maybe the temperature could be warmer due to gravitational friction, if the destination was a moon around a planet instead of a planet, but they discarded the idea again, because they did not want to wander too far away from the exercise.

After 18 minutes, they decided all of a sudden not to use a neutron star, because their luminosity and habitable zone calculations might not work for such and one of the group members searched for the largest star possible, and decided that there should go with that instead (because it would be cool!). The two others followed his track of thoughts and the research began for their newfound star: VY Canis Majoris.

[19] https://eyes.nasa.gov/apps/exo/

An SRP from the first phase can be seen in figure 22.

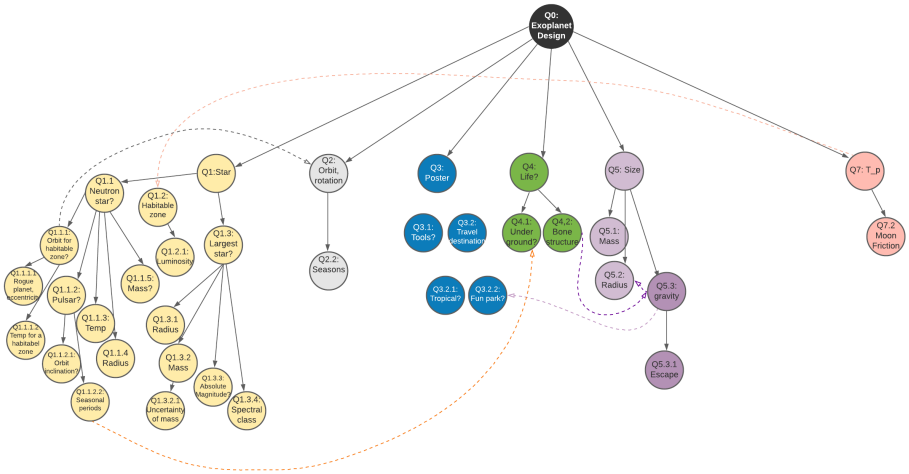


Figure 22: SRP for the first 26 minutes

2) Step by step (22 mins.)

After discussing the size of the found radius of 988 million km, trying to figure out the luminosity and mass and a discussion of magnitudes and distances (still not in exercise) they decided that maybe they should follow the exercise guide. **This was 27 minutes in**. In the exercise it was mentioned to consider whether the star system was just one star or binary or more. They discussed that their star could have a neutron star companion, too far away to do much damage. Or maybe a black hole, ”Interstellar”-style. They wanted a cool star system and decided that a neutron star could be part of that. They decided on a name of their combined initials and their birth months.

Shortly after (**30 minutes in**), they started discussion the planets surface temperature, where they stumbled on, for some, unknown concept: The albedo of a planet. The albedo and examples was described in the presentation, but not in the exercise sheet itself. Meanwhile, they continued with their own equation for the luminosity including searching for and discussing the magnitude of VY Majoris and distances in parsec and lightyears, how bright the objects would seem, to figure out whether the luminosity made sense. From the equation, they got a value for a distance to the star ($2.99 \cdot 10^{16}$ m), which did not make sense to them, because they wanted this to be a distance for a habitable zone.

In parallel they discussed the actual exercise including liquid water (being a tropical paradise, they wanted the planet to have fresh liquid water), the greenhouse effect (which they decided that there should be), the planet type, where they decided that it should be Earth-like, but perhaps with a smaller mass, and they discussed the implications of a lower surface gravity, such as whether the mountains would rise higher, and how fun it would be to have a trampoline park at this holiday destination. Previously

they have also talked about higher density and having your body muscles trained more automatically.

About 40 minutes in, during writing down the answers to the exercise, they had some technical difficulties. First, the word-document, that was created from a template from the OO-project, did not allow them to fill in the answers in the text boxes, because the text continued outside the border of the page in stead of on the next page, and hence was unreadable. They created a new document, but then had trouble with permissions after renaming it and hence had to create another one. While not relevant to the solution of the exercise, it is important to note that such technicalities were time consuming and part of the online environment.

They continued with researching albedo and discussing their planetary surfac and atmosphere. They googled and found a source for albedo values of different surfaces, and decided it should be Earth-like, because there would be oceans and tropical nature and plenty of high mountains, due to the low surface gravity.

After 44 minutes, they discussed the length of a year, while trying to figure out the distance of the planet still. They have looked up a habitable zone for the star in question (VY Canis Majoris) and since it should be about 900 AU away from the star, they figured they would get an idea of distances and years, when comparing to Pluto, which is 40 light years away. They found that Pluto had a year of 248 Earth years, so their planet orbit time would be much higher than that.

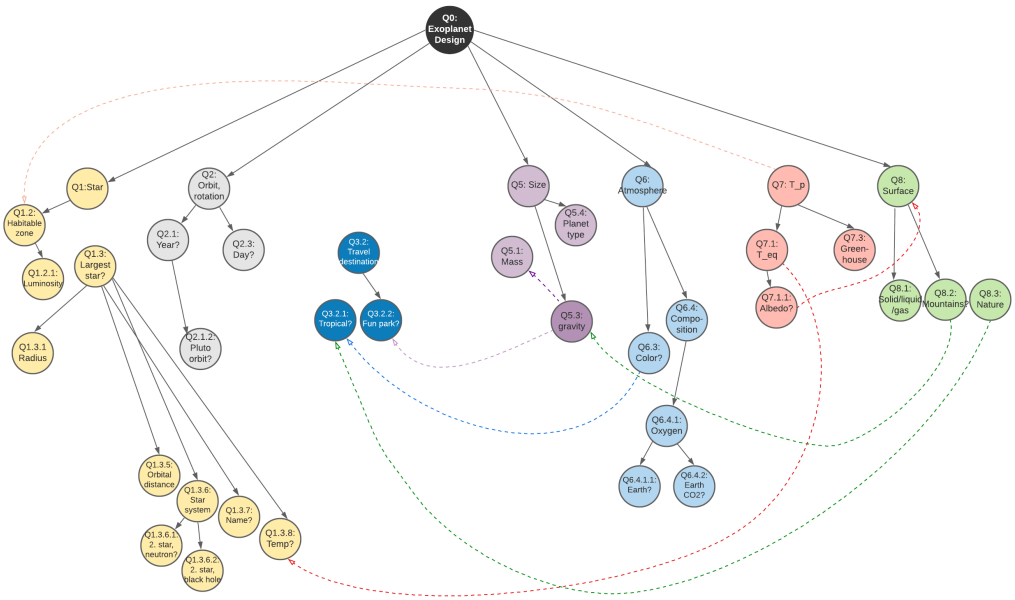


Figure 23: SRP 27-49 minutes in

While one was trying to calculate the length of the year, they discussed the length of the day and the atmospheric composition, where they decided to have a higher level of oxygen, figuring that it would be good for human growth. They compared to Earth

atmosphere composition and adjusted with more oxygen, less nitrogen, a bit of CO_2 for the greenhouse effect, where they also used the value for Earth atmosphere. For the last percent, they put neon - with a fun argument that they could have fluorescence light.

An SRP from this middle phase can be seen in figure 23.

3) Tying up the ends (23 min.)

About 49 minutes in, the group member with the luminosity calculations continued to have problems and now got a result of 0.4519 watts, which he discussed parallel with the other discussions going on and kept cycling back to the same luminosity equation (not in exercise), that would not give the desired results for figuring out a habitable zone. One pointed out that habitable zone just meant that there could be liquid water, but the group member was determined to get a quantitative result.

They discussed the possibility of a tidally locked planet and a day or night that lasts forever. The discussed the implication of being burned to crisp or maybe living in the middle zone. Shortly after, they realized that they only had 20 minutes left, and continued going wrapping up on the atmospheric composition in exercises, while one member still struggled with the luminosity-equation outside the exercise. They also discussed whether the planet should have a moon and the implications of tide, which I have not mentioned in the exercise.

Some of the last time was also spend on discussing how they should make the poster, which they were a bit worried about. Then they also discussed the weather and whether it could rain with acid or diamonds and they decided in a humorous tone, that they would have biological creatures living in the clouds, that would enrich the rain so it became like drinkable juice for the guests in the paradise destination.

Otherwise, they spend most of the time wrapping up the loose end from the exercise, and trying to figure calculate the equilibrium temperature, where they got a value close to 0K, due to an error where they mistook "," for a decimal. The **last 10 minutes**, or about 1 hour into the exercise, were spend on trying to calculate the equilibrium temperature with different values for the distance from star to planet and checking up on all the values, but still getting an unrealistically low result because of the decimal error.

An SRP from the last phase can be seen in figure 24.

Key-points from the observation:

- The decisions in the free choice of parameters in the exercise, were made by "what could be cool" (neutron star, black hole, largest star) or "fun" (trampoline park, raining juice) - e.g. the student created their own context based on their own inner motivation and curiosity, even before reading the exercise text.
- One group member spend most of the time trying to use an equation, that was not part of the exercise in order to find the habitable zone. This reminded of the D-curiosity, driven by wanting to close a knowledge gap with hunter-style kinesthetic.

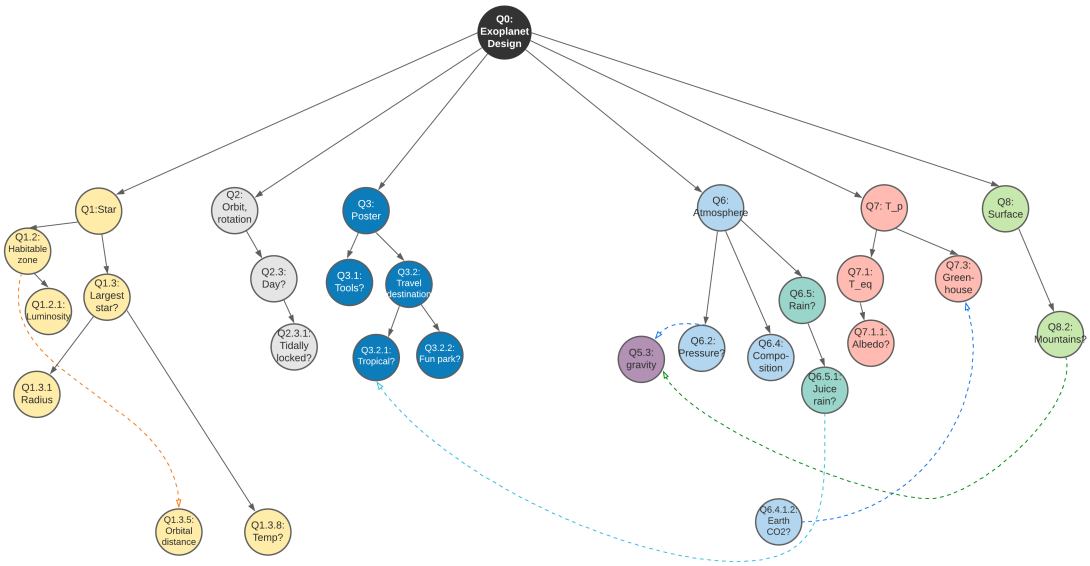


Figure 24: SRP for the last 22 minutes

- They cycled a lot through different topics in non-chronological order: I-curiosity was used during most of the exercise with busybody or dancer kinesthetics.
- The group had many creative physical ideas outside the questions of the exercise, that they argued for logically while using their knowledge of physics and astronomy, e.g. neutron star = original planets are dead, surface gravity implications on mountains and human movement, the influence of a moon.
- It made sense to write the answers directly in the given word-document, but it gave technical difficulty, since the text-boxes were not made for writing. They spend some time on this on and other technical problems with new documents in their online teaching environment.
- The students said they could have used "5 times as much time" for the assignment.

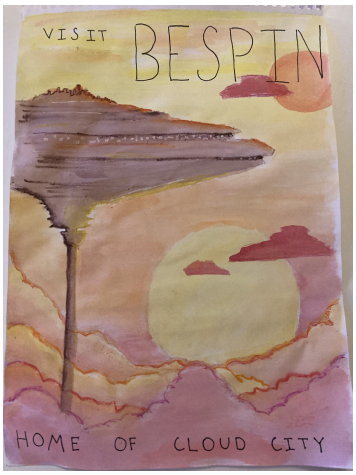
12.3 "Exoplanet Design" posters and presentation

Although I only followed one group solving the exercise, I was able to see the resulting poster presentation of 5 other groups and got permission to use posters from all 8 groups in total. The poster results from all groups can be seen in fig. 25, while relevant notes from the presentations from group 1-6 are attached in appendix G and summarized in key-points in table 2 and feedback in table 3. A few general notes from the poster presentation:

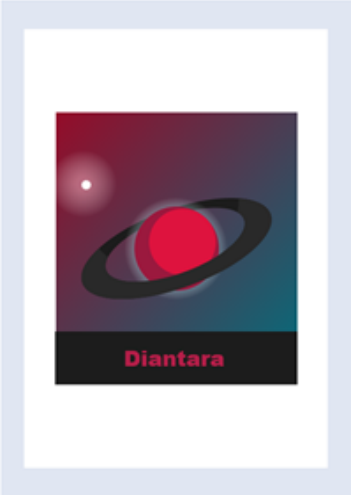
- Most groups used relative masses, sizes surface gravity etc, instead of absolute, which also makes more sense in the context of relating to the Earth and the Sun. Improved package could focus on that.
- Great variety of planet types.
- Many have "Earth-like" atmosphere conditions, most likely due to this being a travel destination and that it is easier to relate to "what we know".

(a) Group 1 (Test group)

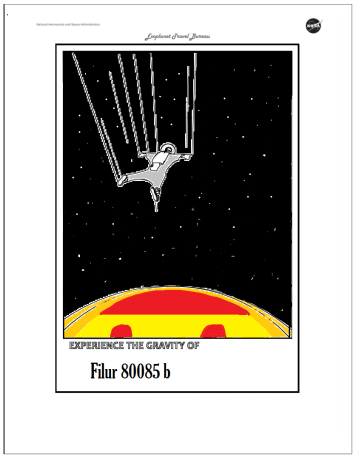
(b) Group 2



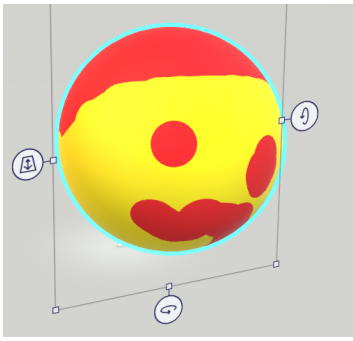
(c) Group 3



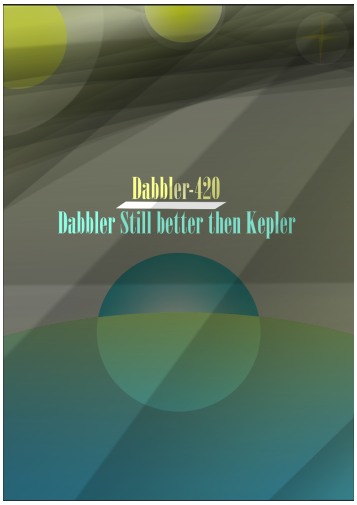
(d) Group 4



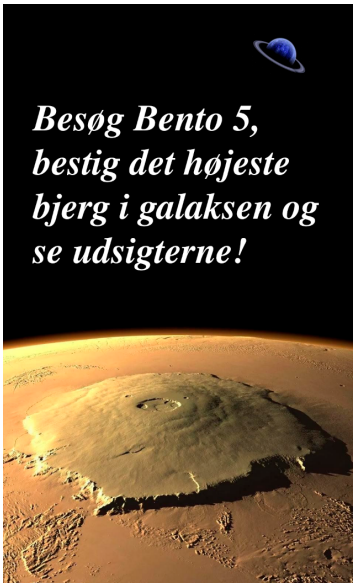
(e) Group 5



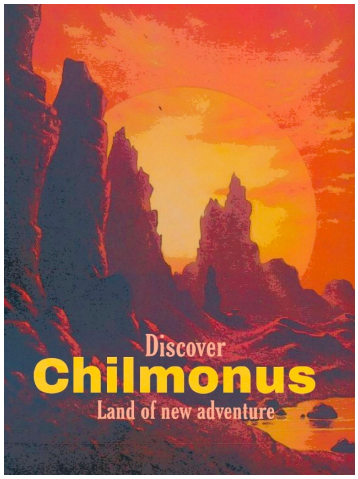
(f) Group 5, extra illustr.



(g) Group 6



(h) Group 7



(i) Group 8

Figure 25: Posters from group 1-8

12.4 Results from survey

The point of the survey after the test was to get a general sense of the group work of the exercise, since I could only follow one test group, and to get an idea of the differentiation of my test group compared to other groups, by asking questions that I knew the answer for for my group. (e.g. which formulas they have used and whether they have considered other factors than mentioned).

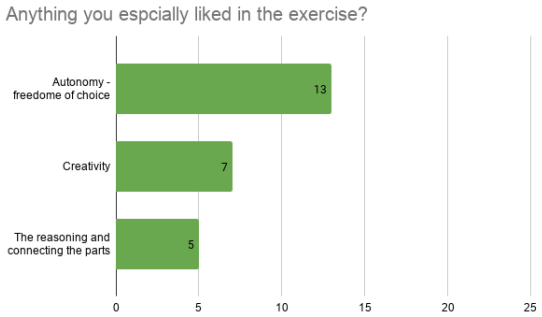
It turned out though, that the answers did not carry that much information about how the test group differed, since even they did not remember all parts of their thinking process and all of those ideas about other factors, that they had come up with, a week after the test where the survey was conducted. Therefore, answers to questions such as "which other considerations did you have?" and "which other equation did you use?" might be considered incomplete due to the fact that as student did not expect to document their whole process, they would not remember all of the different considerations they had during their process.

The survey is still useful regarding questions about the overall feeling about the exercise, the challenges and some thoughts about which parts they especially enjoyed. The full survey with questions and answers in Danish are attached in appendix H. For analyzing the results, I have made a bottom-up analysis, identifying patterns in the answers, categorizing them in main key-points for what I could consider useful as feedback for an improved version of the package. Results from this are shown in figure 26.

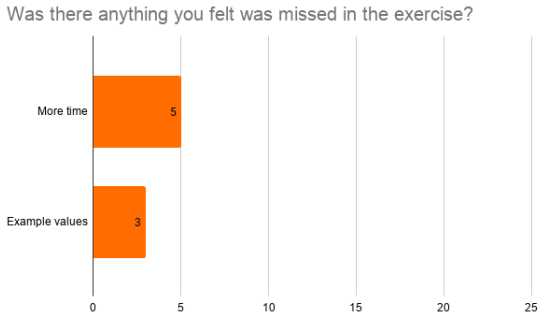
To summarize, the students especially liked the autonomy and freedom of choice, the creativity, and "the reasoning and connecting the parts". The students could have used more values examples and calculation examples and more time. Directly asked, 2/3 of the students would like to have more time for the assignment (or less assignment). The were few things the students found challenging in the assignment, and that was using the equations for calculating values and again: the time constrain.

Not surprisingly, it was the equilibrium temperature calculation, that was the most challenging, and from the further comments about the calculations, most mentioned that they could have used more example values, especially with units, as the teaching material did not include an example calculation for the equilibrium temperature.

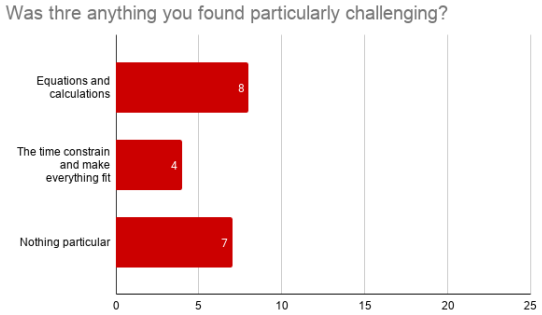
For extra considerations that they had during the exercise, most students answered that they had none, 5 students mentioned something: 1) why did the planet have the color that they chose (1 student), 2) calculating the habitable zone (2 students), 3) whether it is possible to have acidic rain (1 student) and 4) considering a gas and rocky planet. I know from my test group observations and from the poster presentations, that the students also had many other considerations, that they did not mention here, so this shows that the question does not show anywhere near an accurate picture. The groups could have had many small thoughts or discussion, without putting much notice on it and therefore not remembering or not giving it much importance a week after, when the survey was done.



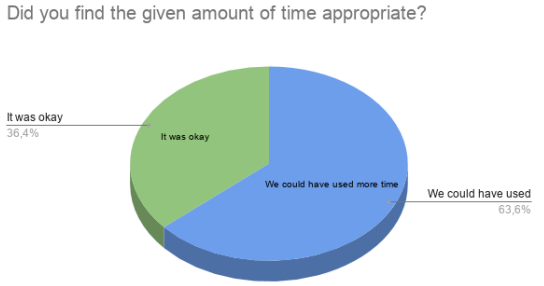
(a) Most liked the freedom of choice, the creativity and connecting the parts using reason



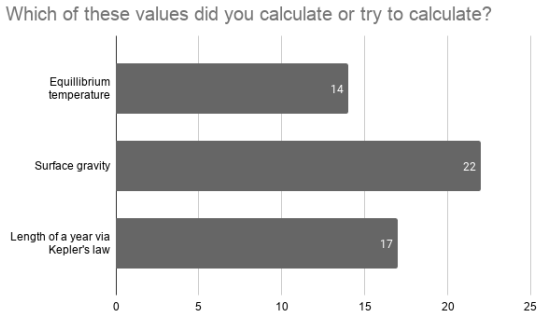
(b) More time and example values would have been appreciated by a few.



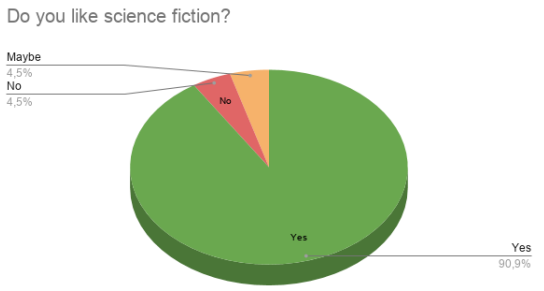
(c) Equations and the time constrain was the most challenging, otherwise not much else was mentioned.



(d) Directly asked, 2/3 would liked to have more time (or less assignment), the rest found it appropriate.



(e) Everyone calculated the simple surface gravity, most also used Kepler's law and many tried the temperature calculation.



(f) A bonus question which could give a hint of a possible context.

Figure 26: Results from a bottom-up analysis of the survey questions

Part V
Analysis and discussion

In this part, I will analyse the results from the previous part and connect them to the previous parts of the thesis, i.e. mainly the content (exoplanet design) and the theoretical framework (learning, ill-structured problems, curiosity), as illustrated in fig. 27.

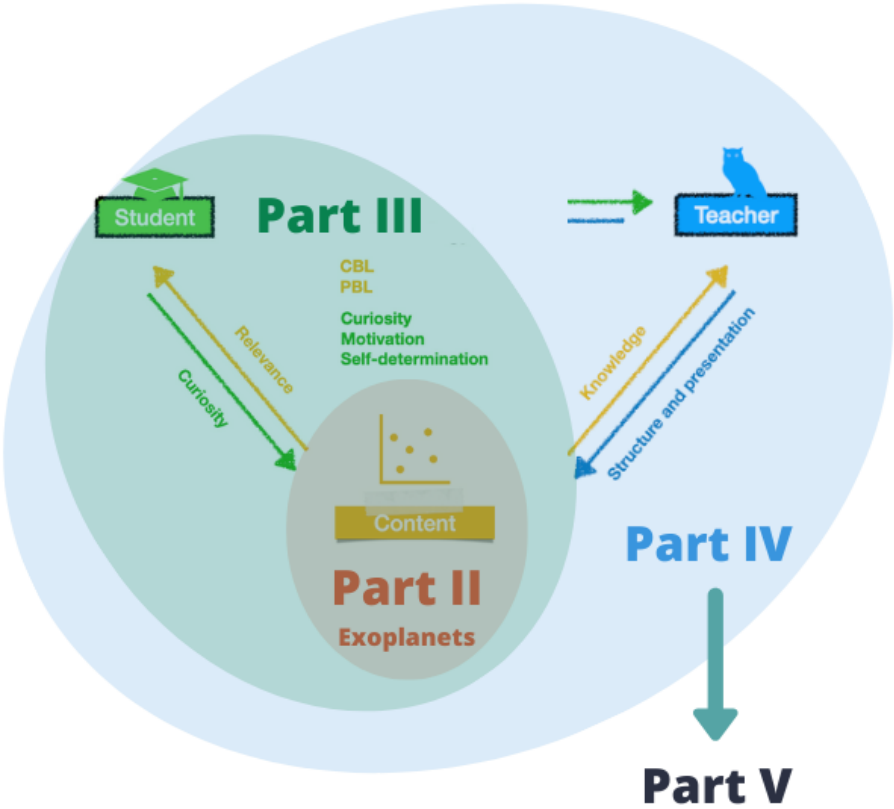


Figure 27: Part V, connecting the parts of the thesis, discussing the results.

13 Analysis and discussion of the test results

Let me start by recapping the most important findings in the theoretical framework, so they are fresh in memory. For a full list, I will point to the summary in section 8. A teaching situation consists of teachers, students and content and the three relations between those. I have focused on the content and the student together in a learning situation. For a prior design of the content, I created an exoplanet design package and implemented it to observe how it was used in an actual learning situation.

With the theoretical framework in mind, I planned to test for and improve those elements in the exoplanet design teaching material: 1) creating context(s), 2) use ill-structured problems for critical thinking, 3) fostering curiosity by creating knowledge gaps or an element of surprise by the use of inconsistency, and considering different kind of curiosities, 4) creating progression in the problems, so that finding information gets more value with further use, 5) give immediate feedback with reasons behind.

In the analysis, I will consider the results from testing the teaching material relating to the above, based on this also discuss improvements for a new version of the teaching material.

13.1 Creating a context

To recap on context-based and problem-based learning (CBL and PBL), CBL would start with a concept that is familiar, or in astronomical terms, a concept that is observable directly with our senses ("macroworld") (fig. 14) and use those terms to give a context for more abstract concepts from the supermacro world or by using representational symbolism. This can be done by analogies to our descrpiptive world. PBL, being a subset of CBL, would be based on a real-live problem form the dsvcriptive world.

In the exoplanet design, we are dealing with planets around other stars, exotic "other worlds" that we need to connect it to something, that the students are more familiar with. One level of context could be connecting it to planets in our solar system, by using known planets as examples. Then by giving examples on planets around other stars, but it would make the assumption, that the students are already familiar with those. Although both my preliminary research and the test situation situation showed that it is a logical step to learn about our solar planets before we learn about extrasolar planets, the term "familiar" is a relative concept. Although knowledge about our solar planets is more familiar than extrasolar ones, they are not familiar in the sense as being pat of the experienced macroworld. After all, different planets in our solar system still have alien environment inconsistent with what we know.

Using context to experienced world could hence be by analogies to alien environments on Earth. Lava world with conditions as in a volcano, water world as being in the middle of the sea with no land in sight or suffocating environment as being in a burning house. Still, extreme conditions on Earth do not measure up to extreme environment on other planets, but perhaps this is not the pat of the exercise in need of more context than a few imaginative images, such as given by the inspirational posters

from NASA, where there is also a halloween edition[20].

Analogies can be useful for explaining equations and relations between physical parameters. There can be different types of analogies used in physics[21]. Some can structural like the analogy of the extreme distances given in distances on Earth by considering a smaller model scaling down all distances with the same scale. A model of the Universe requires different scaling and the vast distances is one of the problems in astronomy teaching where the given models often are not to scale due to the difficulties with sizes of objects that are relatively smaller than vast distances between them. Structural analogies has also compared a planetary system to the Bohr atomic model. Other analogies are functional and about the process, such as in the equilibrium temperature.

For example, for a better understanding of the equilibrium temperature, an analogy for absorbed light by the planet could be water flowing in a bucket, where the temperature would be the level of the water. Thermal energy radiated by the planet would be like a hole in the bucket, analogous to water flowing out,where the albedo will give a larger hole. Albedo, as the reflection of light by different materials or colors, can also be illustrated by thinking of a black t-shirt in the summer which absorbs more light and feels hotter, while a white t-shirt will reflect more, or by considering how sun is reflected in the snow during the winter. This could give an idea that both colors and material have and influence on the albedo and hence the equilibrium temperature of the planet.

Other considerations for context, is simply by more examples relating to conditions on Earth. For example, when calculating the gravity, it makes sense to use a relative gravity and compare with the resulting weight.

For teaching a subject such as astronomy, a real-life context is not always easy to find, because astronomy in its nature is about objects that are out of our everyday reach and for both large distances or submicroscopic sizes, our intuition about the world is not always correct. Sometimes a science fiction setting is also useful, since it places part of something familiar in an unfamiliar, but still plausible, setting. It seems to be an interesting idea for an astronomy class, since the survey seemed to indicate a high correlation between astronomy- and science fiction interest.

13.2 Creating an ill-structured problem

This brings me to the problem itself. The travel destination could be seen as a ”real” problem or at least a case. It could also be relatable in a science fiction setting. To make a problem more real, one could describe a realistic future scenario, and create a visionary future problem. Observing the students in their decision making during the exoplanet design exercise, the decisions were based on feelings. Of course, this is also due to the free nature of the exercise. A neutron star was chosen because ”it would be cool” (and then related to: is it possible within our framework?). A trampoline park for fun reasons and then the surface gravity decided afterwards. An ice cream colored yellow and red planet for the fun aesthetics and then explained by what ele-

[20] https://exoplanets.nasa.gov/alien-worlds/galaxy-of-horrors/
[21] https://www.eduhk.hk/apfslt/v13_issue1/yener/page5.htm

ments of sulphuric compounds an rusting iron. Caramel and coffee colored clouds for the aesthetics, but then came the critical feedback from the teacher - how can it be so, in an Earth-like atmosphere with water vapor? It is like a reverse engineering of a world. First we decide parts of the world using feelings and creative imagination, then we figure out why it must be so and update some properties based on the physics.

Part of the exercise, was that the students needed to familiarise themselves with different planets by browsing NASA's Eye webpage with planets and poster examples. Since the information load is large on especially NASA's page, it was random which knowledge the student would acquire from those sources. To make sure, that they met a variety of ideas before making their own research, I could suggest for an improvement, to choose a variety of examples in different categories. With this, there might also be a better chance for choosing environment that are not default "Earth like". Lack of variety of did not seem to be a big problem when seeing the presentations, but especially when it came to atmosphere and surface, student often relied on the "default". This made also sense to the purpose of a travel destination for humans and also, the atmospheric composition also would require further knowledge would chemistry and biology, and details of this would be outside the scope, but still an interesting fact to consider for an exoplanet design.

The problem given should preferably be ill-structured, which means that the problem is not clearly defined with one answer only, which I believe fits the designed package quite well. It is up to the students where they want to put their focus to solve the problem, and there is no one correct answer. From the survey, the students expressed that they really enjoyed the open-ended creative process with a high degree of freedom of choice, but still within a defined framework. I think this makes it a nice balance of ill-structured learning with a scaffolding structure to follow.

All in all, the package seemed to work as it was, but some students suggested in the survey, that they would like to have more examples of calculations. This might not be for contextualising as such, but could work as a pedagogical scaffolding[34]. For the context, I will put more focus on defining the problem as a travel destination in a science fiction setting.

13.3 Fostering curiosity and motivation

Ill-structured problems should partially pique the curiosity of the students. In the literature-review, I considered different kinds of curiosity, among those the 6 types of curiosity: Mechanic (how), teleological (why), inconsistency, cause-effect, engineering, and general knowledge. One type of curiosity, that should be triggered in the exercise, is especially the cause and effect, a what-if experimental setting. It is the wonder about what would make something have the properties that (we imagine) it has, and was a bit part of the exercise. The student came up with ideas for the star and the planet based on imagination and feelings, and then tried to reason and derive other parameters.

Examples of inconsistencies could be implemented better in the package, by showing examples of planets in the solar system and comparing with examples of very

different types of exoplanets, as mentioned in the previous section. The mechanistic curiosity is about how processes occur. This curiosity could be taken advantage of in such exercise, if there was time to focus on the development for the processes, e.g. how a solar system forms with the protoplanetary disk and how planets form, and thus explaining the components of the planet and partially the atmosphere. The formation of our solar system differs to the theoretical formation of many other star systems due to the hot Jupiters in the inner parts of the solar system. It is interesting that we have water in our inner part of the solar system, while this should theoretically have evaporated during the solar system formation. Such inconsistencies and mechanics behind requires a deeper level of knowledge, than I assume an average high school class would have learned.

For an interdisciplinary or larger project, the focus could also be on geological and chemical processes forming the surface and the atmosphere of the planet, connecting physics of exoplanets with perhaps geology or chemistry.

13.3.1 Teleological curiosity

The teleological curiosity is about why things exist or occur as processes. This curiosity could be about related to life, i.e. such as why life has evolved as it has and how this process then could be imagined in a different settings. There is more focus on the evolution life the original exercise for middle school, which focuses as much on the the biology and evolution of life as physics. In the second half of the exercise, groups were to switch planet posters, and design a life that could thrive on the planet hat they received, having been presented with the evolutionary processes of life on Earth. This part of the original exercise would not only serve a teleological curiosity of why life could evolve and perhaps how human life evolved, but also serve as a new ill-structured problem. New planet and another groups way of thinking might shake up ideas and give birth to new ways of thinking.

For the high school level, students are encouraged to consider, how life could have evolved in the perhaps extreme conditions that their planet could have, although it is not a big part of the exercise, due to the focus on physics and astronomy and time constrain. Nevertheless, also questions on why a planet would have a specific color, some unique surface formation, atmospheric composition and similar, are also teleological. For example, when the group decided that it could rain with juice, they asked themselves why this process could occur, and came up with an explanation of some life form that has juice as a biological bi-product. Of course, the science behind this might be questionable, but this is not the point - the point is that they train their reasoning and coming up with explanations for phenomena to occur. Such skill is needed in scientific thinking, although for a useful setting, they would need to continue asking deeper level's of why's, such as why does the life have a bi-product that suits human life (was it engineered such, have humans evolved in a new ecosystem with this life, or what does it take for it to be a coincidence?). To quote Richard Feynman in an interview where he was asked to explain magnetism:

> When you explain a why, you have to be in a framework where you allow something to be true, otherwise you're perpetually asking why[22] – Richard

[22] https://www.youtube.com/watch?v=36GT2zI8lVA

Feynman

The teological curiosity makes us ask why somethis happens or is the way that it is, and to know why, we need to understand the framework, either by keep asking why or - in the end - accepting some assumptions. This curiosity might especially be relevant for further perspective on learning about more abstract levels and trying to understand the fundamentals of the Universe.

13.3.2 Interest-driven curiosity and self-determination

Although, I do not have information about the underlying interest that the student's would have in the exoplanet design, the survey showed that what they really liked about the exercise was the freedom of choice, which could also indicate a great freedom in the kind of underlying curiosity for their information search about their exoplanet conditions. The freedom of choice led to a more creative process, while they also had to reason for their choices within the physical framework, which was the two other most mentioned success factors in the exercise.

This could also be related to the three basic psychological needs: relatedness, competence and autonomy. The autonomy is what the survey showed, that the students appreciated the most. The relatedness is having a "safe space" in your class and in your group, which I find that the freedom to choose their own group could have been part of, although I do not have any control group with different conditions, so there might be other influences. There can be reasons for groups chosen by the teacher, and assuming that the teacher knows her students best, the autonomy should be granted for the teacher to plan this accordingly to the situation. The competence is optimised by giving a challenge that fits the current knowledge and reinforced with positive feedback, which I will discuss further in the following sections.

13.3.3 Kinesthetic curiosity

I looked into kinesthetic curiosity in section 7.1.2, which tries to map the way we search for information: is it broad searching in various directions or focused on one specific topic? To see how information searching patterns evolved during the exercise, I tried to split up the SRP basd on the observation into three parts, which roughly covered an equal timed beginning, middle and end. It seems like the students in all three parts behaved most like busybodies or dancers, discussing various topics at once and going deeper in some of them. This is not so surprising, since this is a creative exercise, where the various subject are connected and dependent on each other. I might have hypothesized that the beginning would have been like this, while there would be more focus information search at the end of the exercise, but this was mostly in the very end at the last 10 minutes, where all three students focused on solving the problem with the calculations of the temperature of the planet.

It might be a bit hard to analyse the observation for individual student behaviour, since the three students were often working in parallel on different topics while also working together at the same time. From the observation, it did seem though, like one of the students were more hunter-like in focusing on solving the luminosity equation and finding the habitable zone. He seemed driven by closing this one information gap.

Otherwise the creative exercise resulted mostly in busybody and dancer behaviour, where information was simultaneously searched and connected for different properties. The weight in the beginning was as expected on the star, but many other considerations about the planet were made, such as its orbit connected to the temperature, the look for the poster, the travel destination aspect and a bit about its size and gravity for living on the planet. In both the middle and the end phase, many parts of the different properties were still considered.

This interpretation is of course also influenced by both the way I chose to structure the research question nodes for the tree, which is a subjective matter and could be structured differently. Nevertheless, I think it shows a bit about the thinking process and the various considerations the students go through whole solving the exercises. Although they are structured and prioritised, the information is connected. This results in creative patterns of thinking and connecting different subjects and perhaps also trains the students in the many possible connections, as they also mentioned in the survey as one of the things that they liked about the exercise.

13.4 Creating more value in the information search

Progression can be discussed on several levels. One level is the progression through a whole course, and another is the relatively shorter progression through a lesson or one problem-solving exercise. While it is the latter I will focus on, since this is the test of one teaching material, that is the subject of the thesis, the results from the observation shows, that the results of course also depend on a larger context of progression of the teaching. The test group had a large focus on finding the luminosity of their star and use it for finding the habitable zone, even though it was not needed in the exercise. They had recently finished a larger assignment on stars calculating the luminosity, and it made sense for them to try to include it to determine the temperature. Thus, the larger context of a lesson plan and the overall progression in information should also be taken into account when planning and executing the exercise.

The progression in a problem-solving exercise, should also be such, that the information found in one exercise will be used later, to increase the motivation and the understanding the reason for finding the values. In the exercise, this is partially so, since the order of the assignment is such, that information about the star in the beginning of the exercise, will be used to calculate information about the planet temperature, which is again an important factor for habitability of the planet.

From the observation results of the test group, I see that maybe the purpose of finding the temperature for a habitable zone, was not completely clear, since the group had not made the connection until late and hence spend time on finding another method. For an improvement, I will make it clear, what the various values can be used for, and hence hopefully giving an extra motivation for calculating the values or deciding which to calculate.

13.5 Constructive feedback

A constructive prompt feedback with reasoning behind, is part of encouraging students to critical thinking as part of their curious behaviour. In the presentation from the students at day 2 in the test, the teacher gave this kind of feedback for each group, with main questions as seen in table 3 in appendix G. I have not made a teacher's guide for the first iteration of the teaching material, but for the improved package, it would be a good idea to give a few examples for constructive questions and feedback in the teacher's guide.

Other types of feedback has not been considered during the literature review or during the short test, but especially in a time constrain, there could be mentioned the possibility of groups giving feedback or reflecting on each others solutions. Although, during the presentation, students also had the option to ask questions for the group presenting, but there was no-one who had additional question in the class room. If groups were to present to each other, it would be the students themselves, considering another groups solutions and sharing their own reflection that they have made during the exercise, applying it to the other groups solution. Such peer assessment can help the students reflect on different solutions to an open question. The drawback for this procedure, is the the students do not have the same level of physics knowledge, to be able to give the same higher reflective feedback, connecting the different parts of physics as is required in the exercise. If time allows it, it is preferably to reflect with a teacher, as a study shows that it could help students learn effective problem solving strategies[47][48].

13.6 Time for the assignment

The feedback from the students in the survey, was that they would like to have more time for the assignment - either that, or the assignment should be shorter. One student mentioned, that the assignment would be fun as a bigger project interdisciplinary with a design course. My own idea was that the assignment also could be an interdisciplinary project with courses such as biology, where I would implement the second part about evolution of life on the exoplanet, as described in the original package for middle school, and the students would have the opportunity to switch planets with other groups for this second part, giving them an opportunity to reflect on a different planet design and not being attached to "one solution" from their prior design. Other interdisciplinary subjects could be geology with more focus on the surface evolution of the planet.

To accommodate the time given for the assignment, there could be a few suggestions. 1) The assignment could be part of a homework exercise, where the students could have more time to work on the assignment with less time pressure. 2) Another solution could be to prioritize the different part of planetary properties, so that some of the topics could become "bonus"-assignment, only for those who felt they had time for more than the main assignment. The problem with this is what to prioritize and what to take away - because already, the assignment is only a small part of all considerations. One of the things that the students liked about the assignment was also the freedom of choice, which could be influenced with less parts. 3) A third option is giving more time in class for the assignment. Already the assignment lasted two

double-classes, which is weeks of work or a week and a half, depending on the course configuration. 4) A different solution could also be inspired by the alien environment example in section 6, where various aspects of a real life problem were distributed on the groups of students. This might work on other problems, but in this case, the various parts are not independent of each other. It could be solved by deciding on one common exoplanet together before moving on to the group work on each aspect, but this solution might have large drawbacks on the feeling of autonomy in the exercise. 5) It could also be, that removing some of the obstacles that the students had with the equilibrium equation that they mentioned, would give the students more time for considering other properties of the planet.

A final practical solution for the time constrain could simply be to indicate a time interval in the teaching material instead of one specific time, and let the teacher decide individually in the end. The time interval should cover a realistic suggestion. The time frame used in the test was after all realistic for a solution, although more time would have been "nice to have". It should be mentioned when presenting the exercise, that it might not be possible to go through all of the considerations in the given time frame, but that is okay because focus is on figuring out as much as possible and focusing on what the students themselves find interesting as long as they can argue logically or physically for their choices asking critical questions.

14 Improved "Exoplanet Design" package

In the previous section, I have discussed some possible small improvement for the "Exoplanet Design" package for high school students. Overall, I find the exercise was successful regarding connecting the creative aspect with physical reasoning and covered the purpose of getting an overall idea of the variety of exoplanets and their properties. Based on ideas from the literature and the test results of observation, poster presentation and survey, I have made an updated version of the teaching material. The new student- and teacher guide as well as a new presentation, is attached in appendix I in an English version. The main points in the improvements are:

A short science fiction context based on future humans exploring space, mentioned in the introduction of the exercise (not much, the settings was already science fiction like): *Welcome to the future! Tired of staying home? Travel the galaxy! Create your own new world for leisure holiday and new adventures.*

I have kept the overall ill-structured problem as the travel destination with open ended solution and partially given information. I added a note for what to look after other interactive NASA page: *You can "Filter by planet type", where you can view planet, system and star or you can choose "Browse planets" in the top menu.*

I restructured a few parts of the assignment for a better flow and priority, i.e. the type of the planet is now grouped together with the mass, size and gravity instead of with the surface, and I made a clear purpose for the values to be calculated, especially for the temperature and the habitable zone in the first assignment "Property of the star: *The properties of the host star, and the orbital distance to it, are essential for conditions of your planet, especially for the planet surface temperature, and hence the habitability. Consider the following star properties:.*

I have added a mass-radius plot for host stars using online diagram tools[23], for the students to see the relation, see figure 28. I have kept the original HR-diagram to find the relation for the temperature as well, but I also added an online resource for an interactive HR-diagram[24] to see a relation between stellar radius and temperature, where the star also changes size when moving around different positions on the HR-diagram. With these tools students can play around to get an idea of the different relations between stellar radius, mass and temperature. Considering that the students either use NASA's resource or google for information about star mass, radius and temperature, they might not consider the relation, but the observation also showed, that the students in the test group did want to make a calculation based on their previously learned equations, but had trouble finishing it.

I have given more examples in the presentation on calculating the equations, especially for the equilibrium temperature including units, see figure 29. Also, for students that have previously learned about luminosity of stars, and bright students who might want to see the actual derivation of the equilibrium temperature from stellar luminosity, radius and orbital distance, I also added the derivation in the presentation, so that it

[23] https://exoplanet.eu/diagrams
[24] https://astro.unl.edu/mobile/HRdiagram/HRdiagramStable.html

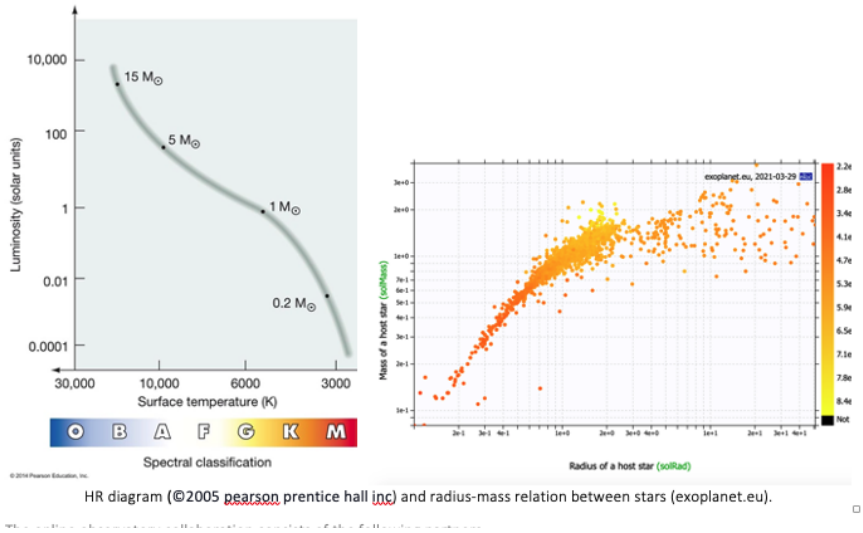


Figure 28: HR diagram (©2005 Pearson Prentice Hall inc) and radius-mass relation between stars (https://exoplanet.eu/diagrams) used in the student guide.

is clear how it came to be, see figure 30. This is added based on the observation of the test group, who struggled with calculation of the luminosity, when in fact it was already used to derive the given equilibrium temperature in the exercise.

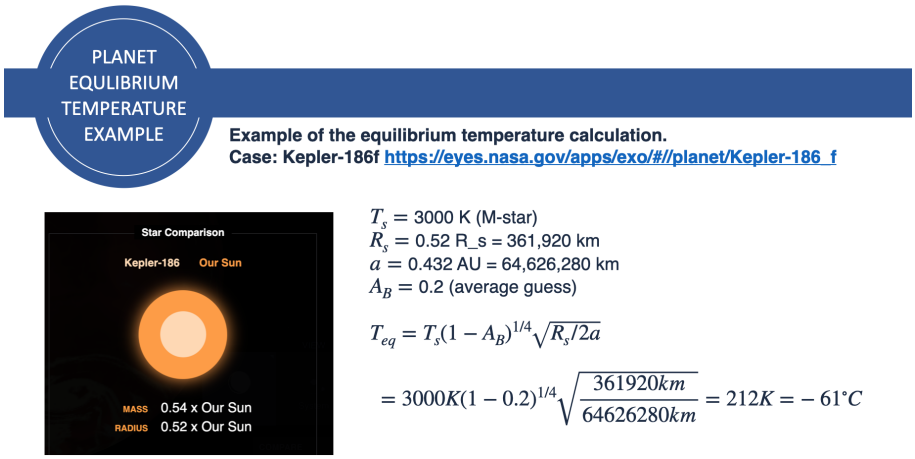


Figure 29: Example for the equilibrium calculation in the presentation. Image from NASA's Eyes on Exoplanets: https://eyes.nasa.gov/apps/exo/#/planet/Kepler-186_f

I have made room for writing down the result of the calculation in the word document, and also there are no boxes giving technical complications.

I also considering adding an extra text for the atmospheric composition: *It does not have to be human breathable, focus on the reasons and processes behind your atmosphere composition*, but have removed it, considering the time constrain and that the students would most likely lack the background knowledge for processes resulting in

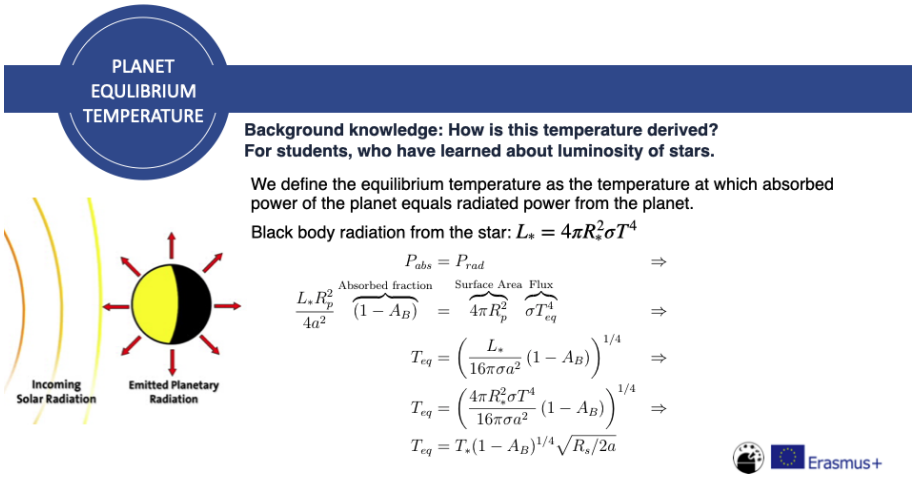


Figure 30: The derivation of the equilibrium temperature, as described in section 3.2.4.

atmospheric composition, perhaps given existence of life. Instead, I have in the presentation included examples from the atmospheric composition of planets in our solar system, see figure 31.

Object	Mass (kilograms)	Carbon Dioxide	Nitrogen	Oxygen	Argon	Methane	Sodium	Hydrogen	Helium	Other
Sun	3.0×10^{30}							71%	26%	3%
Mercury	1000			42%			22%	22%	6%	8%
Venus	4.8×10^{20}	96%	4%							
Earth	1.4×10^{21}		78%	21%	1%					<1%
Moon	100,000				70%		1%		29%	
Mars	2.5×10^{16}	95%	2.7%		1.6%					0.7%
Jupiter	1.9×10^{27}							89.8%	10.2%	
Saturn	5.4×10^{26}							96.3%	3.2%	0.5%
Titan	9.1×10^{18}		97%			2%				1%
Uranus	8.6×10^{25}					2.3%		82.5%	15.2%	
Neptune	1.0×10^{26}					1.0%		80%	19%	
Pluto	1.3×10^{14}	8%	90%			2%				

Figure 31: Example values for the atmospheric composition of planets in our solar system given in the presentation. Source: NASA https://www.nasa.gov/sites/default/files/files/YOSS_Act_4.pdf

Also, I changed a few of the considerations into bonus "extra" considerations as to prioritize the most important physics considerations and make room for some few extras for those that have enough time or just to get an idea about different rich amount of possible influences. The list of extras are: 1) single star or a double or triple system? (Like the Alpha Centauri system). We won't use this in our calculations, but it's important to note that many stars out there are double systems, and it might affect the orbit and habitability of the planet, not to mention the view. A planet usually revolves around one of the stars, but it is also possible for a planet to revolve about both. 2) the density your planet would have with those values (size and mass) and why 3) Does the surface changes over time. Are there any tectonic plates or volcanoes? 4) Does your planet have a magnetic field and why? (it helps keeping the atmosphere, although it is not crucial – compare with Venus, Earth and Mars. Only Earth has a magnetic field) 5) (extra) Are there any seasons? Consider axial tilt and eccentricity. An axial tilt is the reasons for seasonal changes on Earth. If the planet has a very eccentric orbit,

this could also result in seasons, which is the case on Mars, while Earth's orbit is too circular to influence. For the similar reasons, I also added a note in the presentation at the end, stating that: *You might not have time for all considerations, but do as many as you can, and remember to reason and argue for how your choices could be realistic!*

I added a teacher's guide, and in there information about which competences are needed, and a suggested time interval for the exercise as "at least 2x1,5 hours". In also added suggestions for a few constructive feedback on presentation and suggestions for further activities both in the student guide and teacher's guide: *This project could be part of an interdisciplinary project with either biology (with focus on evolution of life on Earth and how life on the designed planet could possibly evolve), geology (with focus on the planet structure, and the surface evolution), and design and communication (with more focus on the poster and presentation)..*

The full teacher and student guides can be found in the appendix I. The language is in English as for use in general in the Online Observatory.

15 Perspective

I will end this part by returning to the beginning. In the theoretical framework and the testing of the material, I focused on the students and their learning. In the preliminary domain research, I mainly focus on teacher reported challenges (section 2.2). Learning and teaching are two sides of the teaching situation that influence each other. The rhetoric of the teaching will influence the feeling of relevance for the students, which will influence the motivation and curiosity in their learning experience (fig. 12). Beside the observational problems, for high school teachers, challenges involved 1) the complexity of topics, that seemed easy on the surface, 2) the lack of mathematical skills and 3) abstract topics that tended to become more superficially descriptive instead of understanding of the physics behind. I would like to connect those challenges to some of my findings here, and consider a perspective on the rest.

I might have chosen the easy path, by focusing on a creative exercise where I did not chose to go in depth with too many equations. On the other hand, as we have seen in the Problem based learning, a pattern-matching of equations to solve well-structured problems is not necessarily the best way to learn scientific thinking. In a way, by giving the students various physical relations between observed and derived parameters to consider, we focus on the physical meaning of the equation, instead of getting a specific value. Of course, being able to calculate and in the end evaluate a value in is also important for doing science, but practicing general scientific thinking while combining it with a fun and curious-relevant context, might be more inspiring for students, who might otherwise lose their sense of wonder and interest in science.

Regarding some of the topics being too abstract, I have already addressed some of it in Content based learning in section 6. We can use context, in the form of analogies to connect the world outside our senses to he experienced world, as shown in figure 14. I would like to elaborate on that by zooming into the "supermacro" and levels of abstraction. Not everything "abstract" is equally abstract. Exoplanets, one can imagine, if one knows the solar system and the planets. Distances we can contextualize by scaling, although the enormous distance scales compared to sizes makes it harder. Although this is a higher level of abstraction than the experienced macroworld, we still have our intuitive understanding of what a size and distance means based on our macroworld experience and intuition. All the properties that we discussed and considered in the exoplanet design exercise were not unknown properties, even though their values and context are unfamiliar to many. We could use our intuition and assumptions of what matter is, and how it behaves, what distances and sizes are, and how they can be measured.

What if the level of abstraction became such, that we no longer could trust our instincts about how matter, space and time behave? This happens on large distances, at relativistic velocities and in the smallest quanta of building blocks of matter and energy. Or what if we could not even trust all of our assumptions about the building blocks themselves, because our knowledge is not complete, as is the case of dark matter, and even worse in the case of dark energy.

I see this as at least two further abstraction levels above the exoplanetary unfamiliar

environment abstraction:

Level 1 (exoplanets): Assumption from our macroworld are useful for "supermacro" world

Level 2 (relativity, quantum mechanics): Assumption from our macroworld are not useful, but we can rely on the representative equations build upon principle theories[49][50][25]

Level 3 (relativity and quantum mechanics combined, dark matter, dark energy): Our scientific assumptions or concepts might be wrong or at least incomplete

Problems with higher levels of abstraction

I mentioned in section 3.2 about derivation of exoplanet parameters, that we make derivations based on our assumptions of the fundamental principles of space and time, that we assume are true. History has seen several examples of scientific revolutions with frameshifting of principles, as Thomas Kuhn[52] described in 1962, where fundamental scientific assumptions have been replaced. From geocentric to heliocentric worldview by Copernicus in 1514[53] and from fixed space and time to relative spacetime by Einstein's theories of relativity and gravitation[54] that unified matter, energy, space and time, with an interaction summed up by John A. Wheeler as:

> Matter tells space how to curve, and curved space tells matter how to move[55]
> – John Archibald Wheeler

Even though more than 100 years have passed since Einstein's first publication on that relativity, it is still something that is hard for us to grasp because it goes against our intuition from our everyday experience. We do not experience the effects because its influence is neglectable in our macroworld. Our brain's interpretation of what our senses experience is optimized through long evolution to understand the world that we need to navigate.

Matter resulting in the curvature of a 4-dimensional spacetime has been conceptualized by rubber sheets where mass distorts the shape of the sheet and hence influences the movement of other mass. This analogy might be useful for initial introductions to the nature of spacetime curvature, but it has some flaws, such as making it seem like spacetime curves in "something else" outside spacetime and trying to explain gravity by the use of gravity[26]. My point here is not so on much how to create specific contextual analogies to such abstract problems, but rather that some abstraction levels

[25] A principle theory is a fundamental theory based directly on empirical observation and which cannot be deducted from other laws, a definition made by Einstein: "We can distinguish various kinds of theories in physics. Most of them are constructive. They attempt to build up a picture of the more complex phenomena out of the materials of a relativity simple formal scheme from which they start out [...] Along with this most important class of theories there exists a second, which I will call 'principle-theories.' These employ the analytic, not synthetic, method. The elements which form their basis and starting-point are not hypothetically constructed but empirically discovered ones, general characteristics of natural processes, principles that give rise to mathematically formulated criteria which the separate processes or the theoretical representations of them have to satisfy"[51]

[26] An attempt to make a digital analogy that takes the flaws into account can be seen for inspiration here: https://www.youtube.com/watch?v=wrwgIjBUYVc

are hard to contextualize, or even impossible without losing some part of the truth. As Feynman said in an interview about magnetism:

> I really can't do a good job, any job, of explaining magnetic force in terms of something else you're more familiar with, because I don't understand it in terms of anything else you're more familiar with.[27]
> – Richard Feynman

Nevertheless, making different contextual analogies might still be a good help to get a better understanding of parts of an abstract reality, when there is none, by illuminating a concept from several angles and examining the resulting shadows to get a better idea of the whole. Meanwhile, as students of the Universe, we need to remember that we are only seeing part of the truth, like in the tale of "The Blind Men and The Elephant"[28]. Just like the particle-wave duality is like two shadows of some reality we still have not yet been able to grasp..

Would the theoretical framework presented here still be of some use? Context-based learning is still useful, but there are different aspects to consider, the more abstract the problem. While problem-based learning with ill-structured problems is a good way to foster critical thinking, one needs to take the level into account for students to be able to identify the problem and ask the right questions. While the theoretical framework is still relevant, it would need to have different focus and be applied differently for higher abstraction level problems. Further testing of teaching material on more abstract matters could be interesting to do.

[27] https://www.youtube.com/watch?v=36GT2zI8lVA
[28] Originally an ancient Indian folk tale, https://www.pitt.edu/~dash/type1317.html

Conclusion

16 Conclusion

I started this thesis as a very open project, which I could define along the way. The main purpose of the thesis, was to test one or two teaching materials for the Online Observatory, and perhaps create a teaching package for the purpose, preferably by the use of observational data, which I planned to do with a telescope at Brorfelde Observatory. The process in the beginning was diverging in many directions for the purposes of 1) figuring out the most interesting topic and target group to test, and 2) figuring out the purpose of the test. I did a domain research of the educational system in Denmark and a few informal surveys and semi-structured interviews for pinpointing challenges in teaching astronomy, and I decided that my focus would be on on fostering scientific curiosity and astronomy interest, rather than on the specific learning outcomes.

My theoretical framework was about context- and problem-based learning (CBL, PBL) and curiosity used as a driver for motivation in learning. I found through a literature-study, that a context could give a better understanding of the relevance of a problem and that ill-structured problems could foster critical thinking and motivation. I also did some literature-study on the topic of curiosity, and different categorisation of curiosities. One main categorisation was on the liking vs. wanting scale, where an interest-driven curiosity was purely driven by liking and neurologically triggered different areas than deprivation-driven curiosity, that was driven by a wanting to close a knowledge gap. Both typos of curiosities could motivate for a search of knowledge, but could also give different kinesthetic movement through the information space (e.g. how you search for information). While I-curiosity, which is also neurologically linked to impulsivity, could lead to a broader busybody pattern of information search, meaning broad search on information on various topics, the D-curiosity could result in a more focused hunter-style in the hunt for solving one specific problem. Different patterns are not only a question of personality, but can also be dependent on the phase of a project. I also found, that curiosity is important for the intrinsic motivation and that three basic psychological needs will foster a higher intrinsic motivation, including curiosity and result in self-determination in learning. Those three needs were: Relatedness, competence and autonomy.

This theoretical framework was used as focus for my analysis of the exercise and the following test results. I used the interpretivist approach to the analysis, where I focused on the one just the one example of a teaching situation, not necessarily being able to project the results on other teaching situations, although maybe some clues could be found, that could result in a hypothesis that could be further tested and evaluated.

I planned to use teaching material for Exoplanet Design, that was already made for the OO, and start with testing it directly with its target group of middle school students. Due to COVID-19 restriction, my planned pilot-test could not be completed. I developed the teaching material to use for high school and for an online teaching situation, and tested this with one high school astronomy class, following a group of

three students and observing them during their work with the exercises and then the presentation of 6 out of 8 groups.

I analyzed the recording by creating study- and research paths for their thinking process, and tried to analyse it in three phases; beginning, middle and end. I discovered that the students had a creative approach with design decisions based on feelings such as what could be cool or fun, but also they were focused on getting the quantity right for the exoplanet properties. Their study- and research pah indicated that they overall used a busybody kinesthetic curiosity by considering different ideas about the exoplanet at ones, but at the same time, one of the students had a focused determination on closing a knowledge gap by getting a correct result for the habitability zone and temperature of the planet. The students were both creative in ideas for their exoplanet, but at the same time, they used critical thinking to reason and evaluate their results.

During the presentation for the whole class, the students showed a variety of creative solutions in their poster presentation. They all had considered the properties of the host star and orbital distance and a resulting estimate for the planet temperature. They had different focus in their solution for the planet as a travel destination, but all of them had come up with something that was both creative and used some reasoning and physics. Each group were given immediate feedback including extra question to exercise their critical thinking.

The survey after the test of the teaching showed that the students enjoyed the creative aspect combined with reasoning and physics in the exercise, and also the freedom of choice on how to solve the assignment. Some struggled with especially one of the equations due to the lack of examples with units, and they would have liked to have more time to do the assignment. This was one of the thing that I tried to improve upon in the updated version of the teaching material, where I have added an example calculation with units. I also elaborated om the mass-radius relation of the host star and highlighted the purpose of finding he values for the star used in figuring out the habitability. Generally, the improved version had more clear purpose and progression of finding the values. Other improvements included more examples, such as atmospheric compositions on planets in our solar system. For the time constrain, I made some of the considerations into ”extras” and made a note about not necessarily being able to include all of the considerations in the final result.

Since the test was only with one single class, it does not necessarily reflect a general result of using this teaching material. With an interprivistic view, every teaching situation will be different due to different students and different teacher. Instead, I have shown one example on how using this teaching material could evolve and made small improvements based on the results and the theoretical framework that I created for the purpose of fostering more motivation, creativity, and critical thinking in astronomy.

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Acronyms

CBL Content based learning. 44, 45, 90, 93

JWST James Webb Space Telescope. 26, 28

OO Online Observatory. 8, 17, 93

PBL Problem based learning. 45, 46, 90, 93

SCS Science Curiosity Scale. 52

SRP Study and research path. 61, 62, 64, 66, 68–70, 72

Appendix

A Q&A Brorfelde Observatory

1. **Hvad er historien bag OO? Hvem har fundet på ideen og emnerne?**
   Det er Observatoriet i Brorfelde, som oprindeligt har fået idéen til projektet, hvor det var vores daværende astronom, Michael Lindholm, som sammen med Jørgen Gruppe har været primus motor for projektet. Emnerne og det øvrige indhold er udviklet sammen med samarbejdspartnerne. Projektet er desuden en del af at andet projekt, hvor vi er i gang med at udvikle et Virtuelt Observatorium, som jeg har vedhæftet en projektbeskrivelse på. Generelt har vi den holdning, at samarbejde er vejen frem, så vi med fordel kan samarbejde med andre observatorier for at samle de gode idéer, erfaringer og ressourcer i stedet at opfinde den dybe tallerken selv.

2. **Er pakkerne primært ment til undervisere (gymnasie/udskoling) eller er det også til andre grupper, events oa?**
   Pakkerne er primært henvendt til folkeskolens klasser fra mellemtrin og op – og som en hjælp til at få lærerne til at bruge astronomi i klasseværelset. Derfor er lærerkurser og lærerkommunikation en stor del af projektet, som vi også kommer til at have meget fokus på jer, ligesom vi også selv skal tilbyde forløbende på observatoriet. Derfor er test med målgrupperne og forankring på Observatoriet af høj prioritet de næste måneder, hvilket vil være én af de primære arbejdsopgaver for vores kommende astronomiske naturvejleder i samarbejde med NBI og Kristine.

3. **Hvilket formål skal det tjene? Er det mest som inspiration, eller er det evt. noget der skal understøtte nogle særlige læringsplaner?**
   Det skal motivere og inspirere lærerne til at inddrage astronomi i undervisningen med hensyn til Folkeskolens faglige mål. Derudover er det også et formål i sig selv at skabe gode samarbejdsrelationer med de øvrige observatorier, ligesom forløbene også skal integreres i vores egne tilbud.

4. **Og det er gratis/skal forblive gratis umiddelbart, eller er der andre planer også?**
   Det er som udgangspunkt gratis at benytte materialet – men det kommer til at indgå som aspekter af vores egne tilbud, som for det meste kræver brugerbetaling.

5. **Har der været nogle særlige didaktiske overvejelser? (bare så jeg ikke kommer til at opfinde den dybe tallerken forfra, da jeg selv ville lave didaktiske undersøgelser med undervisere/elever, fx undervisernes interesse og agenda i forhold til at bruge pakkerne samt elevernes motivation fx)**
   Nej – de didaktiske overvejelser har ikke været i fokus. Så det er lige præcis her, der er en rigtig spændende og vigtig opgave her i den afsluttende fase. Jeg vil tilbyde projektet, at vi tager ansvaret for at evaluere og teste pakkerne – og det var her, jeg håbede, at du ville kunne inddrage det i dit speciale. Jeg står gerne til rådighed for sparring om metodedesign mm.

6. **Hvad er deadline for pakkerne og er det planen at der kan/skal udvikles videre på pakkerne efterfølgende?**

Vi arbejder efter følgende grove tidsplan: December, januar og februar: Færdiggørelse af undervisningspakker og møde med partnerne i Norge d. 11-12. februar (Kristine: Har du mulighed for at deltage sammen med mig og Jørgen?)

Marts, april og maj: Gennemgang og test af de 7 pakker: Først med observatoriets guider og formidlere – dernæst med Holbæk Kommunes folkeskoleklasser. Især i forbindelse med Forskningens 7 døgn, hvor Observatoriet tilbyder skoleklasser at komme ud gratis og teste forløbende, som evalueres. Juni: Færdiggørelse og kick-off lærerkursus – dato afklares snarest. Juli og august: Projektet afsluttes og det sidste møde afholdes i Helsinki, Finland i august.

Vi vil gøre opmærksom på projektet her: Danmarks Læringsfestival d. 4. og 5. marts: (Jørgen deltager + en repræsentant for NBI/Kristine. Se vedhæftede invitation) Big Bang Konferencen i Odense: 18+19 marts (jeg har søgt om at få et værksted. Jørgen tager afsted sammen med en repræsentant fra NBI + 2-3 guider fra Observatoriet). Jørgen: Kan projektet dække overnatning + deltagergebyr for alle deltagerne?) Science Expo i Lokomotivværkstedet i København d. 19.-21. april

Vi vil teste produkterne med skoleklasser i forbindelse med Forskningens 7 døgn, som er d. 20. – 26. april.

7. **Kan der evt. være tale om online interaktive produkter? (evt. sideløbende med de givne skabeloner)**
   Ja – det kan der helt sikkert. I første omgang er fokus dog at få afsluttet de konkrete forløb, som er lovet i forhold til projektet. Herefter håber jeg, at vi bliver ved med at udvikle, implementerer – så projektet lever videre efter dets officielle afslutning.

8. **Skal sproget være Engelsk, eller skal der evt. være noget til mindre børn på dansk?**
   Samarbejdssproget er engelsk, men alle pakkerne skal oversættes til dansk.

9. **De emner der pt står "still to be completed" under BR, er der nogen der er ved at udvikle på disse? Eller er det bare en idé, som man kan arbejde videre på?**
   Her er det Jørgen Grubbe, du skal spørge.

10. **Hvordan skal sammenhængen være med observationer? Skal det fx være emner der hænger sammen med observationer fra Discovery teleskopet eller i det hele taget hænge sammen med observationer data, eller er det ikke et krav?**
    Det, tænker jeg, er lettere at svare på, når vi kommer i dybden med de forskellige pakker. Som udgangspunkt vil jeg gerne, at observationerne kan foregå uden at skulle på observatoriet – så lærer og elever selv kan observere med håndkikkert en stjerneklar aften fra skolegården, men at de kan supplere med de data og observationer, vi gør os på Observatoriet i Brorfelde – og på de andre observatorier.

B Danish Astronomy Education curriculum

B.1 Natur/Teknologi fælles mål (Elementary school science)

2 Fælles Mål

Kompetencemål

Kompetence-område	Efter 2. klassetrin	Efter 4. klassetrin	Efter 6. klassetrin
Undersøgelse	Eleven kan udføre enkle undersøgelser på baggrund af egne og andres spørgsmål.	Eleven kan gennemføre enkle undersøgelser på baggrund af egne forventninger.	Eleven kan designe undersøgelser på baggrund af begyndende hypotesedannelse.
Modellering	Eleven kan anvende naturtro modeller.	Eleven kan anvende modeller med stigende abstraktionsgrad.	Eleven kan designe enkle modeller.
Perspektivering	Eleven kan genkende natur og teknologi i sin hverdag.	Eleven kan relatere natur og teknologi til andre kontekster.	Eleven kan perspektivere natur/teknologi til omverdenen og aktuelle hændelser.
Kommunikation	Eleven kan beskrive egne undersøgelser og modeller.	Eleven kan beskrive enkle naturfaglige og teknologiske problemstillinger.	Eleven kan kommunikere om natur og teknologi.

Efter 2. klassetrin

Kompetence-område	Kompetencemål	Faser	Færdigheds- og vidensområder og -mål									
Undersøgelse	Eleven kan udføre enkle undersøgelser på baggrund af egne og andres spørgsmål.		Undersøgelser i naturfag		Teknologi og ressourcer		Mennesket		Organismer		Vand, luft og vejr	
		1.	Eleven kan udføre enkle undersøgelser med brug af enkelt udstyr.	Eleven har viden om enkle undersøgelses-metoder.	Eleven kan undersøge, hvordan enkle mekanismer fra hverdagen fungerer.	Eleven har viden om enkle mekanismer.	Eleven kan undersøge sanser.	Eleven har viden om menneskets sanser.	Eleven kan indsamle og undersøge organismer i den nære natur.	Eleven har viden om dyr, planter og svampe.	Eleven kan undersøge lys, vand og vejr i hverdagen.	Eleven har viden om vejr, vands tilstandsformer og karakteristika ved lys.
		2.										
Modellering	Eleven kan anvende naturtro modeller.		Modellering i naturfag		Teknologi og ressourcer		Mennesket		Organismer		Vand, luft og vejr	
		1.	Eleven kan skelne mellem virkelighed og model.	Eleven har viden om naturtro modeltyper.	Eleven kan med skitser og billeder beskrive genstande fra hverdagen.	Eleven har viden om afbildninger af genstande.	Eleven kan fortælle om kropsdelene på en model af menneskekroppen.	Eleven har viden om kroppens ydre opbygning.	Eleven kan med enkle modeller fortælle om organismers opbygning.	Eleven har viden om organismers opbygning.	Eleven kan illustrere vejr og årstider.	Eleven har viden om dagslængde, temperatur og nedbør.
		2.										
Perspektivering	Eleven kan genkende natur og teknologi i sin hverdag.		Perspektivering i naturfag		Teknologi og ressourcer		Mennesket		Organismer		Vand, luft og vejr	
		1.	Eleven kan relatere viden fra natur/teknologi til sig selv og det nære område.	Eleven har viden om natur og teknologi i det nære.	Eleven kan fortælle om ressourcer fra hverdagen.	Eleven har viden om ressourcer fra hverdagen.	Eleven kan fortælle om enkle råd om sundhed i forhold til egen hverdag.	Eleven har viden om enkle råd om sundhed.	Eleven kan fortælle om ændringer i naturen knyttet til årstider.	Eleven har viden om organismers årscyklus.	Eleven kan fortælle om sammenhænge mellem sol, døgn og årstider.	Eleven har viden om karakteristika ved årstider i Danmark.
		2.										
Kommunikation	Eleven kan beskrive egne undersøgelser og modeller.		Formidling		Ordkendskab		Faglig læsning og skrivning					
		1.	Eleven kan fortælle om egne resultater og erfaringer.	Eleven har viden om enkle måder til at beskrive resultater.	Eleven kan mundtligt og skriftligt anvende enkle fagord og begreber.	Eleven har viden om enkle fagord og begreber.	Eleven kan orientere sig i en enkel fagtekst.	Eleven har viden om enkle naturfaglige teksters formål.				
		2.										

Bindende rammer i Fælles Mål Vejledende færdigheds- og vidensmål

Efter 4. klassetrin

Kompetence-område	Kompetencemål	Faser	Færdigheds- og vidensområder og -mål											
Undersøgelse	Eleven kan gennemføre enkle undersøgelser på baggrund af egne forventninger.		Undersøgelser i naturfag		Teknologi og ressourcer		Mennesket		Naturen lokalt og globalt		Vand, luft og vejr			
		1.	Eleven kan sortere og klassificere.	Eleven har viden om naturfaglige kriterier for sortering.	Eleven kan identificere stoffer og materialer i produkter fra hverdagen.	Eleven har viden om materialer og stoffer i produkter.	Eleven kan deltage i dissektion af dyr.	Eleven har viden om sammenlignende anatomi.	Eleven kan indsamle og bestemme dyr, planter, svampe og sten, herunder med digitale databaser.	Eleven har viden om hovedgrupper af sten og enkel klassifikation af dyr, planter og svampe.	Eleven kan udføre enkle undersøgelser om atmosfærisk luft og lys.	Eleven har viden om egenskaber ved atmosfærisk luft og lys.		
		2.	Eleven kan opstille forventninger, der kan testes i undersøgelser.	Eleven har viden om enkle undersøgelsers muligheder og begrænsninger.	Eleven kan designe og afprøve enkle produkter.	Eleven har viden om enkel produktudvikling.	Eleven kan undersøge åndedræt og blodkredsløb.	Eleven har viden om åndedræt og blodkredsløb hos mennesker og dyr.	Eleven kan undersøge dyrs og planters tilpasninger til naturen.	Eleven har viden om dyrs og planters levesteder og livsbetingelser.	Eleven kan gennemføre enkle målinger af vejret, herunder med digitalt måleudstyr.	Eleven har viden om nedbør, vind og temperatur.		
Modellering	Eleven kan anvende modeller med stigende abstraktionsgrad.		Modellering i naturfag		Teknologi og ressourcer		Mennesket		Naturen lokalt og globalt		Vand, luft og vejr		Jorden og solsystemet	
		1.	Eleven kan konstruere enkle modeller.	Eleven har viden om symbolsprog i modeller.	Eleven kan lave elektriske kredsløb ud fra enkle diagrammer.	Eleven har viden om elektriske kredsløb.	Eleven kan med modeller fortælle om menneskers og dyrs indre og ydre opbygning.	Eleven har viden om menneskers og dyrs indre og ydre opbygning.	Eleven kan på enkle kort forklare signaturers betydning, herunder på digitale kort.	Eleven har viden om signaturer på kort.	Eleven kan illustrere nedbør og temperatur over tid.	Eleven har viden om enkle grafer til illustration af nedbørs- og temperaturmålinger.	Eleven kan med modeller fortælle om hovedtræk af Jordens, Månens og Solens indbyrdes bevægelser, herunder med animationer.	Eleven har viden om Jordens, Månens og Solens indbyrdes bevægelser.
		2.	Eleven kan anvende enkle modeller til at vise helheder og detaljer.	Eleven har viden om modellers detaljeringsniveau.	Eleven kan fremstille enkle modeller over en husstands forsyning med vand, el og varme samt spildevands- og affaldshåndtering.	Eleven har viden om lokalområdets forsynings- og afledningssystemer.	Eleven kan anvende flere typer modeller, der illustrerer blodkredsløbet.	Eleven har viden om illustration af blodkredsløbet.	Eleven kan på enkle kort udpege plantebælter og klimazoner, herunder på digitale kort.	Eleven har viden om fordeling af kontinenter, hav, klimazoner og verdensdele.	Eleven kan sammenholde egne vejrobservationer med en enkel vejrudsigt, herunder med digitale vejrkort.	Eleven har viden om en vejrudsigts formål og struktur.	Eleven kan med modeller sammenligne solsystemets planeter.	Eleven har viden om hovedtræk af solsystemets opbygning.
Perspektivering	Eleven kan relatere natur og teknologi til andre kontekster.		Perspektivering i naturfag		Teknologi og ressourcer		Mennesket		Naturen lokalt og globalt		Vand, luft og vejr		Jorden og solsystemet	
		1.	Eleven kan relatere viden fra natur/teknologi til andre regioner.	Eleven har viden om regionale forskelle og ligheder i natur og teknologi.	Eleven kan beskrive en proces fra ressource til færdigt produkt og fra produkt til ressource.	Eleven har viden om enkle produktionskæder.	Eleven kan sammenligne egne levevilkår med andres.	Eleven har viden om levevilkår forskellige steder i verden.	Eleven kan fortælle om dyre- og planteliv andre steder på Jorden.	Eleven har viden om naturområder.	Eleven kan sammenligne vejrdata fra Danmark med vejrdata fra andre regioner.	Eleven har viden om forskelle og ligheder i temperatur, nedbør og vindhastighed.	Eleven kan skelne mellem astronomi og alternative forklaringer om solsystemets opståen og livets begyndelse.	Eleven har viden om solsystemets opståen og livets begyndelse.
		2.	Eleven kan sætte naturfaglig og teknologisk udvikling i historisk perspektiv.	Eleven har viden om centrale naturfaglige og teknologiske udviklinger.	Eleven kan beskrive sammenhæng mellem behov for og udvikling af et produkt.	Eleven har viden om teknologiudvikling gennem tiden.	Eleven kan diskutere årsager til sund og usund livsstil.	Eleven har viden om sundhedsfremmende faktorer.	Eleven kan fortælle om landskabets udvikling gennem tiden.	Eleven har viden om menneskets påvirkning af naturområder gennem tiden.				
Kommunikation	Eleven kan beskrive enkle naturfaglige og teknologiske problemstillinger.		Formidling		Ordkendskab		Faglig læsning og skrivning							
		1.	Eleven kan formidle egne data mundtligt og skriftligt.	Eleven har viden om medier og formidlingsformer.	Eleven kan mundtligt og skriftligt anvende centrale fagord og begreber.	Eleven har viden om fagord og begreber.	Eleven kan læse og skrive enkle naturfaglige tekster.	Eleven har viden om enkle naturfaglige teksttypers formål og struktur.						
		2.												

Bindende rammer i Fælles Mål Vejledende færdigheds- og vidensmål

Efter 6. klassetrin

Kompetence-område	Kompetencemål	Faser	Færdigheds- og vidensområder og -mål											
Undersøgelse	Eleven kan designe undersøgelser på baggrund af begyndende hypotesedannelse.		Undersøgelser i naturfag		Teknologi og ressourcer		Mennesket		Natur og miljø		Stof og energi			
		1.	Eleven kan gennemføre enkle systematiske undersøgelser.	Eleven har viden om variable i en undersøgelse.	Eleven kan identificere stoffer og materialer i produkter.	Eleven har viden om stoffers og materialers egenskaber og kredsløb.	Eleven kan gennemføre fysiologiske forsøg ved brug af enkelt digitalt måleudstyr.	Eleven har viden om motion.	Eleven kan udføre enkle feltundersøgelser i naturområder, herunder med digitalt måleudstyr.	Eleven har viden om karakteristiske naturområder.	Eleven kan gennemføre undersøgelser af energiformer.	Eleverne har viden om energiformer.		
		2.	Eleven kan designe enkle undersøgelser.	Eleven har viden om undersøgelsesdesign.	Eleven kan udvikle enkle produkter.	Eleven har viden om udvikling og vurdering af produkter.	Eleven kan sammensætte et sundt måltid.	Eleven har viden om kost og hygiejne, herunder hånd-hygiejne.	Eleven kan beskrive et naturområde på baggrund af egne undersøgelser.	Eleven har viden om faktorer til at beskrive naturområder.				
Modellering	Eleven kan designe enkle modeller.		Modellering i naturfag		Teknologi og ressourcer		Mennesket		Natur og miljø		Stof og energi		Jordklodens forandringer	
		1.	Eleven kan anvende sammensatte modeller til at beskrive processer.	Eleven har viden om sammensatte modeller.	Eleven kan med enkle procesmodeller beskrive forsynings-produktion.	Eleven har viden om forsynings-produktion.	Eleven kan med modeller forklare ørets og øjets fysiologi og anatomi.	Eleven har viden om syn og hørelse.	Eleven kan med modeller forklare om organismers samspil i naturen.	Eleven har viden om enkle fødekæder og fødenet.	Eleven kan fremstille modeller af vandets kredsløb.	Eleven har viden om vandets kredsløb.	Eleven kan med modeller fortælle om jordskælv og vulkanudbrud, herunder med digitale modeller.	Eleven har viden om enkle principper i pladetektonikken.
		2.	Eleven kan diskutere enkle modellers egnethed.	Eleven har viden om muligheder og begrænsninger ved modeller.	Eleven kan designe modeller af et produkt eller en produktion.	Eleven har viden om modeller til at beskrive teknologi.	Eleven kan opstille modeller om fordøjelsessystemet.	Eleven har viden om fordøjelse.	Eleven kan med enkle cykliske modeller fortælle om fotosyntese og respiration.	Eleven har viden om organismers opbygning og nedbrydning af stof.	Eleven kan med enkle modeller forklare enkelte stoffers molekyl-opbygning.	Eleven har viden om nogle atomer og molekyler.	Eleven kan fortælle om aktuelle natur-katastrofer og andre begivenheder ved brug af kort.	Eleven har viden om atlas og digitale kort.
Perspektivering	Eleven kan perspektivere natur/teknologi til omverdenen og aktuelle hændelser.		Perspektivering i naturfag		Teknologi og ressourcer		Mennesket		Natur og miljø		Stof og energi		Jordklodens forandringer	
		1.	Eleven kan beskrive natur og teknologis anvendelse i samfundet og fremstilling i medier.	Eleven har viden om centrale interesse-modsætninger.	Eleven kan beskrive interessemodsæt-ninger ved produk-tionsforhold.	Eleven har viden om produktioners afhængighed og påvirkning af naturgrundlaget.	Eleven kan skelne mellem livsstils-faktorer og levevilkår.	Eleven har viden om afgørende faktorer for livsstil og levevilkår.	Eleven kan fortælle om livets udvikling.	Eleven har viden om hovedtræk af livets udvikling.	Eleven kan forklare om sammenhænge mellem energi-udnyttelse og drivhuseffekt.	Eleven har viden om energiudnyttelse og drivhuseffekt.	Eleven kan sammenholde naturkatastrofer til menneskers levevilkår.	Eleven har viden om sammenhæng mellem pladetektonik og udbredelsen af naturkatastrofer.
		2.	Eleven kan sætte anvendelse af natur og teknologi i et bæredygtigt perspektiv.	Eleven har viden om enkle principper for bæredygtighed.	Eleven kan iden-tificere ressource-besparende teknologier.	Eleven har viden om enkel miljøvurdering af produkter og produktioner.	Eleven kan vurdere enkle kost- og motionsråd.	Eleven har viden om kost- og motionsråd.	Eleven kan beskrive interessemodsæt-ninger i menneskers forvaltning af naturen lokalt og globalt.	Eleven har viden om forskellige natursyn.	Eleven kan diskutere energikilder i et bæredygtigheds-perspektiv.	Eleven har viden om vedvarende og ikke vedvarende energikilder.	Eleven kan beskrive hovedtræk af land-skabsdannelse i Danmark.	Eleven har viden om vand, vejr og den sidste istids påvirkning på landskabsdannelse.
Kommunikation	Eleven kan kom-munikere om natur og teknologi.		Formidling		Ordkendskab		Faglig læsning og skrivning							
		1.	Eleven kan argumentere om enkle forhold inden for natur og teknologi.	Eleven har viden om enkel naturfaglig argumentation.	Eleven kan mundtligt og skriftligt udtrykke sig med brug af naturfaglige og teknologiske fagord og begreber.	Eleven har viden om naturfaglige og teknologiske fagord og begreber.	Eleven kan læse og skrive naturfaglige tekster.	Eleven har viden om naturfaglige teksters formål og opbygning.						
		2.	Eleven kan diskutere enkle problem-stillinger om natur og teknologi.	Eleven har viden om enkel naturfaglig kildekritik.										

Bindende rammer i Fælles Mål Vejledende færdigheds- og vidensmål

Fælles Mål efter kompetenceområde

Undersøgelse

Klassetrin	Kompetencemål	Faser	Færdigheds- og vidensområder og -mål									
Efter 2. klassetrin	Eleven kan udføre enkle undersøgelser på baggrund af egne og andres spørgsmål.		Undersøgelser i naturfag		Teknologi og ressourcer		Mennesket		Organismer		Vand, luft og vejr	
		1.	Eleven kan udføre enkle undersøgelser med brug af enkelt udstyr.	Eleven har viden om enkle undersøgelsesmetoder.	Eleven kan undersøge hvordan enkle mekanismer fra hverdagen fungerer.	Eleven har viden om enkle mekanismer.	Eleven kan undersøge sanser.	Eleven har viden om menneskets sanser.	Eleven kan indsamle og undersøge organismer i den nære natur.	Eleven har viden om dyr, planter og svampe.	Eleven kan undersøge lys, vand og vejr i hverdagen.	Eleven har viden om vejr, vands tilstandsformer og karakteristika ved lys.
		2.										
Efter 4. klassetrin	Eleven kan gennemføre enkle undersøgelser på baggrund af egne forventninger.		Undersøgelser i naturfag		Teknologi og ressourcer		Mennesket		Naturen lokalt og globalt		Vand, luft og vejr	
		1.	Eleven kan sortere og klassificere.	Eleven har viden om naturfaglige kriterier for sortering.	Eleven kan identificere stoffer og materialer i produkter fra hverdagen.	Eleven har viden om materialer og stoffer i produkter.	Eleven kan deltage i dissektion af dyr.	Eleven har viden om sammenlignende anatomi.	Eleven kan indsamle og bestemme dyr, planter, svampe og sten, herunder med digitale databaser.	Eleven har viden om hovedgrupper af og enkel klassifikation af dyr, planter og svampe.	Eleven kan udføre enkle undersøgelser om atmosfærisk luft og lys.	Eleven har viden om egenskaber ved atmosfærisk luft.
		2.	Eleven kan opstille forventninger, der kan testes i undersøgelser.	Eleven har viden om enkle undersøgelsers muligheder og begrænsninger.	Eleven kan designe og afprøve enkle produkter.	Eleven har viden om enkel produktudvikling.	Eleven kan undersøge åndedræt og blodkredsløb.	Eleven har viden om åndedræt og blodkredsløb hos mennesker og dyr.	Eleven kan undersøge dyrs og planters tilpasninger til naturen.	Eleven har viden om dyrs og planters levesteder og livsbetingelser.	Eleven kan gennemføre enkle målinger af vejret, herunder med digitalt måleudstyr.	Eleven har viden om nedbør, vind og temperatur.
Efter 6. klassetrin	Eleven kan designe undersøgelser på baggrund af begyndende hypotesedannelse.		Undersøgelser i naturfag		Teknologi og ressourcer		Mennesket		Natur og miljø		Stof og energi	
		1.	Eleven kan gennemføre enkle systematiske undersøgelser.	Eleven har viden om variable i en undersøgelse.	Eleven kan identificere stoffer og materialer i produkter.	Eleven har viden om stoffers og materialers egenskaber og kredsløb.	Eleven kan gennemføre fysiologiske forsøg ved brug af enkelt digitalt måleudstyr.	Eleven har viden om motion.	Eleven kan udføre enkle feltundersøgelser i naturområder, herunder med digitalt måleudstyr.	Eleven har viden om karakteristiske naturområder.	Eleven kan gennemføre undersøgelser af energiformer.	Eleverne har viden om energiformer.
		2.	Eleven kan designe enkle undersøgelser.	Eleven har viden om undersøgelsesdesign.	Eleven kan udvikle enkle produkter.	Eleven har viden om udvikling og vurdering af produkter.	Eleven kan sammensætte et sundt måltid.	Eleven har viden om kost og hygiejne, herunder håndhygiejne.	Eleven kan beskrive et naturområde på baggrund af egne undersøgelser.	Eleven har viden om faktorer til at beskrive naturområder.		

Bindende rammer i Fælles Mål Vejledende færdigheds- og vidensmål

Modellering

Klasse-trin	Kompetence-mål	Faser	Færdigheds- og vidensområder og -mål											
Efter 2. klasse-trin	Eleven kan anvende naturtro modeller.		Modellering i naturfag		Teknologi og ressourcer		Mennesket		Organismer		Vand, luft og vejr			
		1.	Eleven kan skelne mellem virkelighed og model.	Eleven har viden om naturtro modeltyper.	Eleven kan med skitser og billeder beskrive genstande fra hverdagen.	Eleven har viden om afbildninger af genstande.	Eleven kan fortælle om kropsdelene på en model af menneskekroppen.	Eleven har viden om kroppens ydre opbygning.	Eleven kan med enkle modeller fortælle om organismers opbygning.	Eleven har viden om organismers opbygning.	Eleven kan illustrere vejr og årstider.	Eleven har viden om dagslængde, temperatur og nedbør.		
		2.												
Efter 4. klasse-trin	Eleven kan anvende modeller med stigende abstraktions-grad.		Modellering i naturfag		Teknologi og ressourcer		Mennesket		Naturen lokalt og globalt		Vand, luft og vejr		Jorden og solsystemet	
		1.	Eleven kan konstruere enkle modeller.	Eleven har viden om symbolsprog i modeller.	Eleven kan lave elektriske kredsløb ud fra enkle diagrammer.	Eleven har viden om elektriske kredsløb.	Eleven kan med modeller fortælle om menneskers og dyrs indre og ydre opbygning.	Eleven har viden om menneskers og dyrs indre og ydre opbygning.	Eleven kan på enkle kort forklare signa-turers betydning, herunder på digitale kort.	Eleven har viden om signaturer på kort.	Eleven kan illustrere nedbør og temperatur over tid.	Eleven har viden om enkle grafer til illustration af nedbørs- og temperatur-målinger.	Eleven kan med modeller fortælle om hovedtræk af Jordens, Månens og Solens indbyrdes bevægelser, herunder med anima-tioner.	Eleven har viden om Jordens, Månens og Solens indbyrdes bevægelser.
		2.	Eleven kan anvende enkle modeller til at vise helheder og detaljer.	Eleven har viden om modellers detaljeringsniveau.	Eleven kan fremstille enkle modeller over en husstands forsyning med vand, el og varme samt spildevands- og affaldshåndtering.	Eleven har viden om lokalområdets forsynings- og afledningssystemer.	Eleven kan anvende flere typer modeller, der illustrerer blodkredsløbet.	Eleven har viden om illustration af blodkredsløbet.	Eleven kan på enkle kort udpege plante-bælter og klimazoner, herunder på digitale kort.	Eleven har viden om fordeling af kontinenter, hav, klimazoner og verdensdele.	Eleven kan sammen-holde egne vejrobser-vationer med en enkel vejrudsigt, herunder digitale vejrkort.	Eleven har viden om en vejrudsigts formål og struktur.	Eleven kan med modeller sammenligne solsystemets planeter.	Eleven har viden om hovedtræk af solsystemets opbygning.
Efter 6. klasse-trin	Eleven kan designe enkle modeller.		Modellering i naturfag		Teknologi og ressourcer		Mennesket		Natur og miljø		Stof og energi		Jordklodens forandringer	
		1.	Eleven kan anvende sammensatte modeller til at beskrive processer.	Eleven har viden om sammensatte modeller.	Eleven kan med enkle procesmodeller beskrive forsynings-produktion.	Eleven har viden om forsyningsproduktion.	Eleven kan med modeller forklare ørets og øjets fysiologi og anatomi.	Eleven har viden om syn og hørelse.	Eleven kan med modeller forklare om organismers samspil i naturen.	Eleven har viden om enkle fødekæder og fødenet.	Eleven kan fremstille modeller af vandets kredsløb.	Eleven har viden om vandets kredsløb.	Eleven kan med modeller fortælle om jordskælv og vul-kanudbrud, herunder med digitale modeller.	Eleven har viden om enkle principper i pladetektonikken.
		2.	Eleven kan diskutere enkle modellers egnethed.	Eleven har viden om muligheder og begrænsninger ved modeller.	Eleven kan designe modeller af et produkt eller en produktion.	Eleven har viden om modeller til at beskrive teknologi.	Eleven kan opstille modeller om fordøjelsessystemet.	Eleven har viden om fordøjelse.	Eleven kan med enkle cykliske modeller fortælle om fotosyn-tese og respiration.	Eleven har viden om organismers opbygning og nedbrydning af stof.	Eleven kan med enkle modeller forklare enkelte stoffers molekyleopbygning.	Eleven har viden om nogle atomer og molekyler.	Eleven kan fortælle om aktuelle naturkatastrofer og andre begivenheder ved brug af kort.	Eleven har viden om atlas og digitale kort.

Bindende rammer i Fælles Mål Vejledende færdigheds- og vidensmål

Perspektivering

Klasse-trin	Kompetence-mål	Faser	Færdigheds- og vidensområder og -mål											
Efter 2. klasse-trin	Eleven kan genkende natur og teknologi i sin hverdag.		Perspektivering i naturfag		Teknologi og ressourcer		Mennesket		Organismer		Vand, luft og vejr			
		1.	Eleven kan relatere viden fra natur/teknologi til sig selv og det nære område.	Eleven har viden om natur og teknologi i det nære.	Eleven kan fortælle om ressourcer fra hverdagen.	Eleven har viden om ressourcer fra hverdagen.	Eleven kan fortælle om enkle råd om sundhed i forhold til egen hverdag.	Eleven har viden om enkle råd om sundhed.	Eleven kan fortælle om ændringer i naturen knyttet til årstider.	Eleven har viden om organismers årscyklus.	Eleven kan fortælle om sammenhænge mellem sol, døgn og årstider.	Eleven har viden om karakteristika ved årstider i Danmark.		
		2.												
Efter 4. klasse-trin	Eleven kan relatere natur og teknologi til andre kontekster.		Perspektivering i naturfag		Teknologi og ressourcer		Mennesket		Naturen lokalt og globalt		Vand, luft og vejr		Jorden og solsystemet	
		1.	Eleven kan relatere viden fra natur/teknologi til andre regioner.	Eleven har viden om regionale forskelle og ligheder i natur og teknologi.	Eleven kan beskrive en proces fra ressource til færdigt produkt og fra produkt til ressource.	Eleven har viden om enkle produktions-kæder.	Eleven kan sammenligne egne levevilkår med andres.	Eleven har viden om levevilkår forskellige steder i verden.	Eleven kan fortælle om dyre- og planteliv andre steder på Jorden.	Eleven har viden om naturområder.	Eleven kan sammen-ligne vejrdata fra Danmark med vejrdata fra andre regioner.	Eleven har viden om forskelle og ligheder i temperatur, nedbør og vindhastighed.	Eleven kan skelne mellem astronomi og alternative forklaringer om solsystemets opståen og livets begyndelse.	Eleven har viden om solsystemets opståen og livets begyndelse.
		2.	Eleven kan sætte naturfaglig og teknologisk udvikling i historisk perspektiv.	Eleven har viden om centrale naturfaglige og teknologiske udviklinger.	Eleven kan beskrive sammenhæng mellem behov for og udvikling af et produkt.	Eleven har viden om teknologiudvikling gennem tiden.	Eleven kan diskutere årsager til sund og usund livsstil.	Eleven har viden om sundhedsfremmende faktorer.	Eleven kan fortælle om landskabets udvikling gennem tiden.	Eleven har viden om menneskets påvirkning af naturområder gennem tiden.				
Efter 6. klasse-trin	Eleven kan perspektivere natur/tekno-logi til omverdenen og aktuelle hændelser.		Perspektivering i naturfag		Teknologi og ressourcer		Mennesket		Natur og miljø		Stof og energi		Jordklodens forandringer	
		1.	Eleven kan beskrive natur og teknologis anvendelse i sam-fundet og fremstilling i medier.	Eleven har viden om centrale interesse-modsætninger.	Eleven kan beskrive interesse-modsætninger ved produktionsforhold.	Eleven har viden om produktioners afhængighed og påvirkning af naturgrundlaget.	Eleven kan skelne mellem livsstilsfaktorer og levevilkår.	Eleven har viden om afgørende faktorer for livstil og levevilkår.	Eleven kan fortælle om livets udvikling.	Eleven har viden om hovedtræk af livets udvikling.	Eleven kan forklare om sammenhænge mellem energi-udnyttelse og drivhuseffekt.	Eleven har viden om energiudnyttelse og drivhuseffekt.	Eleven kan sammen-holde naturkatastrofer til menneskers leve-vilkår.	Eleven har viden om sammenhæng mellem pladetektonik og udbredelsen af naturkatastrofer.
		2.	Eleven kan sætte anvendelse af natur og teknologi i et bæredygtigt perspektiv.	Eleven har viden om enkle principper for bæredygtighed.	Eleven kan identificere ressourcebesparende teknologier.	Eleven har viden om enkel miljøvurdering af produkter og produktioner.	Eleven kan vurdere enkle kost- og motionsråd.	Eleven har viden om kost- og motionsråd.	Eleven kan beskrive interessemodsæt-ninger i menneskers forvaltning af naturen lokalt og globalt.	Eleven har viden om forskellige naturhensyn.	Eleven kan diskutere energikilder i et bæredygtigheds-perspektiv.	Eleven har viden om vedvarende og ikke vedvarende energikilder.	Eleven kan beskrive hovedtræk af landskabsdannelse i Danmark.	Eleven har viden om vand, vejr og den sidste istids påvirkning på landskabsdannelse.

Bindende rammer i Fælles Mål Vejledende færdigheds- og vidensmål

Kommunikation

Klasse-trin	Kompetence-mål	Faser	Færdigheds- og vidensområder og -mål					
Efter 2. klasse-trin	Eleven kan beskrive egne undersøgelser og modeller.		Formidling		Ordkendskab		Faglig læsning og skrivning	
		1.	Eleven kan fortælle om egne resultater og erfaringer.	Eleven har viden om enkle måder til at beskrive resultater.	Eleven kan mundtligt og skriftligt anvende enkle fagord og begreber.	Eleven har viden om enkle fagord og begreber.	Eleven kan orientere sig i en enkel fagtekst.	Eleven har viden om enkle naturfaglige teksters formål.
		2.						
Efter 4. klasse-trin	Eleven kan beskrive enkle natur-faglige og teknologiske problem-stillinger.		Formidling		Ordkendskab		Faglig læsning og skrivning	
		1.	Eleven kan formidle egne data mundtligt og skriftligt.	Eleven har viden om medier og formidlings-former.	Eleven kan mundtligt og skriftligt anvende centrale fagord og begreber.	Eleven har viden om fagord og begreber.	Eleven kan læse og skrive enkle naturfaglige tekster.	Eleven har viden om enkle naturfaglige teksttypers formål og struktur.
		2.						
Efter 6. klasse-trin	Eleven kan kommunikere om natur og teknologi.		Formidling		Ordkendskab		Faglig læsning og skrivning	
		1.	Eleven kan argumentere om enkle forhold inden for natur og teknologi.	Eleven har viden om enkel naturfaglig argumentation.	Eleven kan mundtligt og skriftligt udtrykke sig med brug af naturfaglige og teknologiske fagord og begreber.	Eleven har viden om naturfaglige og teknologiske fagord og begreber.	Eleven kan læse og skrive naturfaglige tekster.	Eleven har viden om naturfaglige teksters formål og opbygning.
		2.	Eleven kan diskutere enkle problem-stillinger om natur og teknologi.	Eleven har viden om enkel naturfaglig kildekritik.				

Bindende rammer i Fælles Mål Vejledende færdigheds- og vidensmål

B.2 Fysik C - C-level physics in high school

Bilag 100

Fysik C – stx, august 2017

1. Identitet og formål

1.1. Identitet

Det naturvidenskabelige fag fysik omhandler menneskers forsøg på at udvikle generelle beskrivelser, tolkninger, forklaringer og modeller af fænomener og processer i natur og teknik. Gennem et samspil mellem eksperimenter og teorier udvikles en teoretisk begrundet, naturvidenskabelig indsigt, som stimulerer nysgerrighed og kreativitet. Samtidigt giver den baggrund for at forstå og diskutere naturvidenskabeligt og teknologisk baserede argumenter vedrørende spørgsmål af faglig, almen menneskelig eller samfundsmæssig interesse.

1.2. Formål

Faget fysik giver på C-niveau eleverne grundlæggende viden og kundskaber inden for fysik og derigennem indsigt i naturvidenskabelige arbejdsmetoder og tænkemåder med vægt på almendannelsen og som en del af grundlaget for deres studievalg. Eleverne ser gennem undervisningen, hvordan fysiske modeller kan fungere som middel til at give kvalitative og kvantitative forklaringer af fænomener, så de derigennem får kendskab til eksempler på naturvidenskabelige tolkninger af verden omkring os. Det eksperimentelle arbejde giver eleverne fortrolighed med samspillet mellem teori og eksperiment, så de kender betydningen af naturvidenskabs eksperimentelle grundlag.

De faglige problemstillinger åbner for, at eleverne møder perspektivering af faget, herunder fysiske og teknologiske aspekter af bæredygtighed.

2. Faglige mål og fagligt indhold

2.1. Faglige mål

Eleverne skal:

- kende og kunne anvende enkle modeller, som kvalitativt eller kvantitativt kan forklare forskellige fysiske fænomener eller kan føre til løsninger af problemstillinger, hvor faglige begreber og metoder anvendes
- kunne beskrive og udføre enkle kvalitative og kvantitative fysiske eksperimenter, herunder opstille og teste enkle hypoteser
- kunne præsentere eksperimentelle data hensigtsmæssigt og ved hjælp af blandt andet it-værktøjer behandle data med henblik på at afdække enkle matematiske sammenhænge mellem fysiske størrelser
- gennem eksempler kunne perspektivere fysikkens bidrag til såvel forståelse af naturfænomener som teknologi- og samfundsudvikling
- kunne formidle et emne med et elementært fysikfagligt indhold til en valgt målgruppe
- kunne demonstrere viden om fagets identitet og metoder
- kunne behandle problemstillinger i samspil med andre fag.

2.2. Kernestof

Gennem kernestoffet skal eleverne opnå faglig fordybelse, viden og kundskaber.

Kernestoffet er:

Fysikkens bidrag til det naturvidenskabelige verdensbillede

- grundtræk af den nuværende fysiske beskrivelse af Universet og dets udviklingshistorie, herunder Universets udvidelse
- Jorden som planet i solsystemet som grundlag for forklaring af umiddelbart observerbare naturfænomener
- atomer som grundlag for forklaring af makroskopiske egenskaber ved stof

Energi

- beskrivelse af energi og energiomsætning, herunder effekt og nyttevirkning
- eksempler på energiformer og en kvantitativ behandling af omsætningen mellem mindst to energiformer

Lyd og lys

- grundlæggende egenskaber: bølgelængde, frekvens og udbredelsesfart
- det elektromagnetiske spektrum, fotoner og atomers absorption og emission af stråling
- fysiske egenskaber ved lyd og lys.

2.3. Supplerende stof

Eleverne vil ikke kunne opfylde de faglige mål alene ved hjælp af kernestoffet. Det supplerende stof, der udfylder ca. 25 pct. af undervisningstiden, skal uddybe og perspektivere kernestoffet og kan også omfatte nye områder og metoder.

Det supplerende stof skal inddrage fagligt aktuelle, hverdagsorienterede, samfundsrelevante eller globale problemstillinger, herunder aspekter af bæredygtig udvikling.

Der kan indgå læsning af tekster på engelsk samt, når det er muligt, på andre fremmedsprog.

Det supplerende stof vælges i samarbejde med eleverne.

Hvis fysik C er valgfag, skal der i valget af supplerende stof tages hensyn til målene for den gymnasiale uddannelse, valgfaget indgår i.

2.4. Omfang

Det forventede omfang af fagligt stof er normalt svarende til 100-200 sider.

3. Tilrettelæggelse

3.1. Didaktiske principper

Undervisningen tager udgangspunkt i et fagligt niveau svarende til elevernes niveau fra grundskolen.

Undervisningen tilrettelægges, så formålet med undervisningen er tydeligt for eleverne, og så eleverne motiveres til at arbejde med faget samtidig med, at deres nysgerrighed og kreativitet stimuleres. Som hovedregel opbygges undervisningen af forløb, der hver for sig er styret af et perspektiverende tema, som inddrager forhold uden for fysikken. Hovedvægten lægges på brug af fysik som et middel til at skabe naturvidenskabelig indsigt og på at vise fysik som et kvantitativt naturvidenskabeligt fag. Det eksperimentelle arbejdes centrale betydning for udviklingen af naturvidenskabelig erkendelse betones.

Undervisningen skal indeholde eksempler på, hvordan matematik indgår i fysik, men det er ikke hensigten, at eleverne skal kunne lave egentlige matematiske udledninger af fysiske sammenhænge.

3.2. Arbejdsformer

Undervisningen skal tilrettelægges, så der er variation i de benyttede arbejdsformer under hensyntagen til de mål, der ønskes nået med det enkelte forløb. Valget af arbejdsformer skal give eleverne mulighed for at udvikle og realisere egne ideer inden for faget og at indgå i samarbejde med andre i en faglig sammenhæng.

Elevernes eksperimentelle arbejde udgør ca. 20 pct. af undervisningstiden. Det eksperimentelle arbejde indgår som en integreret del af undervisningen og skal sikre dem fortrolighed med eksperimentelle metoder og brugen af eksperimentelt udstyr, herunder it-baseret udstyr til dataopsamling og databehandling. Arbejdet med eksperimenter tilrettelægges, så de har et konkret læringsmål, der også styrer valget af dokumentationsform. Det eksperimentelle arbejde skal rumme eksempler på både kvalitative og kvantitative eksperimenter, og eleverne skal have mulighed for at arbejde undersøgelsesbaseret såvel som med opstilling og test af enkle hypoteser.

Mundtlig fremstilling og skriftlighed indgår som væsentlige dele af arbejdet med faget.

Den skriftlige dimension skal medvirke til at sikre elevernes fordybelse i faget og omfatter:

- efterbehandling og dokumentation af eksperimentelt arbejde
- simple numeriske problemer med vægt på træning af de behandlede begreber og faglige metoder
- formidling af naturvidenskabelig indsigt i form af tekster, præsentationer, posters og lignende.

Hvis faget har fået tillagt fordybelsestid, skal det skriftlige arbejde planlægges, så der er progression og sammenhæng med det skriftlige arbejde i de øvrige fag. Progressionen omfatter såvel fordybelsesgraden som kravene til elevernes selvstændige indsats.

3.3. It

It og digitale ressourcer skal indgå i alle aspekter af undervisningen og understøtte elevernes læringsproces gennem f.eks. informationssøgning, modellering og visualisering. Eleverne skal kunne anvende it-værktøjer og digitale ressourcer til eksperimentelt arbejde og databehandling.

3.4. Samspil med andre fag

Dele af kernestoffet og det supplerende stof vælges og behandles, så det kan bidrage til styrkelse af det faglige samspil mellem fagene og i studieretningen. I tilrettelæggelsen af undervisningen inddrages desuden elevernes viden og kompetencer fra andre fag, som eleverne hver især har, så de bidrager til perspektivering af emnerne og belysning af fagets almendannende sider.

Der skal lægges særlig vægt på en faglig koordinering med klassens øvrige naturvidenskabelige fag og med matematik, så undervisningen i fysik er tilpasset elevernes naturvidenskabelige og matematiske kompetencer.

4. Evaluering

4.1. Løbende evaluering

Elevernes udbytte af undervisningen skal evalueres jævnligt, særligt mht. deres forståelse af teori og eksperiment. Herved tilvejebringes grundlag for en fremadrettet vejledning af den enkelte elev i arbejdet med at nå de faglige mål og for justering af undervisningen.

4.2. Prøveform

Der afholdes en mundtlig prøve på grundlag af en bredt formuleret opgave inden for de områder, holdet har arbejdet med. Opgaven skal indeholde et ukendt bilag, der kan være grundlag for perspektivering af opgavens emne. Opgaverne, der indgår som grundlag for prøven, skal tilsammen i al væsentlighed dække de faglige mål, kernestoffet og det supplerende stof. Den enkelte opgave må anvendes højst tre gange på samme hold. Bilag må genbruges i forskellige opgaver efter eksaminators valg. Opgaverne uden bilag skal være kendt af eksaminanderne inden prøven.

Eksaminationstiden er ca. 24 minutter pr. eksaminand. Der gives ca. 24 minutters forberedelsestid. Benyttet apparatur, som er relevant for opgaven, skal være til rådighed i forberedelses- og eksaminationslokalet.

Eksaminationen former sig som en faglig samtale mellem eksaminand og eksaminator, hvor det perspektiverende bilag inddrages. Som hovedregel inddrages både teoretiske og eksperimentelle elementer i eksaminationen.

4.3. Bedømmelseskriterier

Bedømmelsen er en vurdering af, i hvilken grad eksaminandens præstation opfylder de faglige mål, som de er angivet i pkt. 2.1.

Ved den mundtlige prøve lægges der vægt på, at eksaminanden i den faglige samtale:

- kan inddrage relevante og væsentlige fysiske elementer
- viser fortrolighed med faglige begreber, modeller og metoder som redskaber til at følge en faglig argumentation
- kan redegøre for og analysere resultater fra eksperimentelt arbejde
- kan perspektivere faglig indsigt.

Der gives én karakter ud fra en helhedsvurdering af eksaminandens præstation.

Ved en prøve, hvor faget indgår i fagligt samspil med andre fag, lægges der vægt på, at eksaminanden kan:

- demonstrere viden om fagets identitet og metoder
- behandle problemstillinger i samspil med andre fag.

4.4. Selvstuderende

En selvstuderende skal have gennemført laboratoriekursus i fysik C (Bek. om de gymnasiale uddannelser § 49) med attestation fra den institution, der afholdt kurset, for at kunne indstilles til prøve. Hvis den selvstuderende kan dokumentere gennemførelse af eksperimentelt arbejde i et omfang svarende til niveauets eksperimentelle arbejde fra tidligere fysikundervisning, f.eks. i form af rapporter eller journaler, kan den selvstuderende indstilles til prøve uden at gennemføre laboratoriekursus. Det tidligere gennemførte eksperimentelle arbejde indgår på samme måde som grundlag for prøven som eksperimentelt arbejde i en almindelig undervisningssammenhæng. Lederen af den institution, hvor prøven finder sted, beslutter, om tidligere eksperimentelt arbejde kan udgøre et tilstrækkeligt grundlag for den selvstuderendes prøve.

B.3 Fysik B - B-level physics in high school

Bilag 99

Fysik B – stx, august 2017

1. Identitet og formål

1.1. Identitet

Det naturvidenskabelige fag fysik omhandler menneskers forsøg på at udvikle generelle beskrivelser, tolkninger, forklaringer og modeller af fænomener og processer i natur og teknik. Gennem et samspil mellem eksperimenter og teorier udvikles en teoretisk begrundet, naturvidenskabelig indsigt, som stimulerer nysgerrighed og kreativitet. Samtidigt giver den baggrund for at forstå og diskutere naturvidenskabeligt og teknologisk baserede argumenter vedrørende spørgsmål af faglig, almen menneskelig eller samfundsmæssig interesse.

1.2. Formål

Faget fysik giver på B-niveau eleverne fortrolighed med væsentlige naturvidenskabelige metoder og synsvinkler, der sammen med viden og kundskaber vedrørende fysiske fænomener og begreber åbner for en naturvidenskabelig tolkning af verden. Dette bidrager til elevernes almendannelse, danner et fagligt grundlag for studier inden for naturvidenskab, teknik og sundhed og andre fagområder, der støtter sig på enkel modellering, samt kvalificerer deres studievalg.

Eleverne møder gennem undervisningen eksempler på aktuelle teknisk-naturvidenskabelige problemer inden for videnskab, samfundsudvikling og teknologi, hvor fysik spiller en væsentlig rolle i løsningen. Gennem arbejdet med eksperimenter og teoretiske modeller opnår de kompetence i opstilling og anvendelse af fysiske modeller som middel til kvalitativ og kvantitativ forklaring af fænomener og processer.

De faglige problemstillinger åbner for, at eleverne møder perspektivering af faget, herunder fysiske og teknologiske aspekter af bæredygtighed, og får indsigt i faglig formidling.

2. Faglige mål og fagligt indhold

2.1. Faglige mål

Eleverne skal:

- kende og kunne opstille og anvende modeller til en kvalitativ eller kvantitativ forklaring af fysiske fænomener og sammenhænge
- ud fra grundlæggende begreber og modeller kunne foretage beregninger af fysiske størrelser
- ud fra en given problemstilling kunne tilrettelægge, beskrive og udføre fysiske eksperimenter med givet udstyr og præsentere resultaterne hensigtsmæssigt
- kunne behandle eksperimentelle data ved hjælp af blandt andet it-værktøjer med henblik på at afdække og diskutere matematiske sammenhænge mellem fysiske størrelser
- kende til simple eksempler på simulering eller styring af fysiske systemers opførsel ved hjælp af it-værktøjer
- gennem eksempler kunne perspektivere fysikkens bidrag til såvel forståelse af naturfænomener som teknologi- og samfundsudvikling
- kunne formidle et emne med et fysikfagligt indhold til en valgt målgruppe
- kunne demonstrere viden om fagets identitet og metoder
- kunne undersøge problemstillinger og udvikle og vurdere løsninger, hvor fagets viden og metoder anvendes
- kunne behandle problemstillinger i samspil med andre fag.

2.2. Kernestof

Gennem kernestoffet skal eleverne opnå faglig fordybelse, viden og kundskaber.

Kernestoffet er:

Fysikkens bidrag til det naturvidenskabelige verdensbillede

- grundtræk af den nuværende fysiske beskrivelse af Universet og dets udviklingshistorie, herunder Universets udvidelse og spektrallinjers rødforskydning
- Jorden som planet i solsystemet som grundlag for forklaring af umiddelbart observerbare naturfænomener
- naturens mindste byggesten, herunder atomer som grundlag for forklaring af makroskopiske egenskaber ved stof og grundstoffernes dannelseshistorie

Energi

- beskrivelse af energi og energiomsætning, herunder effekt og nyttevirkning
- kinetisk og potentiel energi i tyngdefeltet nær Jorden
- indre energi og energiforhold ved temperatur- og faseændringer
- ækvivalensen mellem masse og energi, herunder *Q*-værdi ved kernereaktioner

Elektriske kredsløb

- simple elektriske kredsløb med stationære strømme beskrevet ved hjælp af strømstyrke, spændingsfald, resistans og energiomsætning, herunder eksempler på kredsløb med elektriske sensorer

Bølger

- grundlæggende egenskaber: bølgelængde, frekvens, udbredelsesfart og interferens
- lyd og lys som eksempler på bølger
- det elektromagnetiske spektrum

Kvantefysik

- atomers og atomkerners opbygning
- fotoners energi, atomare systemers emission og absorption af stråling, spektre
- radioaktivitet, herunder henfaldstyper, aktivitet og henfaldsloven

Mekanik

- kinematisk beskrivelse af bevægelse i én dimension
- kraftbegrebet, herunder tyngdekraft, tryk og opdrift
- Newtons love anvendt på bevægelser i én dimension.

2.3. Supplerende stof

Eleverne vil ikke kunne opfylde de faglige mål alene ved hjælp af kernestoffet. Det supplerende stof, der udfylder ca. 20 pct. af undervisningstiden, uddyber arbejdet med kernestoffet, indeholder nye emner, områder eller metoder og perspektiverer undervisningen.

Det supplerende stof skal inddrage aktuelle faglige, teknologiske, samfundsrelevante eller globale problemstillinger, herunder en belysning af fysiske aspekter af bæredygtig udvikling.

Der skal indgå læsning af tekster på engelsk samt, når det er muligt, på andre fremmedsprog.

Det supplerende stof vælges i samarbejde med eleverne.

2.4. Omfang

Det forventede omfang af fagligt stof er normalt svarende til 200-350 sider.

3. Tilrettelæggelse

3.1. Didaktiske principper

Undervisningen tager udgangspunkt i et fagligt niveau svarende til elevernes niveau fra grundskolen.

Undervisningen tilrettelægges, så formålet med undervisningen er tydeligt for eleverne, og så eleverne motiveres til at arbejde med faget samtidig med, at deres nysgerrighed og kreativitet stimuleres. Det eksperimentelle og teoretiske arbejde integreres, så eleverne lærer at kombinere egne eksperimenter og teori, og så de inspireres til selv at foreslå relevante undersøgelser og problemløsninger. Der sikres progression i kravene til elevernes selvstændighed og i den faglige fordybelse. Det eksperimentelle arbejdes centrale betydning for udviklingen af naturvidenskabelig erkendelse betones.

Der lægges vægt på koordinationen med matematik, så undervisningen i fysik bygger på realistiske forudsætninger om elevernes matematiske kompetencer og så vidt muligt leverer et relevant eksempelmateriale til brug i matematikundervisningen. Matematik anvendes i undervisningen i studiet af fysiske systemer, herunder med inddragelse af it-baserede matematiske værktøjer.

3.2. Arbejdsformer

Undervisningen skal tilrettelægges, så der er variation og progression i de benyttede arbejdsformer under hensyntagen til de mål, der ønskes nået med det enkelte forløb. Valget af arbejdsformer skal give eleverne mulighed for at udvikle og realisere egne ideer inden for faget og for at indgå i samarbejde med andre i en faglig sammenhæng.

Elevernes eksperimentelle arbejde udgør mindst 20 pct. af undervisningstiden. Elevernes eksperimentelle arbejde indgår som en integreret del af undervisningen og skal sikre dem fortrolighed med eksperimentelle metoder og brugen af eksperimentelt udstyr, herunder it-baseret udstyr til dataopsamling og databehandling samt digitale ressourcer. Arbejdet med eksperimenter tilrettelægges, så de har et konkret læringsmål, der også styrer valget af dokumentationsform. Eksperimenterne skal udvælges, så der er progression i kravene til elevernes selvstændighed fra simple registreringer af eksperimentelle data over arbejde med mere komplekse sammenhænge til selvstændige eksperimentelle undersøgelser. Heri indgår modellering med brug af matematiske it-værktøjer.

Der skal tilrettelægges mindst ét længerevarende forløb, hvor eleverne i mindre grupper arbejder med en selvvalgt, eksperimentel problemstilling.

Mundtlig fremstilling og skriftligt arbejde indgår som væsentlige dele af arbejdet med faget.

Det skriftlige arbejde skal medvirke til at sikre elevernes fordybelse i faget og omfatter:

- efterbehandling og dokumentation af eksperimentelt arbejde
- løsning af fysikfaglige problemer, herunder træning i anvendelse af begreber, metoder og modeller
- formidling af fysikfaglig indsigt i form af f.eks. tekster, præsentationer, posters og lignende.

Arbejdet med problemløsning skal tilrettelægges med en voksende progression. Eleverne skal præsenteres for de krav til løsning af skriftlige opgaver, som gælder ved den skriftlige prøve i fysik på A-niveau. En del af fagets fordybelsestid skal benyttes til elevernes selvstændige arbejde med løsning af fysiske problemer. Det skriftlige arbejde planlægges med variation i formen, og så der er progression og sammenhæng med skriftligt arbejde i de øvrige fag. Progressionen omfatter såvel fordybelsesgraden som kravene til elevernes selvstændige indsats.

Eleverne skal arbejde med mundtlig fremstilling, hvor de inddrager såvel faglig argumentation som beskrivelse af fysiske fænomener og modeller.

Der skal tilrettelægges mindst ét forløb, hvor eleverne undersøger en problemstilling og udvikler og vurderer løsninger, hvor fagets viden og metoder anvendes.

Inddragelse af private eller offentlige virksomheder og institutioner skal bidrage til at tydeliggøre studie- og karrieremuligheder for eleverne og belyse relevante fysiske problemstillinger.

3.3. It

It og digitale ressourcer skal indgå i alle aspekter af undervisningen og understøtte elevernes læringsproces gennem f.eks. informationssøgning, modellering, simulering og visualisering. Eleverne skal kunne anvende it-værktøjer og digitale ressourcer til eksperimentelt arbejde og databehandling også med større datamængder.

3.4. Samspil med andre fag

Dele af kernestoffet og det supplerende stof vælges og behandles, så det kan bidrage til styrkelse af det faglige samspil mellem fagene og i studieretningen. I tilrettelæggelsen af undervisningen inddrages desuden elevernes viden og kompetencer fra andre fag, som eleverne hver især har, så de bidrager til perspektivering af emnerne og belysning af fagets almendannende sider.

Når fysik B indgår i en studieretning, skal der tilrettelægges forløb sammen med fag i studieretningen, som viser styrken i fagenes samspil og perspektiverer fysikken. Den faglige progression skal koordineres med matematik, så eleverne oplever sammenhæng mellem de to fag. Der skal specielt tilrettelægges forløb, hvor fysik og matematik arbejder sammen om behandlingen af modeller for konkrete fysiske systemer, så begrebsdannelsen i begge fag understøttes.

4. Evaluering

4.1. Løbende evaluering

Elevernes udbytte af undervisningen skal evalueres jævnligt, særligt mht. deres forståelse af teori og eksperiment samt problemløsning. Herved tilvejebringes grundlag for en fremadrettet vejledning af den enkelte elev i arbejdet med at nå de faglige mål og for justering af undervisningen.

4.2. Prøveform

Der afholdes en mundtlig prøve. Prøven er todelt. Opgaverne, der indgår som grundlag for prøven, skal tilsammen i al væsentlighed dække de faglige mål, kernestoffet og det supplerende stof.

Første del af prøven er eksperimentel, hvor op til 10 eksaminander arbejder i laboratoriet i ca. 90 minutter i grupper på normalt to og højst tre med en kendt eksperimentel problemstilling. Eksaminanderne må ikke genbruge data fra tidligere udførte eksperimenter. Eksaminator og censor taler med den enkelte eksaminand om det konkrete eksperiment, den tilhørende teori og den efterfølgende databehandling. Den enkelte eksperimentelle delopgave må anvendes højst tre gange på samme hold. De eksperimentelle delopgaver må ikke være kendt af eksaminanderne inden prøven.

Anden del af prøven er individuel og mundtlig. Den teoretiske delopgave skal omhandle et fortrinsvis teoretisk, fagligt emne og indeholde et ukendt bilag, der kan være grundlag for perspektivering af emnet.

Den enkelte teoretiske delopgave må anvendes højst tre gange på samme hold. Bilag må genbruges i forskellige opgaver efter eksaminators valg. De teoretiske delopgaver uden bilag skal være kendt af eksaminanderne inden prøven.

Den eksperimentelle og den teoretiske delopgave skal være kombineret, så de angår forskellige emner.

Eksaminationstiden er ca. 24 minutter. Der gives ca. 24 minutters forberedelsestid. Eksaminationen former sig som en faglig samtale mellem eksaminand og eksaminator.

4.3. Bedømmelseskriterier

Bedømmelsen er en vurdering af, i hvilken grad eksaminandens præstation opfylder de faglige mål, som de er angivet i pkt. 2.1.

Den mundtlige prøve

Ved den eksperimentelle del lægges der vægt på, at eksaminanden

- kan udføre eksperimentelt arbejde og behandle de indsamlede data
- kan reflektere over samspillet mellem teori og eksperiment.

Ved den mundtlige del lægges der vægt på, at eksaminanden i den faglige samtale har et selvstændigt initiativ og:

- har et sikkert kendskab til fagets begreber, modeller og metoder som grundlag for en faglig analyse og underbygning af den faglige argumentation
- kan perspektivere faglig indsigt.

Hver eksaminand gives én individuel karakter ud fra en helhedsvurdering af prøvens eksperimentelle og mundtlige del.

Prøve, hvor faget indgår i fagligt samspil

Ved en prøve, hvor faget indgår i fagligt samspil med andre fag, lægges der vægt på, at eksaminanden kan:

- demonstrere viden om fagets identitet og metoder
- behandle problemstillinger i samspil med andre fag.

4.4. Selvstuderende

En selvstuderende skal have gennemført laboratoriekursus i fysik B (stx) (Bek. om de gymnasiale uddannelser § 49) med attestation fra den institution, der afholdt kurset, for at kunne indstilles til prøve. Hvis den selvstuderende kan dokumentere gennemførelse af eksperimentelt arbejde i et omfang svarende til niveauets eksperimentelle arbejde fra tidligere fysikundervisning, f.eks. i form af rapporter eller journaler, kan den selvstuderende indstilles til prøve uden at gennemføre laboratoriekursus. Det tidligere gennemførte eksperimentelle arbejde indgår på samme måde som grundlag for prøven som eksperimentelt arbejde i en almindelig undervisningssammenhæng. Lederen af den institution, hvor prøven finder sted, beslutter, om tidligere eksperimentelt arbejde kan udgøre et tilstrækkeligt grundlag for den selvstuderendes prøve.

B.4 Fysik A - A-level physics in high school

Bilag 98

Fysik A – stx, august 2017

1. Identitet og formål

1.1. Identitet

Det naturvidenskabelige fag fysik omhandler menneskers forsøg på at udvikle generelle beskrivelser, tolkninger, forklaringer og modeller af fænomener og processer i natur og teknik. Gennem et samspil mellem eksperimenter og teorier udvikles en teoretisk begrundet, naturvidenskabelig indsigt, som stimulerer nysgerrighed og kreativitet. Samtidigt giver den baggrund for at forstå og diskutere naturvidenskabeligt og teknologisk baserede argumenter vedrørende spørgsmål af faglig, almen menneskelig eller samfundsmæssig interesse.

1.2. Formål

Faget fysik giver på A-niveau eleverne fortrolighed med væsentlige naturvidenskabelige metoder og synsvinkler, der sammen med viden og kundskaber vedrørende fysiske fænomener og begreber åbner for en naturvidenskabelig tolkning af verden. Dette bidrager til elevernes almendannelse, danner et fagligt grundlag for studier inden for naturvidenskab, teknik og sundhed og andre fagområder, der støtter sig på modellering, samt kvalificerer deres studievalg.

Eleverne møder gennem undervisningen eksempler på aktuelle teknisk-naturvidenskabelige problemer inden for videnskab, samfundsudvikling og teknologi, hvor fysik spiller en væsentlig rolle i løsningen. Gennem arbejdet med eksperimenter og teoretiske modeller opnår de kompetence i opstilling og anvendelse af fysiske modeller som middel til kvalitativ og kvantitativ forklaring af fænomener og processer.

De faglige problemstillinger åbner for, at eleverne møder perspektivering af faget, herunder fysiske og teknologiske aspekter af bæredygtighed, og får indsigt i faglig formidling.

2. Faglige mål og fagligt indhold

2.1. Faglige mål

Eleverne skal:

- kende, kunne opstille og kunne anvende et bredt udvalg af modeller til en kvalitativ eller kvantitativ forklaring af fysiske fænomener og sammenhænge samt kunne diskutere modellers gyldighedsområde
- kunne analysere et fysikfagligt problem ud fra forskellige repræsentationer af data og formulere en løsning af det gennem brug af en relevant model
- kunne tilrettelægge, beskrive og udføre fysiske eksperimenter til undersøgelse af en åben problemstilling og præsentere resultaterne hensigtsmæssigt
- kunne behandle eksperimentelle data ved hjælp af blandt andet it-værktøjer med henblik på at afdække og diskutere matematiske sammenhænge mellem fysiske størrelser
- i simple tilfælde kunne simulere eller styre fysiske systemers opførsel ved hjælp af it-værktøjer
- gennem eksempler kunne perspektivere fysikkens bidrag til såvel forståelse af naturfænomener som teknologi- og samfundsudvikling
- kunne formidle et emne med et fysikfagligt indhold til en valgt målgruppe
- kunne demonstrere viden om fagets identitet og metoder
- kunne undersøge problemstillinger og udvikle og vurdere løsninger, hvor fagets viden og metoder anvendes
- kunne behandle problemstillinger i samspil med andre fag.

2.2. Kernestof

Gennem kernestoffet skal eleverne opnå faglig fordybelse, viden og kundskaber.

Kernestoffet er:

Fysikkens bidrag til det naturvidenskabelige verdensbillede

- grundtræk af den nuværende fysiske beskrivelse af Universet og dets udviklingshistorie, herunder Universets udvidelse og spektrallinjers rødforskydning
- Jorden som planet i solsystemet som grundlag for forklaring af umiddelbart observerbare naturfænomener

- naturens mindste byggesten, herunder atomer som grundlag for forklaring af makroskopiske egenskaber ved stof og grundstoffernes dannelseshistorie

Energi
- arbejde, energi og energiomsætning samt effekt og nyttevirkning
- indre energi og energiforhold ved temperatur- og faseændringer
- ækvivalensen mellem masse og energi, herunder *Q*-værdi ved kernereaktioner

Elektriske kredsløb
- simple elektriske kredsløb med stationære strømme beskrevet ved hjælp af strømstyrke, spændingsfald, resistans og energiomsætning, herunder eksempler på kredsløb med elektriske sensorer

Bølger
- grundlæggende egenskaber: bølgelængde, frekvens, udbredelsesfart og interferens
- lyd og lys som eksempler på bølger
- det elektromagnetiske spektrum

Elektriske og magnetiske felter
- elektrisk felt og kraften på en elektrisk ladning, herunder feltet omkring en kuglesymmetrisk ladning og homogent elektrisk felt
- eksempler på magnetiske felter, herunder homogent magnetisk felt og kraften på en strømførende leder
- ladede partiklers bevægelse i homogene elektriske og magnetiske felter
- induktion, herunder Faradays induktionslov

Kvantefysik
- atomers og atomkerners opbygning
- fotoners energi og bevægelsesmængde, partikel-bølge-dualitet, atomare systemers emission og absorption af stråling, spektre
- radioaktivitet, herunder henfaldstyper, aktivitet og henfaldsloven

Mekanik
- bevægelser i én og to dimensioner, herunder skråt kast og jævn cirkelbevægelse
- bevarelsessætningen for bevægelsesmængde, herunder elastiske og uelastiske stød i én dimension
- kraftbegrebet og Newtons love, herunder tryk, opdrift, gnidning og luftmodstand
- gravitationsloven og bevægelse om et centrallegeme
- kraft- og energiforhold ved harmonisk svingning
- mekanisk energi i et homogent tyngdefelt og for gravitationsfeltet om et centrallegeme

Fysik i det 21. århundrede
- et emne, der udmeldes hvert år før 3.g-skolestart.

2.3. Supplerende stof

Eleverne vil ikke kunne opfylde de faglige mål alene ved hjælp af kernestoffet. Det supplerende stof, der udfylder ca. 20 pct. af undervisningstiden, uddyber arbejdet med kernestoffet, indeholder nye emner, områder eller metoder og perspektiverer undervisningen.

Det supplerende stof skal inddrage
- aktuelle faglige, teknologiske, samfundsrelevante eller globale problemstillinger, herunder en belysning af fysiske aspekter af bæredygtig udvikling
- stof, der kan uddybe behandlingen af den moderne fysik.

Der skal indgå læsning af tekster på engelsk samt, når det er muligt, på andre fremmedsprog.

Det supplerende stof vælges i samarbejde med eleverne.

2.4. Omfang

Det forventede omfang af fagligt stof er normalt svarende til 350-500 sider.

3. Tilrettelæggelse

3.1. Didaktiske principper

Undervisningen tager udgangspunkt i et fagligt niveau svarende til elevernes niveau fra grundskolen.

Undervisningen tilrettelægges, så formålet med undervisningen er tydeligt for eleverne, og så eleverne motiveres til at arbejde med faget samtidig med, at deres nysgerrighed og kreativitet stimuleres. Det eksperimentelle og teoretiske arbejde integreres, så eleverne lærer at kombinere egne eksperimenter og teori, og så de inspireres til selv at foreslå relevante undersøgelser og problemløsninger. Der sikres progression i kravene til elevernes selvstændighed og i den faglige fordybelse. Det eksperimentelle arbejdes centrale betydning for udviklingen af naturvidenskabelig erkendelse betones.

Ved tilrettelæggelsen lægges vægt på koordinationen med matematik, så undervisningen i fysik bygger på realistiske forudsætninger om elevernes matematiske kompetencer. Det er væsentligt, at matematik anvendes integreret i undervisningen i studiet af fysiske systemer, herunder med inddragelse af it-baserede matematiske værktøjer. Formel matematisk argumentation indgår i enkelte eksempler på udledning af fysiske sammenhænge.

3.2. Arbejdsformer

Undervisningen skal tilrettelægges, så der er variation og progression i de benyttede arbejdsformer under hensyntagen til de mål, der ønskes nået med det enkelte forløb. Valget af arbejdsformer skal give eleverne mulighed for at udvikle og realisere egne ideer inden for faget og for at indgå i samarbejde med andre i en faglig sammenhæng.

Elevernes eksperimentelle arbejde udgør mindst 20 pct. af undervisningstiden. Elevernes eksperimentelle arbejde indgår som en integreret del af undervisningen og skal sikre dem fortrolighed med eksperimentelle metoder og brugen af eksperimentelt udstyr, herunder it-baseret udstyr til dataopsamling og databehandling. Arbejdet med eksperimenter tilrettelægges, så de har et konkret læringsmål, der også styrer valget af dokumentationsform. Eksperimenterne skal udvælges, så der er progression i kravene til elevernes selvstændighed fra simple registreringer af eksperimentelle data over arbejde med mere komplekse sammenhænge til selvstændige eksperimentelle undersøgelser. Heri indgår modellering med brug af matematiske it-værktøjer samt simulering.

Der skal tilrettelægges mindst to længerevarende forløb, hvor eleverne i mindre grupper arbejder med en selvvalgt eksperimentel problemstilling.

Mundtlig fremstilling og skriftligt arbejde indgår som væsentlige dele af arbejdet med faget.

Det skriftlige arbejde skal medvirke til at sikre elevernes fordybelse i faget og omfatter:

- efterbehandling og dokumentation af eksperimentelt arbejde
- løsning af fysikfaglige problemer, herunder træning i anvendelse af forskellige begreber, metoder og modeller
- formidling af fysikfaglig indsigt i form af f.eks. tekster, præsentationer, posters og lignende.

Arbejdet med problemløsning skal tydeliggøre kravene til elevernes beherskelse af de faglige mål i forbindelse med den skriftlige prøve i fysik A. En væsentlig del af fagets fordybelsestid skal benyttes til elevernes selvstændige arbejde med løsning af fysiske problemer. Det skriftlige arbejde planlægges med variation i formen, og så der er progression og sammenhæng med skriftligt arbejde i de øvrige fag. Progressionen omfatter såvel fordybelsesgraden som kravene til elevernes selvstændige indsats.

Eleverne skal arbejde med mundtlig fremstilling, hvor de inddrager såvel faglig argumentation som beskrivelse af fysiske fænomener og modeller.

Der skal tilrettelægges mindst ét forløb, hvor eleverne undersøger en problemstilling og udvikler og vurderer løsninger, hvor fagets viden og metoder anvendes.

Inddragelse af private eller offentlige virksomheder og institutioner skal bidrage til at tydeliggøre studie- og karrieremuligheder for eleverne og belyse relevante fysiske problemstillinger.

3.3. It

It og digitale ressourcer skal indgå i alle aspekter af undervisningen og understøtte elevernes læringsproces gennem f.eks. informationssøgning, modellering, simulering, styring og visualisering. Eleverne skal kunne anvende it-værktøjer og digitale ressourcer til eksperimentelt arbejde og databehandling også med større datamængder.

3.4. Samspil med andre fag

Dele af kernestoffet og det supplerende stof vælges og behandles, så det kan bidrage til styrkelse af det faglige samspil mellem fagene og i studieretningen. I tilrettelæggelsen af undervisningen inddrages desuden elevernes viden og kompetencer fra andre fag, som eleverne hver især har, så de bidrager til perspektivering af emnerne og belysning af fagets almendannende sider.

Når fysik A indgår i en studieretning, skal der tilrettelægges forløb sammen med fag i studieretningen, som viser styrken i fagenes samspil og perspektiverer fysikken. Den faglige progression skal koordineres med matematik, så eleverne oplever sammenhæng mellem de to fag. Der skal specielt tilrettelægges forløb, hvor fysik og matematik arbejder sammen om behandlingen af modeller for konkrete fysiske systemer, så begrebsdannelsen i begge fag understøttes.

4. Evaluering

4.1. Løbende evaluering

Elevernes udbytte af undervisningen skal evalueres jævnligt, særligt mht. deres forståelse af teori og eksperiment samt problemløsning. Herved tilvejebringes grundlag for en fremadrettet vejledning af den enkelte elev i arbejdet med at nå de faglige mål og for justering af undervisningen.

4.2. Prøveform

Der afholdes en centralt stillet skriftlig prøve og en mundtlig prøve.

Den skriftlige prøve

Skriftlig prøve på grundlag af et centralt stillet opgavesæt. Prøvens varighed er fem timer.

Det faglige grundlag for opgaverne er det i pkt. 2.2. beskrevne kernestof, men andre emner og problemstillinger kan inddrages, idet grundlaget så beskrives i opgaveteksten.

Den mundtlige prøve

Den mundtlige prøve er todelt. Opgaverne, der indgår som grundlag for prøven, skal tilsammen i al væsentlighed dække de faglige mål, kernestoffet og det supplerende stof.

Den første del af prøven er eksperimentel, hvor op til 10 eksaminander arbejder i laboratoriet i ca. 120 minutter i grupper på normalt to og højst tre med en eksperimentel problemstilling. Eksaminanderne må ikke genbruge data fra tidligere udførte eksperimenter. Eksaminator og censor taler med den enkelte eksaminand om det konkrete eksperiment, den tilhørende teori og den efterfølgende databehandling. Den enkelte eksperimentelle delopgave må anvendes højst tre gange på samme hold. De eksperimentelle delopgaver må ikke være kendt af eksaminanderne inden prøven.

Anden del af prøven er individuel og mundtlig. Den teoretiske delopgave skal omhandle et fortrinsvis teoretisk, fagligt emne og indeholde et ukendt bilag, der kan være grundlag for perspektivering af emnet.

Den enkelte teoretiske delopgave må anvendes højst tre gange på samme hold. Bilag må genbruges i forskellige opgaver efter eksaminators valg. De teoretiske opgaver uden bilag skal være kendt af eksaminanderne inden prøven.

Den eksperimentelle og den teoretiske delopgave skal være kombineret, så de angår forskellige emner.

Eksaminationstiden er ca. 24 minutter. Der gives ca. 24 minutters forberedelsestid. Eksaminationen former sig som en faglig samtale mellem eksaminand og eksaminator.

4.3. Bedømmelseskriterier

Bedømmelsen er en vurdering af, i hvilken grad eksaminandens præstation opfylder de faglige mål, som de er angivet i pkt. 2.1.

Den skriftlige prøve

Ved den skriftlige prøve lægges der vægt på, at eksaminanden:

- behersker et bredt udvalg af faglige begreber og modeller
- kan analysere et fysikfagligt problem, løse det gennem brug af en relevant model og formidle analyse og løsning klart og præcist
- kan opstille en model og diskutere dens gyldighedsområde.

Der gives én karakter ud fra en helhedsvurdering.

Den mundtlige prøve

Ved den eksperimentelle del lægges der vægt på, at eksaminanden:

- kan tilrettelægge og udføre eksperimentelt arbejde samt behandle og analysere de indsamlede data
- kan reflektere over samspillet mellem teori og eksperiment.

Ved den mundtlige del lægges der vægt på, at eksaminanden i den faglige samtale har et selvstændigt initiativ og:

- har et sikkert kendskab til fagets begreber, modeller og metoder som grundlag for en faglig analyse og underbygning af den faglige argumentation
- kan perspektivere faglig indsigt.

Hver eksaminand gives én individuel karakter ud fra en helhedsvurdering af prøvens eksperimentelle og mundtlige del.

Prøve, hvor faget indgår i fagligt samspil

Ved en prøve, hvor faget indgår i fagligt samspil med andre fag, lægges der vægt på, at eksaminanden kan:

- demonstrere viden om fagets identitet og metoder
- behandle problemstillinger i samspil med andre fag.

4.4. Selvstuderende

En selvstuderende skal have gennemført laboratoriekursus i fysik A (stx) (Bek. om de gymnasiale uddannelser § 49) med attestation fra den institution, der afholdt kurset, for at kunne indstilles til mundtlig prøve. Hvis den selvstuderende kan dokumentere gennemførelse af eksperimentelt arbejde i et omfang svarende til niveauets eksperimentelle arbejde fra tidligere fysikundervisning, f.eks. i form af rapporter eller journaler, kan den selvstuderende indstilles til mundtlig prøve uden at gennemføre laboratoriekursus. Det tidligere gennemførte eksperimentelle arbejde indgår på samme måde som grundlag for den mundtlige prøve som eksperimentelt arbejde i en almindelig undervisningssammenhæng. Lederen af den institution, hvor den mundtlige prøve finder sted, beslutter, om tidligere eksperimentelt arbejde kan udgøre et tilstrækkeligt grundlag for den selvstuderendes mundtlige prøve.

C Exoplanet Design Package, middle school

Original student guide, middle school

Exoplanet Design

Create a Unique World!

Classroom Activity

Material List:

- Large piece of paper
- Coloured pens/pencils
- Access to internet or books
- Other craft resources, including rulers, scissors, coloured card and more

Outline

Learn as much as you can about exoplanets and then combine your imaginations to come up with a unique exoplanet all your own. Tell your classmates about the planet you created and learn about theirs.

Then consider what kind of life could exist on these planets, how they might adapt to live in extreme conditions. Finally design a life form for one of the planets, making a poster explaining how its features help it survive.

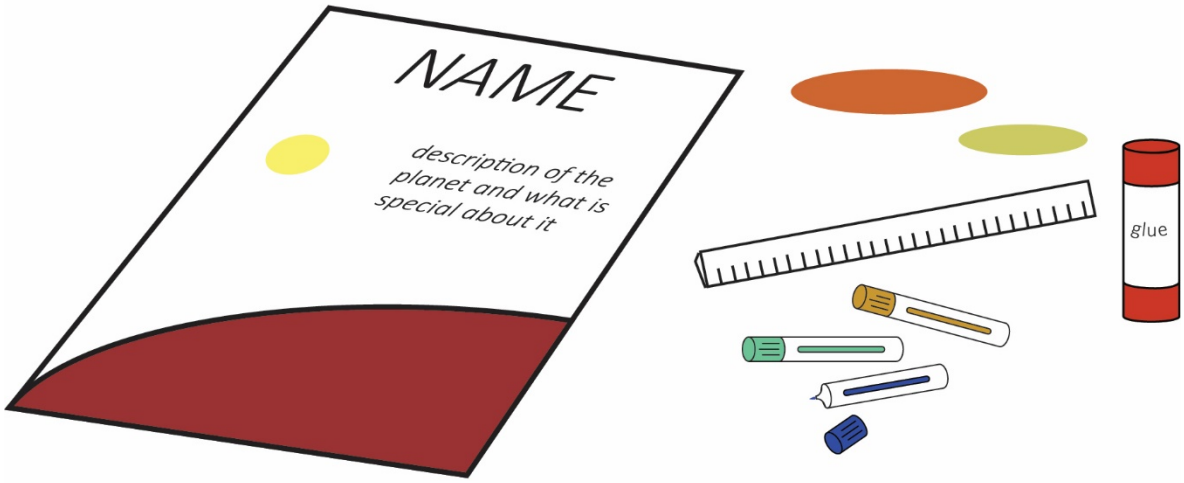
Procedure:

1. Look at the example travel posters for real exoplanets at https://exoplanets.nasa.gov/alien-worlds/exoplanet-travel-bureau/ and explore the surface of some of the planets.

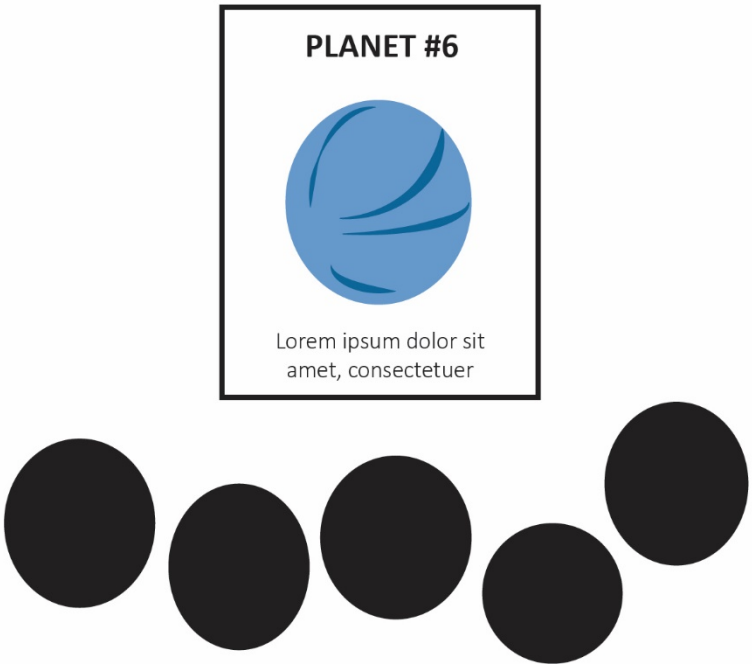
2. Work in your group to decide on the conditions for your exoplanet, what's the temperature like? How's the weather? What does the surface look like? How does the atmosphere and size affect it? Write a description of the planet

The online observatory collaboration consists of the following partners:
Baldone Observatory, Brorfelde Observatory, Cardiff University, Harestua Solar Observatory, Helsinki Observatory

3 Design a travel poster to advertise your exoplanet to the rest of the class, give your planet a name and be as creative as possible.



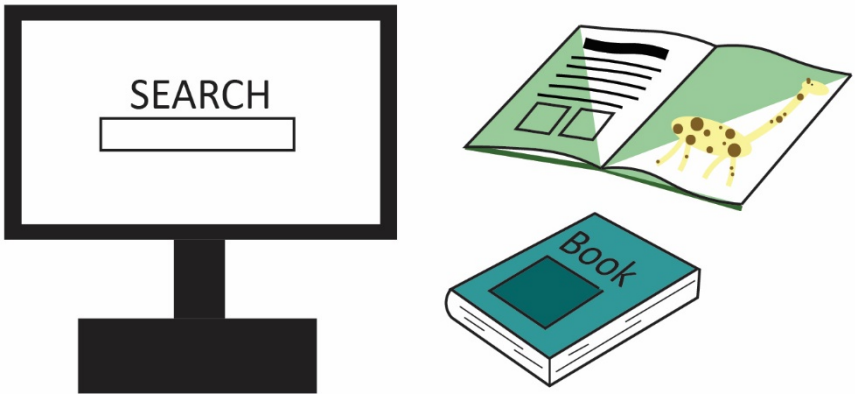
4 Present your planet to others.



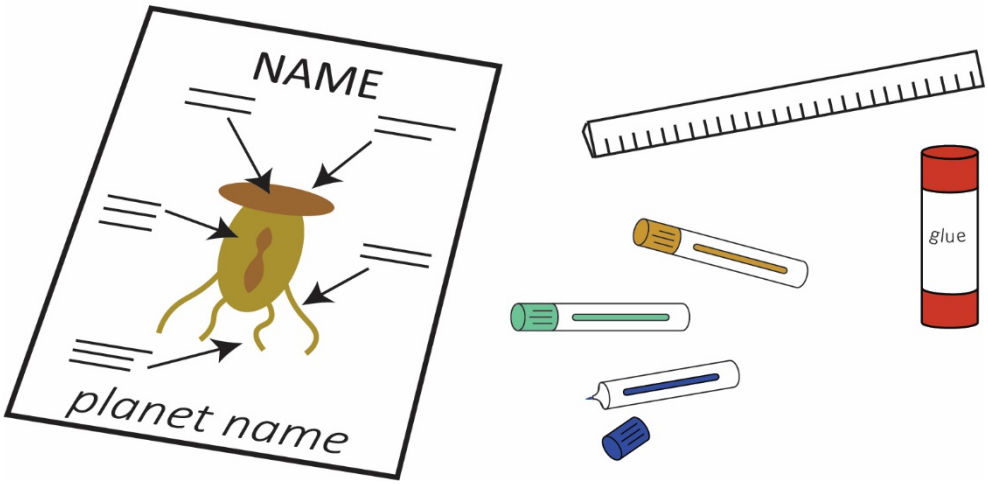
5 Listen to the teacher introducing the next stage of the activity and then switch planets with another group.

The online observatory collaboration consists of the following partners:
Baldone Observatory, Brorfelde Observatory, Cardiff University, Harestua Solar Observatory, Helsinki Observatory

6 Research how creatures on Earth have adapted and evolved over time, to survive extreme conditions. Especially conditions similar to that of your exoplanet.
https://www.bbc.com/bitesize/topics/zvhhvcw



7 With your new exoplanet, design a form of life to live there. Consider how it has adapted to its conditions. Create a new poster, drawing your exoplanet inhabitant and labelling the features that help it to survive.



8 Present your poster once more, explaining how the 'alien' has adapted and justify the choices you made.

The online observatory collaboration consists of the following partners:
Baldone Observatory, Brorfelde Observatory, Cardiff University, Harestua Solar Observatory, Helsinki Observatory

Original teacher guide, middle school

Exoplanet Design

Create a Unique World

Classroom Activity

Overview

Age Range:

7-11

Prep. Time:

15 minutes

Lesson Time:

2 hours 15 minutes

Cost per activity:

Medium

Includes the use of:

Arts and crafts supplies, computer or tablets with internet access, books

Outline

Students will learn about exoplanets. Working together in groups to design their own planets, using their imagination to decide on what sort of conditions would be present.

They will then practise their presentation skills, explaining what they have created to the rest of the class.

Finally, they will learn about adaptation and evolution, creating their own unique life form to survive the conditions on one of the planets.

Again, explaining and justifying their decisions to the rest of the class.

Pupils will Learn:

- Exoplanets have a diverse range of conditions, based on a range of factors
- Living things (plants and animals) adapt and evolve over time to survive the environmental conditions (adaptation and evolution)

Lesson Plan:

Overview of the time required to complete lesson.

The online observatory collaboration consists of the following partners:
Baldone Observatory, Brorfelde Observatory, Cardiff University, Harestua Solar Observatory, Helsinki Observatory

Description	Time	Notes
Introduction to the subject	15 min	Use Eyes on Exoplanets application https://eyes.jpl.nasa.gov/eyes-on-exoplanets.html
Activity 1	45 min	Students will use https://exoplanets.nasa.gov/alien-worlds/exoplanet-travel-bureau/
Break	15 min	
Introduction to Activity 2	15 min	Videos to explain adaptation: https://www.bbc.com/bitesize/clips/z3hxpv4 https://www.bbc.com/bitesize/articles/zxg7y4j
Activity 2	45 min	Any relevant resources, such as books, to help students understand adaptation and evolution https://www.bbc.com/bitesize/topics/zvhhvcw

Introduction to the subject:

If not previously covered, explain to students that exoplanets are planets that orbit stars other then our Sun, creating different solar systems. Scientist have found several of these exoplanets that have suitable conditions to support life.

Show students some examples of exoplanets orbiting other stars using the Nasa app: https://eyes.jpl.nasa.gov/eyes-on-exoplanets.html (download the app prior to the lesson).

Point out the diverse range of planets, mentioning different weather conditions, surface geography and day and night cycles. Take time to look at some of the most unique exoplanets discovered ('extreme planets - weirdest').

Activity 1:

- Divide into groups of 3-6 students

The teacher will provide each group with the materials required to make a poster. Telling the groups to design their own exoplanet and make a poster for it.

1. Students will use https://exoplanets.nasa.gov/alien-worlds/exoplanet-travel-bureau/ to have a look at example travel posters for real exoplanets, some even have interactive designs of the imagined planet surface to explore.
2. The groups should create their own exoplanets, making decisions on the temperature, weather conditions, orbit from its star, size, gravity, surface formation

etc. and write a description for their new exoplanet. Encourage them to only think of the planet, no life forms/inhabitants yet.

3. Now the groups should design a travel poster for their exoplanet, to advertise it to the rest of the class (if more time and resources are available you may consider having students also make models and other display material).
4. Have the groups take turns to present their planet to the rest of the class, allowing the students to ask questions about each planet. You might want to class to vote on whether or not they would like to visit the exoplanets.

- Alternatively, if time is an issue, have the groups pair up and just present to each other.

Introduction to Activity 2:

Explain that to survive all life forms require water, but they can adapt to a range of extreme conditions, from extremely hot too extremely cold, or really dry or really wet environments. Show the class some videos, with specific examples, to help them understand:

https://www.bbc.com/bitesize/clips/z3hxpv4

https://www.bbc.com/bitesize/articles/zxg7y4j

Activity 2:

- Have the groups switch posters/exoplanets

Make sure the students understand the exoplanet that they have been given, then ask them to design a lifeform to survive its unique conditions.

1. Groups should research further into how creatures on earth have adapted and evolved to survive extreme conditions, especially those conditions relevant to their exoplanet.
2. Next they should begin designing an inhabitant (alien) to live on the planet on a new poster. Considering how it has adapted for survival and labelling key features.
3. Have the groups present their 'alien' life, explaining how it survives to the rest of the class.

Assessment:

Have the groups provide feedback and suggestions after presentation, allowing for peer assessment.

Background Material/Knowledge:

Exoplanets are planets that orbit other stars, and scientists have been interested in finding out more about them to discover if they may be capable of supporting life. To support life planets must orbits within the 'goldilocks zone' of a star, where conditions are not too hot or cold and water could be present.

C.3 Planned presentation for middle school pilot test

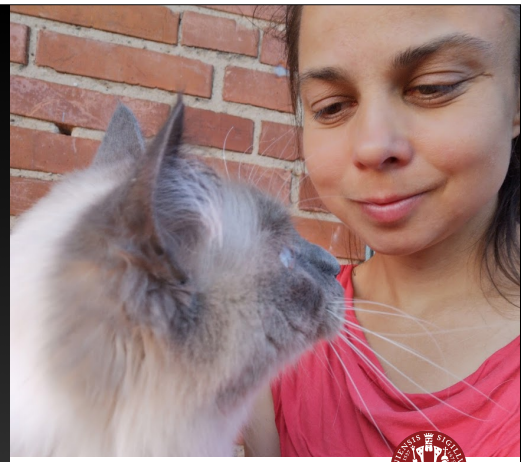
Lenka Otap

Studerer astrofysik.

Tidligere uddannet datalog (nørd)

Nysgerrig på livet, universet og alt det der.

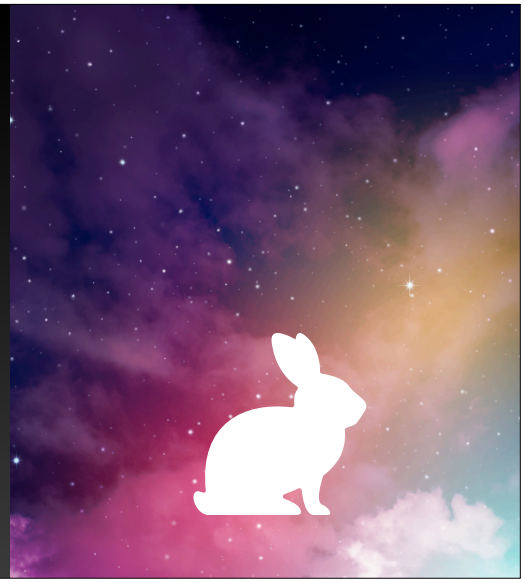
Skriver, formidler.



KØBENHAVNS UNIVERSITET

Videnskaben om liv i universet

Astronomi
+
Biologi
=
Astrobiologi



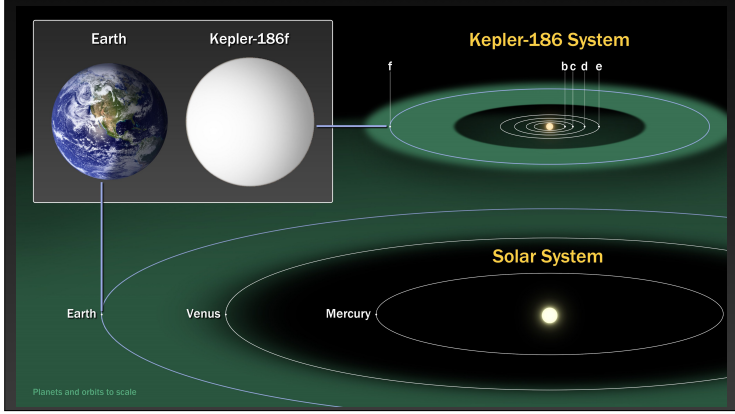
Hvad er liv?

- Jordens liv, eneste vi kender
- "Spise" og formere sig

- Det meste liv er en-cellet
- Flercellet: planter, svampe, dyr

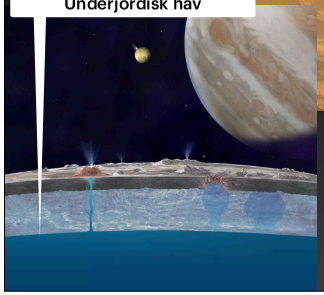
- Liv på jorden er mærkeligere end aliens i film!

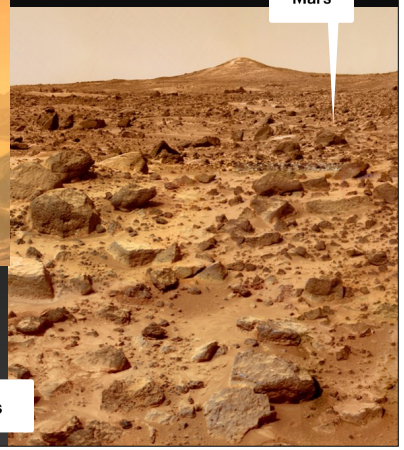
Betingelser for liv

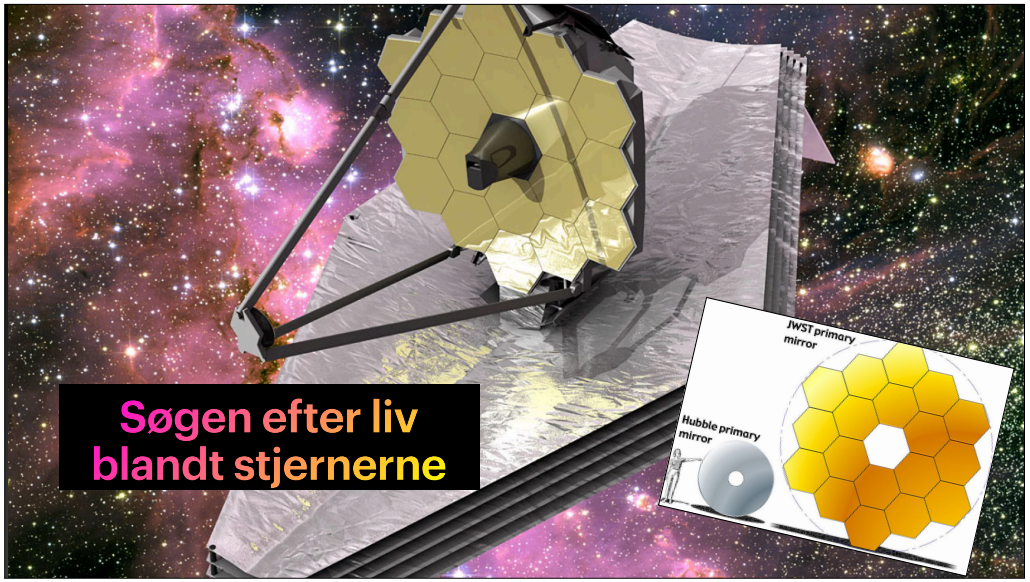


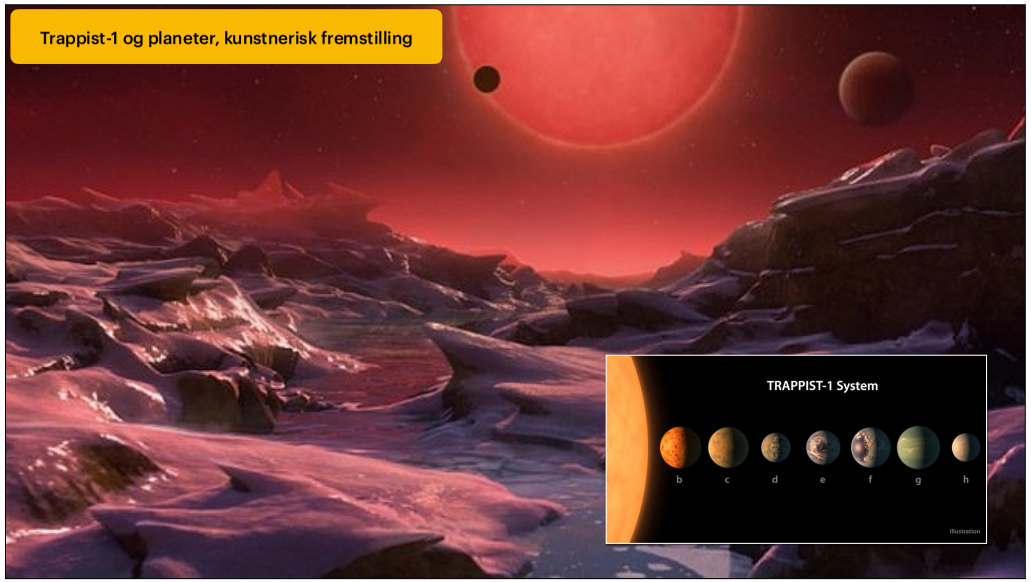
- Flydende vand
- Guldlokzonen (afstand fra stjerne)
- Atmosfære / tryk

Liv i solsystemet?









Hvor mange civilisationer findes der derude?

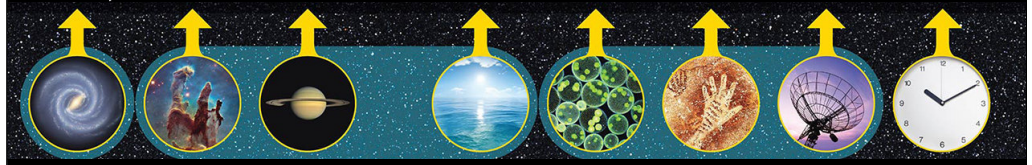
$$N = R_* \times f_p \times n_e \times f_e \times f_i \times f_c \times L$$

Antal civilisationer i mælkevejen

Nye stjerner m. Planeter i beboelig zone

Hvor mange af disse får liv -> intelligent liv -> kommunikerende liv?

Hvor længe overlever vi/de?



Liv som vi ikke kender det?

Spørgsmål?

D Exoplanet Design Package, high school

EXOPLANET DESIGN

SKAB EN UNIK VERDEN

Erasmus+

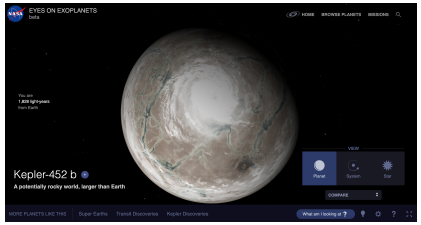
INTRODUKTION

En exoplanet er en planet udenfor vores solsystem (kredser om en anden stjerne).

Hvad lærer du?

- Exoplaneter har mange forskellige egenskaber, der afhænger af mange faktorer.
- Fysikken bag nogle af disse faktorer.

- Vi har fundet tusinder af disse planter via forskellige metoder, fx **transitmetoden, radial hastighed (wobble), mikrolensing og direkte billeder**.
- Nogle af disse planeter kunne have betingelser for at liv kunne opstå.
- Brug NASAs visualisering app til at undersøge forskellige planeter: eyes.nasa.gov/apps/exo - klik visuelt rundt eller vælg "Browse planets".



ØVELSEN

I skal bruge

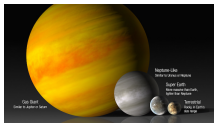
- Et stort ark papir eller digitalt tegnebræt
- Evt. farveblyanter/tusser (eller online)
- Adgang til internet eller bøger

I skal om lidt I grupper **designe jeres egen exoplanet** og lave en reklameposter for den. Gå ind på NASAs Exoplanet Travel Posters for at blive inspireret og undersøge kunstneriske repræsentationer af exoplaneters overflader.

Se også Halloween-versionen her.

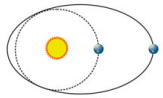
PÅ DE FØLGENDE SIDER GENNEMGÅR VI NOGLE AF DE OVEVEJELSER, SOM I KAN GØRE JER OM JERES EXOPLANET SAMT FYSIKKEN BAG.

PLANETENS STJERNE OG INDFLYDELSE PÅ TEMPERATUREN



PLANETENS STØRRELSE OG TYNGDE

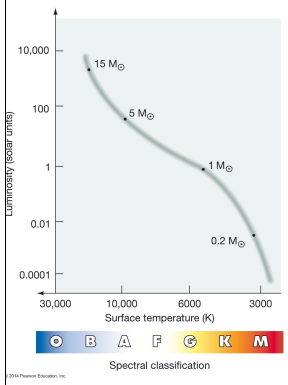
PLANETENS TYPE OG OVERFLADE



PLANETENS PERIODER

PLANETENS STJERNE

Hvilken slags stjerne kredser den om og i hvilken afstand?
Dette vil have en afgørende betydning for planetens temperatur og overflade.

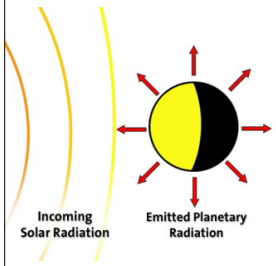


Overvejelser:

- Hvad er **stjernens masse**, M_s? *Gerne i solmasser, fx 2M_sol*
- Hvor er **stjernens overfladetemperatur,** T_s? *Hænger sammen med masse.Tjek graf her på næste side for ca.-værdier.*
- Hvad er **afstanden, a, fra planeten til stjernen**? *Gerne i AE, hvor 1AE er afstanden fra Jorden til Solen.*
- Er det en **enkelt stjerne eller en del af dobbelt/trippelt** system? *Planeten vil kun kredse om en stjerne, men det kan give uregelmæssigheder at have en ekstra tyngde i nærheden. Og specielle solnedgange!*

PLANETENS LIGEVÆGTSTEMPERATUR I

Stjernens temperatur, størrelse og afstanden til den har afgørende betydning for plantens ligevægtstemperatur.



$$T_p = T_s(1 - A_B)^{1/4}\sqrt{R_s/2a}$$

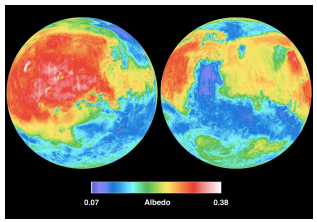
- T_p: Planetens ligevægts-temperatur
- T_s: Stjernens temperatur - direkte proportionel
- R_s: Stjernens radius - proportionel, men med kvadratrods indflydelse
- a: Afstanden - omvendt proportionel, planetens temperatur aftager kvadratisk med afstanden
- A_B: Albedo - angiver hvor meget lys planeten reflekterer, mellem 0 og 1.
  0 betyder at al lys bliver absorberet af planeten (det giver varme).
  1 betyder at alt bliver reflekteret, dvs. intet af stjernens varme varmer planeten op.

Hvad tror du kan have betydning for hvor meget lys der reflekteres fra overfladen?

PLANETENS LIGEVÆGTSTEMPERATUR - ALBEDO

Stjernens temperatur, størrelse og afstanden til den har afgørende betydning for plantens ligevægtstemperatur.

- A_B: Albedo - angiver hvor meget lys planeten reflekterer. Albedo = 0 betyder ingen refleksion, planeten optager al lys fra stjernen. Sæt albedo = 0 som udgangspunkt, ret evt. til senere.



Mars Albedo

- Albedo afhænger af planetens overflade. Eksempler:
  - Havoverflade (albedo = 3,5%)
  - Lava (albedo = 4%)
  - Græsområder (albedo = 20%)
  - Jordens overflade (albedo (gennemsnit) = 37-39%)
  - Is (albedo 30-50%)
  - Sne (albedo op til 80-85%)
  - Skyer (albedo op til 70-80%)

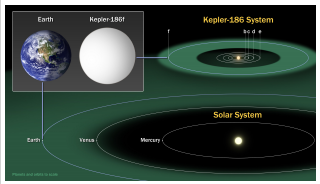
Man kan endnu ikke observere en exoplanets overflade, og derfor er albedo mest et gætværk endnu.

PLANETENS LIGEVÆGTSTEMPERATUR II

Stjernens temperatur, størrelse og afstanden til den har afgørende betydning for plantens ligevægtstemperatur.

$$T_p = T_s(1 - A_B)^{1/4}\sqrt{R_s/2a}$$

- Opsummeret kan I tænke på formlen på den måde:



1. Jo større stjernens temperatur, T_s, og radius, R_s, jo mere varme får planeten
2. Jo større afstand til stjernen, a, jo lavere temperatur - aftager kvadratisk. Det betyder at en planet dobbelt så langt væk får 4 gange mindre varme.
3. Jo større albedo (refleksion), jo lavere ligevægtstemperatur

For at en planet betragtes som i den **habitable zone,** skal der kunne være flydende vand på den, 0-100 grader C.

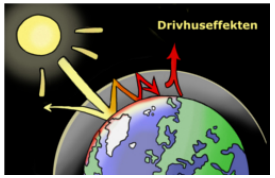
PLANETENS RIGTIGE TEMPERATUR

Hvad kan påvirke ligevægtstemperaturen?

$$T_p = T_s(1 - A_B)^{1/4}\sqrt{R_s/2a}$$

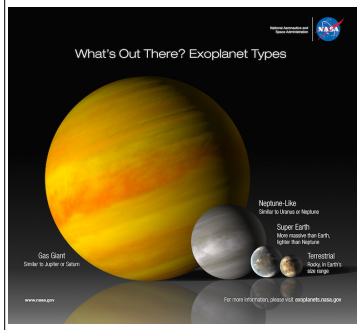
- Jordens ligevægtstemperatur i følge ligningen burde være 255K (-18 grader Celcius). **Hvorfor er der så varmere?**
- **Drivhuseffekten**! Gasser som CO2 og CH4 holder mere på den reflekterede varme.

Vi kan endnu ikke sige så meget om en exoplanets egentlige temperatur, da vi ikke kan kende den nøjagtige atmosfære.



PLANETENS STØRRELSE

Vægt og størrelse af planeten



Der findes forskellige størrelsesklasser for exoplaneter:

- **Terrestial**: Klippeplaneter som jorden eller mindre
- **Super Earth**: Store klippeplaneter, større end Jorden, mindre end Neptun
- **Neptune-like**: Planeter a.la. Neptun eller Uranus
- **Gas Giant**: Enorme gas-planeter a.la. Saturn, Jupiter eller større.
  - Der er funder mange gas-giganter meget tæt på deres stjerne i andre solsystemer - disse kaldes også for **Hot Jupiters**.

Planetens vægt og størrelse har betydning for dens overflade og tyngde.

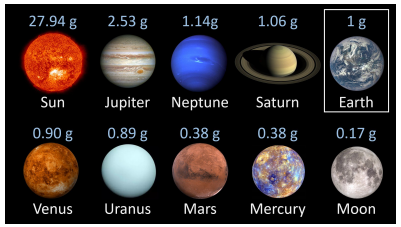
Du kan angive vægt og størrelse i enten kg og km i radius eller du kan angive det i jordmasser og jordradii, dvs. M_jord og R_jord.

PLANETENS TYNGDEKRAFT I

Hvad er tyngdekraften på planetens overflade?
Dvs. hvor meget hiver den dig ned?

Tyngdekraften ved overfladen udregnes som: $g = G\frac{M}{R^2}$

Hvor $G = 6.674 \cdot 10^{-11} m^3\ kg^{-1} s^{-2}$, masse er i kg og radius i m.

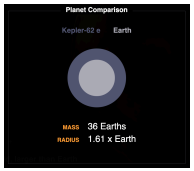


g_Jorden = 9,8 m/s^2
g_Månen = 1,6 m/s^2
g_Mars = 3,7 m/s^2
g_Jupiter = 25 m/s^2

Hvis vi tager udgangspunkt i Jordens tyngdekraft og sætter g = 1, så kan man udregne planetens relative tyngdekraft i stedet for, som set på billedet ved siden af. Her skal du blot bruge plantens radius og masse givet i jordradii og jordmasser: $g_{relativ} = \frac{M}{R^2}$

PLANETENS TYNGDEKRAFT - EKSEMPEL

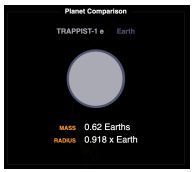
2 eksempel med exoplaneter fra https://eyes.nasa.gov/apps/exo/



Kepler-62e

$$g_{relativ} = \frac{M}{R^2} = \frac{36M_{jord}}{1.61^2 R_{jord}^2} = 13{,}9g$$

En superjord med knap 14 gange overfladetyngde i forhold til jorden!
Det skal tilføjes at den fundne masse er en absolut max-værdi. Et realistisk estimat afhængig under antagelse af klippesammensætning er 4.5 jordmasser hvilket giver 1,74g.



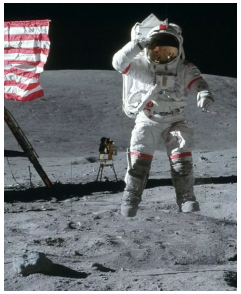
Trappist-1e

$$g_{relativ} = \frac{M}{R^2} = \frac{0.62M_{jord}}{0.918^2 R_{jord}^2} = 0.74g$$

En jordlignende planet med lidt lettere tyngde.
Trappist-1 systemet har flere klippeplanter i habitable zone - et af NASAs "yndlingssystemer" med flere planeter i den habitable zone, 42 lysår fra os.

PLANETENS TYNGDEKRAFT II

Hvor let/tung bliver du på planeten?



Planetens tyngdkraft siger noget om hvor let eller tung du bliver på overfladen.

Fx er **månens tyngdekraft 1/6 af jordens**, så der bliver skridt til hop. Vejer du 60 kg på jorden, så vil du veje 10 kg på månen.

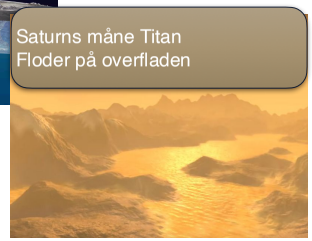
Hvis **Kepler-62e reelt havde 36 jordmasser**, ville 60 kg blive til 834 kg. Et bud på 3.4 jordmasser ville give dig 104 kg. Måske ville det være svært at komme op om morgenen.

Tyngdekraften har stor betydning for hvordan vores krop er bygget, hvordan vi bevæger os og hvad den kan holde til. Det kan man tænke lidt over, hvis man forestiller sig at kolonisere en anden planet eller forestille sig hvordan andet liv kunne se ud på en planet med anderleds tyngde.

På Mars er tyngdekraften lidt over 1/3 af jordens, så vores muskler ville blive brugt mindre af at bo der.

PLANETENS TYPE OG OVERFLADE

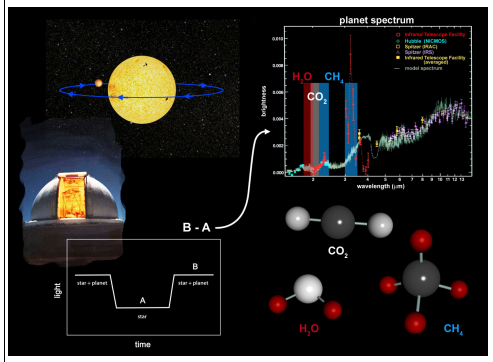
Planetens overflade afhænger også af planetens komposition.



- **Hvordan ser overfladen ud?**
  - Hvis **klippeplanet/superjord:**
    - Fast overflade: jord, klipper, kulstof, is
    - Flydende: vand/lava/andet
      Der findes exoplaneter der menes at være helt dækket af hav: Water worlds.
    - Hvordan er landskabet? Bjerge, oceaner?
    - Er overfladen jævn/ujævn?
  - **Gas- eller is-gigant,** ikke nogen fast overflade
- Hvordan påvirkes overfladen af vind og vejr?

PLANETENS ATMOSFÆRE

Ved transitmetoden kan man forsøge at måle en planets atmosfæres bestanddele. James Webb Space Teleskopet (JWST), som forhåbentlig kommer op her i 2021, vil give mere præcise målinger.

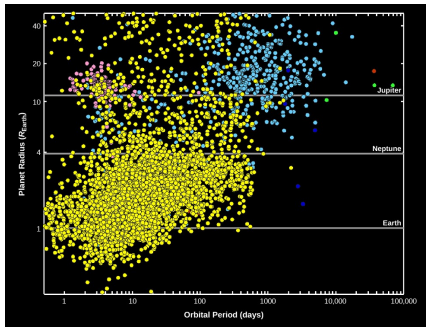


I mellemtiden kan man jo gisne …

- **Er der en atmosfære?**
  - Hvad består den af?
  - Hvad er det atmosfæriske tryk? (lavt/højt relativt til jorden)
- **Hvis der er en atmosfære, hvordan er vejret?**
  - Regner det med vand, syre eller diamanter?
  - Er der vind, storme, skyer?
  - Er der en drivhuseffekt?

PLANETENS PERIODER I

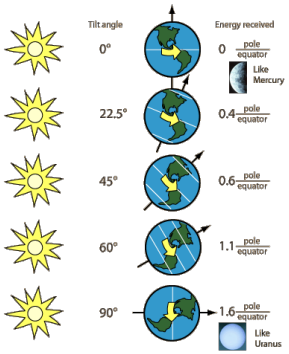
Lidt ekstra at tænke over … planetens bevægelser.



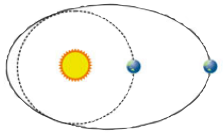
- **Planetens omløbstid: Hvor langt er et år?**
  - Tænk på afstanden fra stjernen, jo længere væk, jo længere er et "år". Brug evt. Keplers 3. lov $T^2 = a^3/M_s$
  - Dette er noget vi kan observere, bl.a. via transitmetoden.
- **Planetens rotation: Hvor lang er en dag?**
  - Eller er planeten låst med en side mod stjernen? (forestil jer en planet "delt i to" med evig nat og evig dag)
  - Dette er indtil videre et gætværk.

PLANETENS PERIODER II

Årstider?



- **Er der årstider, eller på anden vis periodisk skiftende temperaturer?**
  - Planetens hældning kan give årstider, som her på jorden. Hældningen har afgørende betydning for temperaturforholdet mellem polerne og ækvator. http://hyperphysics.phy-astr.gsu.edu/hbase/Astro/orbtilt.html
  - Excentricitet: Hvis planeten har en meget excentrisk (mere aflang) bane, vil forskellen i afstanden fra stjernen også give årstider. Dette er tilfældet på Mars, mens jordens bane er for cirkulær til at det har betydning.



BESKRIVELSE OG POSTER

Design en exoplanet

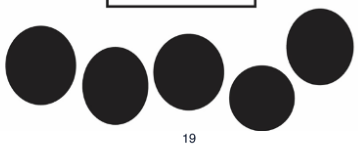
Nu er det jeres tur. Brug eyes.nasa.gov/apps/exo, exoplanets.nasa.gov/alien-worlds/exoplanet-travel-bureau og andre ressourcer på nettet til **inspiration** og beskriv jeres egen planet med de gennemgåede overvejelser.

Understøt gerne jeres besvarelse grafisk, hvis tiden tillader det:

- Design en plakat om jeres planet som rejsedestination. Vær så kreativ som muligt indenfor fysikkens og tidens rammer og giv også jeres planet et navn.
- Digital løsning til gruppearbejde: fx https://aggie.io/

FREMLÆGGELSER

Næste gang: Præsenter jeres planet til andre.



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EXOPLANET DESIGN

ELEVVEJLEDNING

Skab en unik verden!

GRUPPEØVELSE

MATERIALELISTE

- Et stort ark papir (eller et elektronisk whiteboard)
- Farveblyanter eller tuscher (eller online)
- Adgang til internet eller bøger

BESKRIVELSE

Øvelsen går ud på at lære så meget I kan om fysikken bag exoplaneter og deres stjerner og derefter bruge jeres kreativitet til at designe jeres egen exoplanet i grupper. Til sidst fremlægger I jeres planet og kan høre om andres.

Som en ekstra tanke, kan I overveje hvilket slags liv, der kunne leve på disse planeter og hvordan de kunne tilpasse sig til at leve i planetens (måske ekstreme) forhold. Ville mennesket kunne udvikle sig gennem evolution til at overleve på planeten?

FREMGANGSMÅDE

1

Gå sammen i grupper på 3-5. Brug følgende links til at udforske og blive inspireret i 10-15 min tid, sammen eller hver for sig:

- NASAs interaktive "Eyes on exoplanets": https://eyes.nasa.gov/apps/exo - filtrer fx på planettype eller brug "browse planets".
- NASAs "rejseplakater": https://exoplanets.nasa.gov/alien-worlds/exoplanet-travel-bureau/

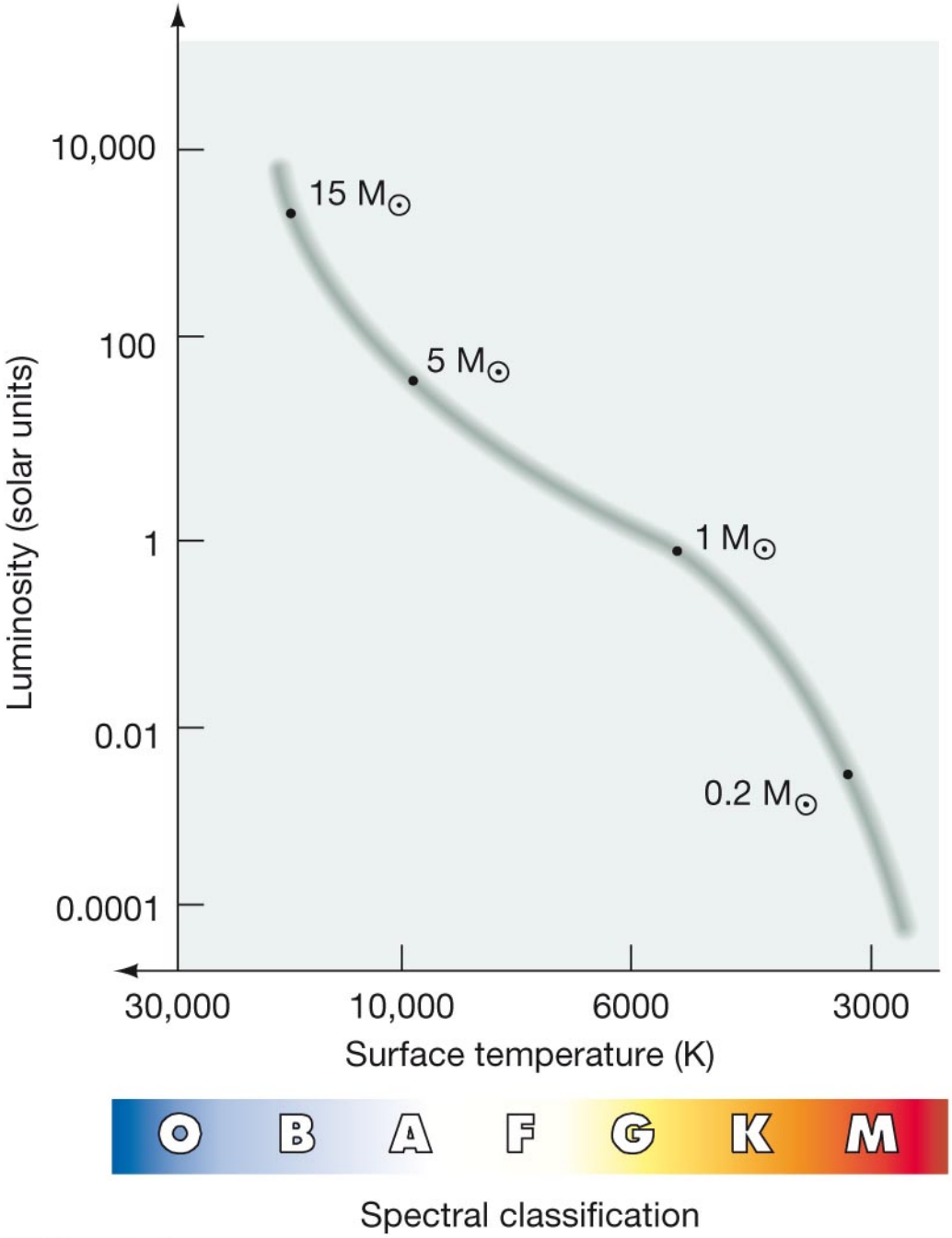
Du kan kigge på posters og bruge det interaktive system til at udforske planet-stjerne-systemer.

2

Beslut sammen med din gruppe hvordan jeres planet skal være. På næste side er der en liste over forskellige egenskaber I kan overveje under jeres kreative arbejde.
Skriv en beskrivelse af jeres planet.

Fx tænk over flere af disse forhold og begrund dem fysisk, hvis muligt. Det behøver ikke at være nøjagtigt, men tænkt over faktorerne og udvælg dem som I synes har en betydning for jeres planet.

- **Hvilken slags stjerne kredser den om?**
  - Hvad er stjernens masse M_s? (angiv gerne denne i solmasse, fx 2 M_s vil være en stjerne dobbelt så tung som solen)
  - Hvor er stjernens overfladetemperatur, T_s?
    - Tjek graf her på næste side for ca.-værdier.
  - Hvad er afstanden, a, fra planeten til stjernen? Gerne i AE, hvor 1AE er afstanden fra Jorden til Solen.
  - Er det en enkelt stjerne eller en del af dobbelt/trippelt system?
- **Hvor varmt eller koldt er der?**
  - Hvad er ligevægtstemperaturen?
    - $T_p = T_s\,(1 - A_B)^{1/4}\,\sqrt{R_s\,/\,2a}$
    - Ts of Rs er stjernens temperatur og radius, A_B er albedo, a er afstand.
    - **TC;DC:** (too complicated, didn't calculate)
      - Jo større stjernens temperatur og radius, jo mere varme får planeten
      - Jo større afstand til stjerne, a, jo lavere temperatur
      - Jo større albedo/refleksion, jo lavere temperatur
  - Er der varmere pga. en drivhuseffekt?
  - Kan der være flydende vand? (den habitable zone)
- **Hvor stor er planeten?**
  - Er den jordlignende, en superjord, Neptun-agtig eller en gas-gigant?
  - Enten i absolutte værdier, km eller kg eller i jordradii (R_{jord}) eller jordmasser (M_{jord}).
- **Hvad er tyngdekraften på overfladen?**
  - $g = G\frac{M_p}{R_p^2}$ hvor $G = 6.674 \cdot 10^{-11} m^3\, kg^{-1}\, s^{-2}$ er gravitationskonstanten
  - *Eller*: $g_{relativ} = \frac{M_p}{R_p^2}$ hvor M_p og R_p angives i jord-radius og jordmasser, således at man får tyngdekraften i forhold til jordens.
- **Er der en atmosfære?**
  - Hvad består den af?
  - Hvad er det atmosfæriske tryk? (lavt/højt relativt til jorden)
- **Hvordan ser overfladen ud?**
  - Fast (jord, klipper, kulstof), flydende (vand/lava/andet), gas?
  - Er overfladen jævn/ujævn?
  - Forandrer overfladen sig med tiden? Hvorfor/hvorfor ikke?
  - Påvirkes det af vind og vejr?
- **Hvis der er en atmosfære, hvordan er vejret?**
  - Regner det med syre eller diamanter? Er der vind, storme, skyer? Drivhuseffekt?
- **Hvor lang er en dag?**
  - Eller er planeten låst med en side mod stjernen med evig dag- og natside?
- **Hvor langt er et år?**
  - Tænk på afstanden fra stjernen, jo længere væk, jo længere er et "år". Brug evt. Keplers 3. lov $T^2 = a^3/M_{stjerne}$
- **Er der årstider, eller på anden vis periodisk skiftende temperaturer?**
  - Hældning eller excentricitet? Hvis planeten har en meget excentrisk bane, vil forskellen i afstanden fra stjernen også give årstider. Dette er tilfældet på Mars, mens jordens bane er for cirkulær til at det har betydning.



3 Design en plakat om jeres planet som rejsedestination, i stil med dem I har set. Vær så kreativ som muligt indenfor fysikkens rammer og giv også jeres planet et navn.

4 Præsenter jeres planet til andre.

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E Transcription of observation, day 1

— [0:01:22] STARTER FAGSNAK HER

M: Det var lidt sejt at lave en rundt om en neutronstjerne ikke Q1,

N: Ja, det er jo det jeg siger, I want Q1.1

M: Åh, men ... det bliver umuligt mand. Det har det vildeste tyngdefelt, jo. Så skal man bare være i det der perfekte orbit, hvor man ... Q1.1.1

F: Det ville jo også være ... [Keplers] ... Q8.1.1

(N) Den skal jo virkelig hurtigt rundt om, for den har jo ...

M: Nej nej nej ... det er jo ikke sikkert at den kommer til at have sådan en der, ehm ... altså, den kommer jo til at have en orbit som er meget sådan ehm, hvad kan man kalde den for ... meget oval, meget ovalt atgigt, ikk ... fordi alle de planeter der er originalt er rundt om den stjerne, den tilhører tidligere neutronstjernen, ikk', altså ... det er jo en kerne fra en stor stjerne nu, ikk', der kom en supernova, så de er jo alle sammen døde, dvs. den planet, altså en rough planet, som den så skal have opfanget, ikk'?

(De andre): uhum ... nåååå.

M: Dvs. Når den så er blevet opfanget, så har den jo ikke sådan en helt lige orbit. Q1.1.1.1

F: Hvis vi skal rejse dertil, så bliver det nødt til at være en planet i den habitable zone, ikk'? Q1.2

N: Nahr, oooooh, men, lad os sige at det skal jo være ...

M: De der som der er blevet lavet plakater til, Kepler-16b og sådan, ikk, ... jeg kan ikke huske det, men der er mange af dem hvor temperaturen er over 100 grader, et eller andet konstant, der kan du alligevel ikke ... du skal jo bruge et eller andet ... når vi siger habitable, skal vi så ikke sige et eller andet Mars-agtigt, ikk'? At det er okay. Q3, Q1.1.1.2

F: Det kan vi godt.

N: Men vi skal jo ...

M: Nu ligger Mars jo så også i den beboelige zone

F: Jeg tror at den kommer til at skulle dreje rigtigt hurtigt rundt om, fordi I kan godt huske temperaturen, ikk', den er jo i 4. i forhold til luminositeten, og den har ret høj temperatur, så det betyder jo at luminositeten er virkelig virkelig høj. Ikk' Q1.2.1

M: Naaaahj ... det er fordi, det er overfladetemperaturen, det er den der gør det, ikk, og det er jo ikke sikkert at det er overfladetemperaturen

F: Jo, overfladetemperaturen, den er virkelig høj, det er sådan noget som million grader eller sådan noget, eller sådan noget der.

M: Jeg tror mere at det var ... aj, vent ... hmm ... surface temperature (søger på google)

F: Når det er du sådan går ud, hvad det hedder, når du sådan går ud ...

M: Jo, 600,000K. Q1.1.3

F: 600,000 ja, en halv million.

M: Men det kan jo, men den har en meget lille surface area skal du tænke på ... (pause) ... så det er rigtigt nok, langt væk fra så ...

F: Ja, det er rigtigt ...

M: Men hvis du er meget tæt på. Altså, så ... så lyser den meget.

—— [0:03:49]: RESEARCH PÅ NEUTRONSTJERNE EFTER INDLEDENDE SNAK

F: Skal vi prøve at finde en neutronstjerne, nogenlunde med nogle værdier på en neu- Q1.1

tronstjerne? Kan vi finde en neutronstjerne ...
M: Crab pulsar
F: Crab pulsar?
M: Ja
F: Nå ja, fuck, eeh, hvad med sådan noget der, hvis det har ,... [magentizer?] og pulsars og ... det kan vi jo ikke overleve, på en planet Q1.1.2
M: Ja, så dør vi.
N: Altså, vi kunne jo godt være i orbit, men sådan en kæmpe-orbit, jo Q1.2
M: Ja, vi kan godt være langt væk fra den
F: Det er rigtigt nok, men stadigvæk, altså, det er jo sådan noget der ... jeg tror at du skal være virkelig, virkelig langt væk for at du ikke bliver ristet af det der ...
N: Hvad var det ... det var pulsars
M: Altså, hvis der kommer sådan et short radio burst, det er sådan et der varer sådan et milisekundt eller noget, hvor der kommer ... det er den energi som der kommer på 3 fulde dage ikk', ud på et milisekundt, ikk', så ... hvis man bliver ramt af det ... Q1.1.2
F: Det skal vi heller ikke have, men skal vi bare prøve at tage højde for det, og så siger vi at det her det er en neutronstjerne der ikke har magnetize eller pulsar ... Okay ... det er ikke en magnetize
N: Men kan vi det?
M: En stille neutronstjerne
F: Ja ... så det er en stille neutronstjerne ... med realistiske værdier, okay, men ... skal vi prøve at se om vi kan finde nogle realistiske værdier
N: Men har I fundet dokumentet begge to?
M: Ja. Jeg har.
F: Jeg har ikk'. (Søger på calculating habitable zone online) Q1.2

— [0:05:04] Læser øvelsen
M: Lad os starte med lige at se på fremgangsmåden, så vi lige kan starte med det her. Lige være sikker på at vi ...
N: Ja, det er nok smartest.
M: Så, ehm. Vi har materialeliste her. Der står et ark papir eller et elektronisk whiteboard. Ja, hvordan skal vi tegne det-agtigt?
(I mens har F også åbnet word-dokumentet og kigger i det)
N: Altså, de plakater der er i 3'eren der er til inspiration, ikk'? Q3
M: MmMm.
N: Jeg ved ikke om det er muligt at vi kan lave sådan noget cool.
M: Naj
F: VI kan lave det med den der ... hvad var det vi brugte til at lave vores plakat i kom-IT? Q3.1
M: Ehm ... PowerPoint (griner)
N: Nej nej ... det var, det var ...
F: Det var ret nemt, ikk ...
N: Det var Canva.
M: Jo ... men jeg ved bare ikke om vi kan sætte sådan noget som neutronstjerner derind. Vi vil gerne have sådan et view, det skal være sådan et sejt view.For jeg tænkte på sådan et view, hvor den har de der jets, ikk', ligesom det der billede jeg tog i en ...
N: Jo, det kan jo godt være en ... hvad det hedder ... det kan jo godt være en pulsar, det skal jo bare sådan der, det skal bare ikke pege, hvis den peger sådan perpendicular Q1.1.2.1

der til planetbanen rundt om. Så er det jo ...
M: Ja, den skal jo bare ikke være i de der ...
F: ja
M: Der kan man bare se
N: Damn
M: Ja, det kunne man også ha' ... (pause) Og det kan den jo også sagtens, det er jo ikke en der er formet sammen med stjernen, det er en der bliver captured. OK, så ... men nu skal vi huske at det er en planet, men vi ser bare stjernen så vi skal lige ... Q1.1.1.1
N: Ja
F: Okay, men ... øvelsen
M: Øvelsen går ud på ... okay, du læser bare
F: okay ... (læser op) "at lære så meget I kan om fysikken bag exoplaneter og stjerner og derefter bruge jeres kreativitet til at designe jeres egen planet i gruppen. Til sidste fremlægger I jeres planet og kan høre om andres. Som en ekstra tanke kan I overveje hvilket slags liv der kunne leve på disse planeter og hvordan de kunne tilpasse sig, til at leve i planetens måske ekstreme forhold."
M: Ja (griner)
F: "Ville mennesket kunne leve gennem evolution til at overleve på planeten?" Q4
N: Overvej, hvis man havde sådan en exoplanet, som der var ret tæt på, ikk', og var påvirket af den der kæmpe tyngdekraft, og du havde mennesker der godt kunne overleve i de der temperaturer, ikk' ... så ville det over tid ... knoglerne og sådan noget ... de ville jo blive ... er du sindssyg Q5.3 Q4.2
F: Åh shit, der er en ting vi ikke har tænkt på. Gutter, hvis den her, den drejer hurtigt rundt om, så sker det jo ligesom det samme som det ... hvad var det nu ... Q2
M: Men det er jo ikke sikkert at den drejer hurtigt rundt om ... jo længere væk den er fra den, jo langsommere drejer den
N: Jaja, men du kan jo ikke have sådan en der er så langt væk at den er sådan -200 grader, altså ... så der er ikke nogen der kan være der. Q1.1.1.2, Q6
M: Hvem siger det? Det kan jo være underjordisk. Q4.1
(Alle griner lidt)
F: Det er rigtigt, men ... skal vi ikke lave en planet i the habitable zone, eller hvad. Q1.1.1.2
N: Jo!
M: Jo.
N: Jeg tænkte at vi skulle lave sådan en feriedestination. Jeg forestiller mig sådan noget med en Campari ... sådan noget tropical trees med sådan nogle sindsyge farver. Q3.2, Q3.2.1[a]
F: Okay, skal vi lige læse videre ...
N: ... hvis det skulle være i orbit om en neutronstjerne Q1.1
F: Skal vi prøve at kigge dem her igennem, de der links, hvad der står ...
M: Der står her, jeg læste lige her: (læser) Habital planets could exist around pulsars. The calculations shows that habitable planets around a neutral star can be as large as the distance from Earth to our sun
N: Oh damn.
F: Jeg fandt jo nogle calculations her, hvor der ... man kan kan calculate the habitable zone. (Tjekker online)
M: Ja, men det ... jeg ved ikke om det virker, men ... aj, prøv hør her, det har vi ikke tid til, det der regnestykke.
F: Det tager to sekunder! Hvis vi regner den her ud, ikk' (markerer formel), så skal vi regne den her ud (markerer anden formel længere nede på siden), og så skal vi regne

de her to ud.
M: Når du snakker to sekunder, så er det to timer. Det når vi ikk'.
F: Årh, vi kunne også godt calculate ...
M: NEJ
F: (snakker videre om formel, samtidig med M)
M: Det har vi ikke tid til det der ... det kan vi gøre bagefter, lad os starte med det her, okay?
(Der sukkegrines)
M: Vi starter med det. Vi starter med grupper. Det har vi gjort. Brug følgende links til at blive inspireret ... okay, det er fair nok, vi bliver inspireret de her 10 til 15 minutter. Så nu har vi stjernen, okay? Hvis det er en neutronstjerne, hvordan skal planeten så være, hvad skal dens atmosfære og alle de der ting.
F: (åbner det første link, EYES ON EXOPLANETS) Jeg tænker at det skal være en forholdsvis tyk atmosfære ... og noget af en magnetfelt den skal have. Q6, Q6.1
M: Det kan være at vi skal skrive nogle ting ned ... kan vi lige adde sådan noget som brainstorm.
N: ÅÅH! NEJ! Det der NASA link, der kan man se habitable zones rundt omkring exoplaneter - eller stjerner. Q1.2, Q2
F: Kan man?
N: Klik på en af dem!
M: Det kan du også godt i ... hvad hedder det ... Universe sandbox 2
N: ... og så det grønne der, det er habitable zone.
M: Hvad for en er det, er det den øverste?
N: Jeg har valgt en der hedder Tau Ceti G
M: N., er det den øverste?
N: Ehm, ja, Eyes on Exoplanets ... beta
F: (klikker rundt i Eyes on Exoplanets) Klik to zoom ... K2 et eller andet.
N: Det er ret fedt, faktisk
F: Den er slet ikke i habitable zone, denne her. Q1.2
N: Potentially rocky worlds larger than Earth
F: Orv, der er en her, der nogle gange er i habitable zone ... og så nogle gange, så zoomer den ind.
(De andre griner lidt)
F: (Kigger på HD 108874b).
N: Den her, den er også lidt udenfor. Det er nok ikke så godt, hvis den ikke hele tiden er inde i den. Og så er der sådan noget masse udryd hver fucking 5. år eller sådan noget. Q1.1.2.2, Q2.2
(De andre griner)
M: Nå ja, aj, kunne det ikke være sejt, dem der bor der, ikk', der kommer sådan nogle burst fra den der neutronstjerne, at præcist et eller andet hvert ... så er det ... de der seasons, ikk', så er det sådan at hver jul eller noget, der skal man nedenunder jorden. Q1.1.2 Q4.1
(De andre griner)
F: Ja, og så har de ligesom evolvet så de går i hi hver femte ... eller sådan der, en dag, ikk' ... hver 5'te år eller sådan noget shit. Eller nej, det er så hver gang den drejer rundt om. [Nej, jeg ve' ikk ...]
(Paise et par sec)
F: Men inden vi beslutter os for det ... inden vi beslutter os for en neutronstjerne, Q1.1

ikk', så synes jeg lige at vi skal finde ud af om denne her faktisk virker til ...
M: Jeg tror bare at det tager lidt tid though. Det er det eneste.
F: nej nej, hvis jeg bare lige får det, så kan jeg hurtigt regne det ud, hvis jeg lige får det, hvadethedder, parametrerne på en neutronstjerne.
M: Hvad er det for nogle ting du skal bruge så?
F: Jeg skal bare bruge temperaturen, jeg skal bruge radius, og jeg skal bruge dens luminositet. Q1.2.1, Q1.1.3,
M: Okay ... 3000K. Q1.1.4
F: 1000 Kelvin ...
M: Og hvad var det du så sagde, diameter eller radius?
F: Radius.
M: Og det ... en radius på ... jeg tror at det var noget der svarede til ... jeg tror at det plejer at være sådan 20 ... 25 km. Q1.1.4
(F åbner lommeregner på computeren. Videnskabelig lommeregner ...
F: Hov, nej, jeg skal ... (mumler og skifter over til Maple)
M: Eller også nej. Det er nok diameteren jeg ville sige ... ehm ... radius på ... det 10 til 20 km.
F: 10-20 km, okay ... (er ved at åbne Maple)
M: Så bare sig 15, bare sig 15 I radius, så 30 i ... hvad ...
F: Jamen jeg skal også bruge luminositeten af en bestemt ... altså, jeg bliver nødt til at bruge en bestemt en, fordi-eh ...
M: Okay, fair nok. Så siger vi Crab Pulsar. Hvad får vi så i luminosity ... den har en luminosity på 0.9 sol-luminositet. Q1.2.1
F: (er ved at skrive 4*pi* i Maple) Ehm, 0.9 ... jeg skriver lige ned (skriver det på linjen under)
M: Ahmen, det er basically bare solens.
F: 0.9 gange, hvad er det nu .... (Søger på google) Sun Luminosity (google viser 1 L_{sol}) Q1.2.1
M: Nå, men I mens han lige gør det, N., så kan vi lige skrive de her ting ned. Okay?
N: Jep.
(F klikker ind på Wikipedia længere nede på google søg og finder solar luminosity i W)
M: Ehm, så ... hvor kan vi adde det henne? Der er vel nogle ting her ... så ... "tænk over faktorerne ... " (læser i elevguide), okay, så ... Stjerne. Eller hvad hedder det ... Du skriver bare alt muligt ... (eller noget som forsvandt)
F: Har du fundet en radius? (Er tilbage i Maple)
M: Ja, radius var 15 km ca. Eller nå nej, det var ikke til den. Crab ... ehm ... 2 sec ... Q1.1.4
F: 22?
M: nej nej nej, vent lige lidt. Den har en radius på 10 km.
F: (skriver i luminositets-formel i Maple ... i anden ... og hvad var det du sagde, det var 600 tusinde eller hvad?
M: Ja.
F: (skriver i Maple)
M: Okay, stjerne ... neutronstjerne. (Skriver) ... Planet. Okay, hvor stor skal planeten være, hvad tænker vi? Hvor meget masse ... og hvor stor? Q5, Q5.1,
(Pause, et par sec) Q5.2
N: Hmm ...

M: Skal vi sige ... noget der minder om ...
N: Jeg kan godt lide tanken om en lille planet. Q5.2,
M: Ja ... men det skal stadig ikke være sådan ... det skal ikke være for lidt tyngdekraft for så bliver vores knogler sådan, alt for sådan ... kan det ikke være sådan en med mindre (M og N kommer til at tale lidt i munden på hinanden) Q5.3, Q4.2
N ... så kunne der være den samme tyngdkraft som vores.
M: Kunne det ikke være sådan ligesom Mars? Det er 50% af jordens tyngdekraft. Der kan du sådan ... vænne dig til det, hvis du træner en masse hver dag. Men der er der stadig de gode benefits med mindre tyngdekraft.
(Pause, et par sec)
N: Åh shit det tog lang tid ...
M: Overvej hvor højt du kunne hoppe i ... på dit skateboard, N.. (wee) Q3.2.2
F: (Udregner i Maple). Nej, vent, det passer ikke helt ... det ser ud til at det ikke passer Q1.2.1
M: Nå ja ... (vender opmærksomheden tilbage)
N: Hvad passer ikke?
M: Prøv hør, hvis vi bare går ud fra det .. hvis vi siger, det er en AE væk, Ikk' ... (Pause et par sec) ... hvis det er det man kan finde på internettet.
N: Jae ...
F: Øhm ... 600.000 i fjerde ...
N: Mm, kan vi ikke have en planet, der ...
F: Er vi ikke enige om at det er 4* pi * r^2 * temperaturen ... nå, ja, jeg mangler stephan Boltzmann ... ehm .. Q1.2.1
M: Stephan boltzmanns konstant.
F: Ja, ehm ... (søger i sine dokumenter på computeren.
M: Nå men planeten ... hvis vi nu siger, hvad med en mellemting. Så 75% af jordens tyngdekraft. Q5.3
F (finder en opgave om stjerner) ... Hvad siger du så?
M: Ja, hvis vi siger det er en med ca. 75% af jordens tyngdekraft, ikk' ...
N: Ja ...
M: Og så måske ...
N: Men ... hvis vi gjorde den lidt mer' ... sådan 110% af vores tyngdekraft, ikk'?
M: Ja?
N: Så behøver man ikke at træne, så ville det være træning bare at gå der. Fordi hvis vi gør det til et feriested, så skal man ikke bruge hele dagen på at holde sig sådan ...
M: Det ville også være sværere at komme fra planeten. Q5.3.1
N: Vi laver sådan nogle ... vi laver sådan nogle trampoliner hvor man kan hoppe virkelig højt
(de griner)
N: Sådan en trampolinpark, hvor man kan hoppe ... Q3.2.2
F: Åh ja, prove lige at overveje nogle [rights] du kan få, fordi ...
N: Der er ingen friction! Det er bare ren wshooom, derhenad!
M: Ja, heh ... det er bare en rutchebane 500 km i timen.
F: Hvordan er det nu Stephan Boltzmanns ...
M: Overvej togene ... sådan nogle lyntog man kan have. Okay. Det er sådan paradise planet. Skal vi sige Q1.2
N: Først siger vi ... hvad mange masser. Hvor mange solmasser. Q1.1.5
M: Solmasser? Ikke planeten. Hvor er du mærkelig.

N: Nåh, jeg troede at vi snakkede om masse lige nu.
M (griner) Jamen planeten skal vi stadig ikke have i solmasser.
N: Det står der da!
M: Står der det?
N: Ja! "Angiv gerne denne i solmasse".
M: Eeeehm ... nå!
N: 1. spørgsmål.
M: Vent hvad? Hvilken stjerne kredser om ... hvad er stjernens masse ... Ja, stjernens masse. Ikke planetens masse.
N: Nåååh. Jaja.
M: Jaja.
N: Jaja!
M: Jaja!
N: Hvad så, hvad er vores neutronstjernens masse? Q1.1.5
M: Øh, det er sikkert ... skal vi se crab ... skal vi få ud fra at det er crab pulsar?
N: Den er I hvert fald (nogen som forsvandt)
M: Ja, det er vores yndlings. Den har en masse, ehm ... lad mig se her, estimated mass, bababa ... ejected ... mostly ... ca ... ca. 4.6 ehm solmasser.
N: Så siger vi 5.
F: Dude, er du sikker på de her tal (kigger stadig på sin luminositet i Maple) Q1.2
M: Ja ... pfff ... jeg har
N: (griner)
M: Altså, jeg kan ikke være mere sikker end at det er det google og internettet siger, F.
F: Nå, okay, Men det var 10.000 km, nåå nej ... Q1.1.4
M: Det har vi jo sagt, det er ikke sikkert ... jo, det er 10 km.
F: Og det er 600.000 grader.
M: Ja. Det er ikke sikkert at den virker for Q1.2
neutronstjerner, F.
F: Nej ... og hvad var luminositeten, den var 90% af vores stjerne ...
M: Ja.
F: ... vores sol ... nå, men så virker den ikke.
M: Ja, men det er det jeg siger, skal vi ikke bare sige at det er tæt på ...
F: Tæt på, det er overhovedet ikke tæt på.
M: Nej nej nej nej, ikke det, no no no. Ikke det, altså. At det er ... altså ... habitable zone.
F/N: Hva'?
M: Det kan jo også være ... prøv hør her ... det behøver ikke at være i habitable Q7.2
zone, hvis det nu er en gasplanet, hvor at vi så er månen der så er rundt om den, hvor vi så bliver varmet af friktion, fra den gasplanets tyngdekraft.
N: Oh my god. Jeg tænker, skal vi ikke lige holde det lidt mere simpelt.
M (Griner) Okay, fair nok.
N: Fordi ... vi har 55 minutter endnu.
M: Okay, okay, okay. Fair, fair, fair.
F: Vi har lige lidt travlt. Okay, så største ... største ... største stjerne (søger på google). Største stjerne overhovedet. (Finder VY Canis Majoris)
M: Det kan også bare være en thick atmosphere ... sådan så den bliver varmet af ... ja, greenhouse effekten.

—— [0:18:13] HER GÅR DE PLUDSELIG VÆK FRA NEUTRONSTJERNEN OG FINDER EN ANDEN STJERNE
F: Okay, der er en hypergigant her, VY Canis Majoris ... Q1.3
M: Ja, hvad vil du med den.
F: Den største stjerne der er hidtil observeret.
M: Ja, hvad snakker vi om nu.
F: Så tager vi den største, den allerstørste stjerne vi overhovedet kan finde.
M: Den største?
F: Ja! Allerstørste stjerne.
N: Jeg er overhovedet ikke med.
N: Jesus. Vil du brænde eller hvad sker der?
F: Nej, vi går bare langt ud.
M. Oh okay ... hvis du gerne vil det ...
F: Vi kunne bruge VY Canis Majoris ...
M: Fair nok. Vi tager den. Ehm. Hvad vil du bruge af tal? (F: Åbner "opgave om stjerner igen) Q1.3.1
M: Radius er 997, øhm ... nej, bare 988 ehm, millioner km.
F (er ved at lede efter nyt dokument) Jeg skriver det lige ned på vores ...
M: Det er radius.
N: Hold da op!
F: Radius er hvad for noget siger du?
M: 988 millioner km.
F: 988 millioner km.
N: Åhh! En stjerne! Aj, mand!
F: (har nu et nyt word-doc åbent, "vores exoplanet", skriver ...) VY Canris Majoris ... hvad er det du sagde det var ... 900 ... millioner km?
M: 988 millioner km.
F 988 ... (skriver)
M: Og så skal du lave det om til meter.
(F skriver)
M: Og en planet. Hvad siger vi .. ehm ... masse. Åh, vi kan jo egentlig bare svare op de her spørgsmål agtigt. Ehm ... Q1.3.2
N: Det er lidt det vi skal. Hvad er massen af den her stjerne du har fundet, F?
M: (læser) Havd er stjernens masse, angiv den gerne i solmasser.
F: Skal vi ... ehm ...
M: Det kan godt være at vi skal skrive regnestykket ind der. Så de kan se at vi regner det ud ... i solmasser.
F (søger på stjernen i google igen, finder wiki), okay, her der står nogle ting om den.
M: Den masse.
F: Den har en ...
M: N, vil du gøre det?
N: Regne dens masse? I solmasser? Altså, eller hvad?
M: Ja, tag bare den og så ... divider den med solens ...
N: Jaja ... hvadøhm, hvordan staver jeg til det ... VY ...
M: Jeg kan, jeg søger bare ... masse ... den har ... okay, det står faktisk her, 17 solmasser. Okay.
N: Så behøver vi jo ikke at regne det ud.

F: Den har ... prøv ... prøv hvaddeethedder, prøv at se 178, prøv at, prøv at se min skærm, M.
M: Erhm ...
F: Prøv at se her, når den siger Luminosity, ikk', så står der både 270 og 178 Q1.2.1
M: Eehm ...
F: Det er som om det er sådan forskellige mål, agtigt.
M: jaerh ... (nok se) ... (mumler noget, mens han selv læser noget). Kan du ikke ... der står 270 tusinde ...
F: Ja, men der står også noget med 170 nedenunder.
M: Jaa ...
N: Måske er det de her ... imperfektioner, eller hvad det nu hedder
M: Ja ... ja, det er jo fordi, at er det ikke denne her der var i astronomi opgaven?
F: Nej ... nej nej, det var en anden en. Jeg tror at den hedder...
M: Jeg synes bare at den havde det samme ... i lysstyrke. Var det ikke 270 tusinde artigt noget?
N: Nej, det var 240.
F: Men, prøv at se.
M: Ja, og her står der også 178 til 270
F: Kan vi ikk' ... altså, selvom det var 178 tusinde
M: Kan vi ikke bare sige ... men der står også ... mmm ...
N: Altså, der står noget med at ...
M: Hvad står der
N: ... at det er 278 sol ... ja ...
F: Ja, men hvad er det her ovenover ... (klikker væk på anden side) ... hov ...
N: Det ved jeg faktisk ikk'.
F: Men det er fordi der stor +/- 40.000 der, ikk' ... se hernede, der står + 40.000 minus 29.000.
M: Mmmm ...
N: Nah
F: Okay, fuck det, jeg tager 178, det er den vi går med ... sagde du ikke ...
M: Nej, kan du så ikke bare sige ... kan vi ikke sige ... jo, men det står bare forskellige steder ... fair nok, det er lige meget. Så bare sig ... bare sig 180. Bare sig 180.
F: Vi siger 178 ...
M: Nah ...
F: skal vi ikke det?
M: Okay, okay, okay.
N: Ja
M: okay
F: 178, ehm.
M: N., skriver du ... den der sommasse.
N: Skal jeg-eh ...
M: Vent, jeg skriver bare ... 17 solmasser
N: Plus/minus 8! Hold da op, hvor er det ...
F: Wow.
M: Hvad? Massen, eller hvad? Q1.3.2.1
N: Ja! 17 plus/minus 8 solmasser.
M: Ja, men det er fordi det er upræcist.
N: Så er det godt nok ikke præcist

M: Nej, det er jeg klar over, det er det jeg siger, det er så det der du skal svare på i opgaven, hvorfor det er så svært, når det er den er så kæmpe stor.
N: Ja, ja selvfølgelig ...
F: Hvad-eh, kan vi lige finde ud af-eh ... eller ... den absolute magnitude (søger på google: Vy Canis Majoris absolut magnitude). Okay det er minus (google viste -9,4 inden han trykkede enter). Okay, det er minus-ehm (da han trykkede enter, kom google frem med resultatet -0,72) ... minu... what? ... Størrelsesklasse, men det skal jo være absolut størrelsesklasse. Q1.3.3
M: Den har ... den absolute magnitude er på ... det står her ... minus 9 tror jeg.
F: -9.4, ikk' ...
M: Jo
F: Så den har en absolute ...
M: Jesus.
F: ... absolute ... (skriver)
M: Så dvs, hvis du er 30 lysår væk fra den, så vil du kunne se den om dagen ... basically ...
F: Nå ja, absolute. Yes, det ... og så ... (passe) ...
N: Fuck, hvor nice
M: Hvad var det, det var -9.4. Ehm ...
F: Kan vi ...
M: Eller vent, hvad, er det minus -9. Der står bare her, fordi der står apparent magnitude is ... eh, 8. På det der app.
F: (+ 8 det igennem - kan ikke tyde)
M: Jamen det ... hmmm ... det er fordi der stod ... nej ... eller er det minus 0,72 ... Jeg tænker også at 30 lysår for er den er lidt meget at lyse ... -9.
F: Ja, det er 30 ... det er 30 parsec ikk,
M: Nå, nej ... nej nej nej nej, det er 10 parsec.
F: 20 parsec. Ja, nå ja, det er det.
M: Dvs. det er 30 lysår. Ja, men det ... minus 9 er for meget. Det minus 0.72, det giver mere mening. -9 ... det er næsten ... minus 9, det er næsten lige så meget som månen. Og 30 lysår er altså stadig ret meget. Selvom det er den største stjerne.
N: Det er godt nok den største, men ... altså ...
M: Ja, men ...
N: Den er jo craaaazy ...
M: I know.
(F søger i mens på størrelsesklasser og kommer ind på en UY Scuti på 11,2 størrelsesklasse) Q1.3.4
N: Det der, det er en anden en ... det er schuit.
F: Hvorfor står der størrelses ... nå ja. Vent.
M: Apparent magnitude ...
N: Du har valgt en anden stjerne, F.
F: Ja, det ved jeg godt. Q1.3.3
N: Men gutter, skal vi ikke se på ...
F: Nej, I ved godt vores sol den har end apparent magnitude på sådan noget der 3, nej absolute magnitude på 3, har den ikke, 4?
M: Solen?
F: Ja
M: Sun magnitude ...

N: Tror I så ikke det passer meget godt med at den er 8
M: Njeeeh ... øøh ...
N: Nej, vent der står
M: Nej, ikke apparent ... absolute ... (mumler)
F: Skal vi ikke bruge ... stellarium? (Er ved at åbne stellarium)
M: Solen har ... solen har 5.
F: 5?
M: Jah ...
F: Jeg prøver at finde den i ... i Stellarium
M: Jamen i stellarium? Det er lige meget hvad den er i Stellarium.
F: Wow, hvad er der sket her? Nå, den er lige der (er i programmet, menuen hoppede)
M: Det er lige meget hvad den er i stellarium, F. ... fordi der står jo visual, det er der er tilsynaldende.
F: Vi kan i hvert fald finde den apparent magnitude, ikk'? Den er ret nem at finde.
M: Men hvad skal vi bruge apparent til?
F: Så kan vi regne den anden ud. Nå ja, vi ...
(Tænkepause et par sec)
M: Kan man ikke bare ... legit få svar. VY canis majoris absolute magnetude
F: Ååh, nejnejnej, okay, den siger ... "it has an apparent magnetude that varies from 0.5 to -9.6"
M: Jamen det, jamen det er jo apparent
F: Nå, apparent, ja okay
M: Nej, det står faktisk ... vent, hvor langt væk er den?
F: Nej, der står: "Absolute magnitude is -9.4"
M: Okay, fair ... det, det kan godt passe, fordi lige nu har den, den har 5, nej 9 her, og den er 5000 lysår væk nærmest. Okay. Det giver mening. Fair! -9. Du kan se den om dagen. Aj ... ja.
F: Hvad for en spectral class? Er det ikke B. Det må det næsten være.
M: Øøøhm ... spectral class (søger). Den er M3.
F: M3 ... ? Nå M ja, ikke B, M. Q1.3.4
M: Er det ikk'? Ehm ... Oh Boy I'm ...
F: Okay, så er det ikke den, så skal vi lige lave et regnestykke der hedder ... så skal vi lige det der M ...
M: Lad os se her ... hvad er stjernens overfladetemperatur i ... soloverflader ... gætter jeg så på, temperatur af sol ... ehm ... "vy majoris" ... ehm ...

— [0:27:03] - GENNEMÅ OPGAVERNE EN FOR EN
N: Skal vi ikke gå igennem den der liste ... en for en ... bare regne det ud. I stedet for at søge på det ene og det andet og samtidig ...
M: Jo
N: ... la lala lala lala ...
(Tænkepause)
F åbner elevguide dokument igen.
M: Ja, men ... øøøh okay ... Hvad er afstanden fra planeten til stjernen, gerne i astronomiske enheder. Okay ... den skal være ... Q1.3.5
F: Ja, jeg er i gang med at regne ...
M: Den skal være meget stor.
F: jeg er i gang med at regne denne her funktion ud.

M: Okay, så det kan vi ikke svare på. Er det en enkelt stjerne eller er det en del af et dobbelt eller trippelt system? Hvorfor kan den ikke kredse rundt om en neutronstjerne der er lige ved siden af. Q1.3.6, Q1.3.6.1
F: Owv ... hohoho ... okay!
M: MmhmmHmmHmm! Skal vi ikke gøre det?
F: Ja, men så den der habitable zone, den dur jo ikke. Eller hvad?
M: Jo, jo, det, prøv hør, hvis det er så langt væk, den der neutronstjerne kommer ikke til at gøre noget, så meget.
F: Nej, nej okay, det er rigtigt.
M: Måske bliver det en halv grad varmere, men altså.
N: Åååh, nej, den kan også kredse om et sort hul! Q1.3.6.2
(Alle griner lidt)
N: En [individual] planet ... om et sort hul.
F: Nej, var det ikke det vi snakkede om tidligere, det ... det ku' godt ... eller Interstellar.
M: Nå ja, overvej sådan, hvis det sorte hul er stort nok, så ... aj... det kommer alligevel ikke til at ku' være stort nok til at du kan se det når det passerer ind foran.
F: Ehm ...
M: Så skal det virkelig være stort, så skal det ... være ... det største ... men det er vel
F. Okay, så ...
M: Enkelt, dobbelt eller trippelt system ... okay, skal vi så ikke sige ... bare for at gøre det mere cool, så siger vi at den kredser rundt om en neutronstjerne, den der, skal vi sige det? Q1.3.6.1
N: Ja.
M: Fordi det gør heller ikke så meget. Vores main ... ehm, hvad kalder vi vores stjerne for? Q1.3.7
(Tænkepause)
M: Vores den store her. Hvad skal den hedde?
(Længere tænkepause)
N: Øøøh ...
(Mere tænkepause)
N: Skal vi ikke kalde den et eller andet mega ... FMN, og så nogle tal.
M: FMN ... FMN ...
F: Ah, det er sådan 10 i ...
M: N., hvad for en måned har du fødselsdag i?
N: Femte.
M: Ja ... 5 7 7.
N: FMN-577.
M: Ja ... og ... (skriver mens han snakker) ... kredser ... om en ... stjerne ... ehm ... har en neutronstjerne ... hvad skal neutronstjernen hedde? Det er også bare FMN, for det ...
N: FMN?
M: Og så er det bare 1. .. FMN ... tilsammen danner de et fælles tyngdepunkt som planeten kredser om. Bum. Okay, ehm ... så. "Hvor varmt eller koldt er der?" "Hvad er ligevægtstemperaturen?" Øøøøøøøøh ... så skal vi bruge stjernens overfladetemperatur, og ... og det der. Og radiussen. Skal vi lige regne det der ud, N. Q7, Q7.1, Q1.3.8, Q1.3.1
N: Ja.

M: Alright.
N: Hvad er det der A_B though. Q7.1.1
M: A_B ... det ... godt spørgsmål. Der står, der står her "T_s og R_s er stjernens temperatur og radius ... A_B er albedo, a det er afstand. (TD;DC: To complicated; didn't ... calculate ... øh ...)
(Tænkepause)
F: Absolute ... eh ... luminosity (søger på absolute luminosity) ... hov ... (tilføjer "of the sun") Q1.2.1
M: Ehm, okay. Så ... A_B ... hvad med det der ... lille a. Nå, der står der, a er afstand. Ja, okay. A er afstand, så ...
N: Albedo ... jeg har aldrig hørt om albedo før ...
M: Men den kan vi ikke regne ud før vi har fundet ud af hvad det er for en planet. Q8
F: Det er en effekt den har, når der er en Albedeo, altså en albedo, den er høj, hvis du har is på, så meget af lyset bliver reflekteret.
M: Ja.
F: Når en albedo den er lav, så er det ... hvad det hedder, lidt af lyset der bliver reflekteret. Albedo på jorden tror jeg er ret høj, fordi vi har have og sådan noget, der skinner lidt ud.
M: Ja ... men ... vi ... den her, vi kan ikke lave den lige nu, N, fordi vi mangler F.'s afstand til planeten, altså ... habitable zone.
N: Når man søger på albedo, så kommer der anime frem. (De griner lidt)
N: OMG
M: Okay, kan der være flydende vand? ... Er der varmere pga. ... Q8.1
N: Det skal der være! Der skal være flydende vand.
M: Vores planet har flydende vand (skriver imens). Det er det bedste kildevand der findes.
F: Hvad er det nu ... hvad det hedder, hvad er det nu absolut luminosity er?
M: Og fra de (skriver) ... fra de dejlige bjerge ... eller hvad kalder man det? Q8.2
N: Absolut? Det har jeg sgu' aldrig hørt før ... vi har da kun snakket om en slags luminosity, har vi ikk'?
M: Hva'? Nej. Absolutte og tilsyneladende.
N: Er det ikke magnitude vi snakker om der?
M: Vent, hvad ... hva' sagde du så?
N: Luminosity.
M: Nååh. Sorry. Hva' ... hvad sagde du så, F.?
F: Nej, ja, jeg tror at jeg har fundet ud af det (har markeret en google søgeresultat af luminosity pf the sun i watts) ... det er fordi jeg prøver at finde ud af hvad for en der ... Q1.2.1
M: Okay, N., kan du ikke lige skrive om der er varmere pga. en drivhuseffekt? Det er der jo. Ligesom på jorden, ikk'? Q7.3
N: Selvfølgelig! (Med italiansk accent)
M: Men det kommer også an på hvor varmt vi regner det ud, det kommer til at blive med den der.
F: Ja ... passer det her (kigger igen på luminositeten på google) ... men hvorfor ...
M: Men hvorfor ændrer du lige det?
F: Vi har bare ... vi har ...
M: nej nej nej, N., det står der allerede. Vent, hvad? Du svarer ovenover spørgsmålet lige nu. Btw.

N: Nej, jeg gør ej.
M: Jo.
N: Nej jeg gør da ej.
M (griner) jo du gør.
N: Nej, jeg gør ej!
M: Jo, på min gør det. Det er bare word, der er dårlig så.
N: Mm ... vi er enige om at det er den der "Er der varmere pga. Drivhuseffekt", ikk'? Q7.3
M: Ja. Du skriver ovenover den (på min)
N: Nej, jeg gør ej.
M: Jeg sagde på min!
N: Naaj!
M: Jo.
N: Wow ...
M: Hvor stor er planeten. Er den jordlignende, en superjord, neptun-lignende eller gas. Den er jordlignende. Q5.4
N: Åååh, vi skal have de vildeste klippeformationer. Så man kan både være på sådan nogle badedage og ski-dage. Q8.2
M: Ja, præcis.
F: Jeg tror ... absolute luminosity, tror du ikke de mener absolute .. hvaddethedder, absolute magnitude? Q1.2.1
M: Det tror jeg.
N: Nej fordi, prøv se, linjen lige nedenunder, der snakker de om det andet. (De kigger fælles på en wiki-side)
F: Ah, det er rigtigt.
M: Men der står at absolute luminosity er et absolute measure of radiated electronic power. Det kan godt være at de bare mener luminosity så.
F: Det er mærkeligt fordi ... luminosity den skulle vi bruge ... nå nej. Nå nej. Den ville jeg bare finde altså ...
M: Nå ... er den jordlignende, neptunlignende ... "den er jordlignende. Vi tænker ... Q5.4,
både i forhold til" (skriver) ... "til størrelse men også med dejlige vand- og" ... jeg Q6,
forestiller mig sådan en helt clean planet, ikk', som er sådan helt ... og atmosfæren, Q6.3,
ikk', det skal være sådan mere ... sådan ... ja, hvordan kan man sige det, sådan lidt Q3.2.1
... måske sådan lidt mere turkis-agtigt, så det ser lidt mere tropisk ud.
N: Jah ... oh yea.
M: Hmm. ... (skriver/læser) "I forhold til størrelse, men også med dejlig vand og bjerge ... bjerge og troper osv ... en rigtig ... "
F: Hvor langt ude ligger Venus, hvor mange meter ude ligger venus?
M: Det kan du søge på.
F (allerede i gang med en browser hvor der står "Venus" i søgefeltet)
M: På Gaugle.
(tænkepause)
M: En rigtig vand ... der varmer vores planet ... drivhuseffekten ... der er masser af planter af alle sorter ... (mumler lidt, mens han skriver/arbejder) ... lister dem vi kender ... og med varmen der var det ikke ... (alderen?) ... Super.
F: 2, 3, 4, 5, 6, 7, 8, ... (tæller cifre i afstand fra sol til venus).
M: Enten i absolutte værdier i enten km eller kg jordradius eller jordmasse. Eeeeeee- Q5
hhhhh ... eh ... hvad betyder det? Læser: "Hvor stor er planeten. Enten i absolutte værdier, km eller kg, eller i jorradii eller jordmasser. Ehm, hvor stor skal den være?

M: Jordmasser. Q5.1
F: Hvor mange jordmasser?
N: Åh, den skal være ... vi skal have en ... det skal seriøst være en paradise island, ikk' ... Q3.2.1
M: MmMm ...
N: Den skal være stor nok til at der både kan være sådan ... dale med ... tropiske resorts, ikk'. Og så der kan være store bjerge ...
M: Men prøv at overvej, jo mindre tyngdekraft, jo større bjerge. Q5.3,
N: Selvfølgelig. Q8.3
M: Mmm. Så ...
N: Vi kan få 25% større bjerge end her i Danmark. Danmark (griner) Q8.3
M: Danmark (griner) ... ja, det vil ikke være særlig meget.
N: Griner mere.
M: Himmelbjerget ... 125 meter i stedet for 100. Skovl ... jeg kan ikke engang huske om himmelbjerget er 100 meter
N: Jeg tror aldrig at jeg har været der.
M: Nåh.
N: (griner)
M: Jeg har kun været ved Møns klint, det er 100 nogle steder.
N: The moans klient.
M: The moans klient ... jo, jeg har også været ved Himmelbjerget tror jeg. Eller har jeg. Ved du hvad, jeg kan ikke huske det, det er også lige meget. Ehm, så ... vi siger jordmasser ... samme som jorden, men en masse som er 0.75. Hvad bliver tyngdekraften så? Det er så ... ja, okay. Skal vi prøve det? Er I med på den? Q5.1, Q5.3
N: Ja, så hvad siger du ... vi har ... dvs. vi har samme overfladearal, men højere masse eller hvad?
M: Ja ... mindre masse. Q5.1
N: Mindre masse simpelt hen.
M: Mmm.
N: Ja okay! Jeg kan godt lide idéen om det her. Og så ... hvis du falder på ski eller sådan noget, så dør du heller ikke. M (griner) Overvej skihop! Q3.2.2
F: Kan det passe at dens habitable zone starter I ... ehm, 2,99 meter gange 10^{16} ude.
M: Øhm, hvorfor søger vi ikke bare på VY Canis Majoris habitable zone? (Griner) Q1.2
N: Oh, goddammit. (Griner også)
F: (søger på google) ... VY Canis Majoris habitable ... OMG!
M: (Læser) "Roughly between 600 ... " det står der, shit mand, google! Nå, men mellem 600 og 1200 astronomiske enheder.
N: (til F, som nu har maple åbent igen) Prøv at lave dig om til astronomiske enheder, så kan det godt være and et bliver det samme.
F: Så jeg skal dividere det her med afstanden til ....
M: Ja, 150 millioner km. Som så også skal laves om til meter.
F: Jeg tror at det her, det ... det her det ... (skriver i formel) ... 150 ...
M: Yes yes yes
N: Det er som om den tekstboks, der er blevet sat ind på den her side ... kan du se, du rykker den bare ned, kan kan ikke se teksten.
M: Nå ja.
N: What the heck!
F: Det giver ikke ... hov.

M: Det er det nok også. Mærkeligt nok. Kan man ikke ... hvordan er det man selecter alt på en side?
N: Ctr-A. Nope, det er wrong det her ... come on.
M: Vi kan kopiere det hele. Og så sætter vi det lige ned i bunden af det hele, hvor der ikke er en tekstboks. Hvis vi kan det. Ah, det gider den ikke. Jeg tror at vi bliver nødt til at lave et dokument, hvor den ikke har de her tekst-bokse. Jeg laver lige et til. Ellers kan man ikke se det. Det er lidt ærgerligt. Ehm ...
F: Okay, det passer ikke, min udregning her, det passer ikke. (Markerer alt i sit maple dokument)
M: Aj, F. ... ! (Med drillende skuffet stemme) ... Nå! Men hvis vi siger mellem 600 og 1200 AE. Kan vi ikke sige 900 eller sådan noget. En god mellemting.
F: 900 ... Q1.3.1
M: Astronomiske enheder.
F: 900 AU orbit.
M: Okay, oog ...
N: Hvor stor var vores stjerne? Fordi var den ikke noget med ...
M: Very thick. Hvad?
F: Vi startede på ...
M: Nej, den var 900 .. ehm ... 988 millioner ... tror jeg eller vent ...
N: Så det er ca. hvad?
F: Hvor har I skrevet det ind henne?
M: Hvad mener du ...
F: Jeg har også et dokument jeg sidder i lige nu, men ... det er ikke det samme dokument som I skriver i lige nu ...
N: Nej nej ... vi har delt det.
M: Ja, men jeg deler ligge et til, for det her det laver lige sådan nogle mærkelige tekstbokse af en elller anden grund.

— [00:40:25 NOTE TO SELF: Elevguidens tekstbokse er ærgerlige hvis man sidder og arbejder direkte i word-dokumentet]
N: Okay ... det der nok det der, F. ... ja, det er det (F har åbnet den elevguide, som de har arbejdet i)
F: Aj, hva'?
N: Jo! Kan du ikke se at vi er inde på det dokument?
F (Scroller lidt op og ned i dokumentet) Jo men ... hvor er I henne?
M: Vi er lige her, F.
N: (Griner) Jaja!
F: Jamen, what?
N: Kan du ikke se de ændringer i har lavet?
F: (samtidig) I har ikke skrevet noget, eller hvad?
M: Jo, vi har.
F: Hvor har I skrevet noget (scroller stadig op og ned ... lukker til sidst ned og vælger "Gem ikke")
M: Jeg kan godt lide at du brugte sådan en halv time på et regnestykke, der ikke er i opgaven ... desværre (griner) Q1.2
N: (griner)
F: Hahahuhu
N: Aj ... vi prøvede ... hvad har du kaldt dit nye dokument nu?

M: Astro-exoplanet2
N: Aj, det ... det kommer seriøst aldrig.
M: Du skal bare lige vente ... 30 sekunder.
N: jah ... det er nok bare ...
M: Det er bare word. Word is gar-bage.
F: Vi vil gerne have at den har en gravitationskonstant på hvad
M: Oh my gad.
F: hvad, 80% af jorden ...
M: Aj, nu virker OneDrive ikke.
N: ... (noget) også OneDrive ... F.
F: Hva'?
N: 75. 75%.
M: Okay, mit OneDrive virker ikke. Den kan ikke åbne det nye dokument. ... Aj, kan ikke oprette forbindelse. Den virker ikke, what?
N: Ej, det er det sidste vi har brug for nu, det er tekniske problemer.
F: Oh, nåå, vent, I har lavet et ... aj ja, jeg kan åbne det her dokument nu (har åbnet et word-dokument, med gruppens noter)
M: Jamen det ... hvad hedder det du kan åbne?
F: Det hedder ... astro-exoplanet2.
M: Kan du åbne det? Jeg kan ikke åbne det. Min siger fejl.
N: LOL. Jeg kan også godt.
M: What. Er du inde på det?
N: Jaa, jeg er inde på det.
M: Jeg kan ikke åbne det!
N: Og det er dig der har lavet det?
M: Den siger "Sorry we couldn't find, it was removed or deleted."
N: Det er nok fordi du har ændret titlen på den eller sådan noget. Prøv ... tag nu og sluk dit OneDrive.
M: Det har jeg gjort to gange nu.
N: Nej nej nej ... tre gange er lykkens gang.
M (sukker let grinende og opgivender)
N: Nå, F., du kan jo se hvor vi har skrevet her og hvor vi ikke har skrevet, ikk' .. de steder vi ikke har svaret på det, det er fordi ... ja ...
M: Fordi vi ikke har svaret endnu.
N: Ja.
M: Den kan ikke, jeg bliver nødt til at lave en til.
N: Nejnejnej.
M: Jeg kan ikke komme ind på dokumentet!
N: (griner lidt)
M: Jeg laver en til.
N: En superjord. Hvad skal det betyde? Q5.4
M: Det er en planet, der minder om jorden, men som har meget mere masse og tyngdekraft.
F: Hvad for en albedo skal vi have? Vel noget der minder om jordens, eller hvad? Q7.1.1
M: Ja, hvad er jordens?
F (slår op på google)
N: Albedo ... det lyder som sådan en Italiansk ret.
M: Ja. ... Albetto ... skal du have noget albetto ... "

F: (har fundet wikis side om albedo) Okey, her er sådan lidt forskellige, f.eks. havoverflade, det er 3.5%, lava 4%, sumpområder, løvfældende skove og sådan noget græsområder 20%, sand 25-30%, is 35%. Skyer ... 70 ...
M: Vi skal bare have sådan noget natur over det hele ... tropisk. Q8.3
F: Havoverflade, det er 3,5 procent. Okay, jeg troede faktisk at det var mere, jeg troede at det var meget.
M: 3.5?
F: Ja, kun.
M: najnaj najnaj naj.
F: jo jo.
M: Hvad mener du med ...
F: Det reflekterer åbenbart kun 3,5 procent.
M: Nåååå, jeg troede at du mente at jorden kun var ... dækket af 3,5 procent vand. Så tænkte jeg, der er noget helt galt der, F.
(Stillepause, et par sec)
M: Okay, nu ... har I set den her, den hedder bare dokument 19.
N: Og lad være med at ændre i navnet, fordi det er det der gav fejl før.
M: Præcis. Why do you think I did this.
N: (griner). Men F ... nu ændrer vi til nyt dokument igen. Nå, jeg svarer lidt på hvordan det fordeler sig geografisk. Gutter, hvor langt er et år? Q2.1
M: Et år? 365 dage.
N: Nej, ikke på den måde ...
M: Nå, nej nej, det er jo noget vi skal regne ud.
F: Ja, fordi hvor langt væk er den fra vores sol? Det var 60, nej, 900 AU, ikk'?
M: Ja.
F: Har du skrevet det ned?
M: Hvor lang er orbit time? (Griner) ... med 900 AU. Pluto, det er legit sådan, med Pluto, ehm ... det er sådan (søger online) ... Pluto, den er 40, ikk', nu skal jeg lige se hvad Pluto ... den er 40 AE væk, hvad er et Pluto år? Et Pluto år er ... ohm, Pluto orbit time, sådan her. (Griner) Det er 248 år! Q2.1.2
N: Damn. ... Skal vi så bare gange det med ...
M: Så hele dit liv ... lever du bare kun i en orbit.
F: Vi kan regne ud hvor meget der er på overfladen .. hvor meget eh ...
M: Men så lad os lade være ... lad os ... hvor lang er en dag, hvor hurtigt kan den dreje rundt om sig selv. Planeten. Q2.3
(Tænkepause ...)
F: Ehm ... ehm, hvor var det vi snakkede om, sådan noget som temperaturen på den? Eller ... ja, jeg laver lige en udregning på den hernede. Det er sådan noget med, eller, nej ved du hvad, det ... det venter jeg lige med. Ehm ...
M: Er der en atmosfære, hvad består den af. Yes sir. Vi vil gerne have oxygen, eller hvor meget ... hvor meget oxygen er der her på jorden. Hvad er det nu, er det ikke 20 ... Q6, Q6.4, Q6.4.1,
F: Jo. Q6.4.1.1
M: Hvor meget oxygen består atmosfæren af så ... somebody help me.
F: Okay, luminositeten det var den vi var blevet enige om ... hvis jeg skriver Vy Canis majors luminosity, så siger den 270(.000) L($_{sol}$). Q1.2.1
N: Der er 21% oxygen I atmosfæren, M. Q6.4.1.1
M: Okay.

N: Der er 78% Nitrogen.
M: 21 ... hvis vi gerne ... vil vi gerne have atmosfæren skal være sådan lidt tyk eller skal det være det samme. F: Skal vi gå med luminositet 270? Q6.4.1.1 Q1.2.1
M: 270?
F: L.
N: Tusind?
F: Ja, 270.000, ja.
M: Hvad nu hvis vi tager en lille smule mere oxygen, så du kan blive sådan rigtig stor og stærk, du kan vokse, men det er ikke sådan for meget. I stedet for 21, ikk', hvis vi så siger sådan 30%.
N: Så bliver vi nødt til at have lavere Nitrogen. Men ja.
M: Ja. Skal vi gøre det?
N: Skal vi sige 69% Nitrogen, og 30% oxygen.
M: (skriver) procent oxygen ...
N: Og så ...
M: Nej, ikke 69% oxygen.
N: Nej. Nitrogen.
M: Ja (griner), det var fordi jeg skrev forkert. Det ville være ... ikke så godt.
N: Giv mig lige to sekunder ...
F: Bruger vi luminositeten til noget nu?
M: Ehm ... nej, vi skulle bruge ... jeg tror at jeg skulle bruge den til et regnestykke derover, men så havde jeg ikke lige ... nogen ting ...
N: Vi siger 270.000, ikk', for det er det, altså wikipedia er ret godt med. Ehm ...
M: Fair. Ellers kan vi sige en mellemting. Kan vi ikke sige en mellemting? Bare 220.000.
F: Nah men ... armen, vi siger 2 ... altså ... det er i hvert fald forkert, lige meget hvad, altså ... nu er det 50-50 for at ...
M: Okey, okey okey.
F: 1,5 ... 150 gange 150 gange 10^9 ...
M: Det var bare fordi jeg tænkte, at hvis det var vi fik den forkert, så var det ikke så slemt
F: Nå ja, det er rigtigt ... og så gange med 900, det er 900 AU, ikk' ... ja.
M: 69% nitrogen og 30% oxygen ... hvor meget CO2 er der i jordens atmosfære? Q6.4.2
N: Oh my god ... oh my god, nu gider min ...
M: Percentage ... (søger)
F: Er der en der kan regne ud den her ...
M: 0.04.
F: Kan du gå ned og trykke ALT-B på den der, jeg kan åbenbart ikke få den til at virke.
M: Eeeeeeeehhh ... hva'?
F: Nede i det her regnestykke jeg har lavet i bunden, prøv at trykke ALT-B
M: Hvad mener du, det kan jeg ikke, du er ikke engang på online versionen, F.
F: Online-versionen?
M: Nu er du. Den skiftede lige til online. Jeg kigger bare lige på dine ...
N: Jeg er tilbage igen.
M: Yes.
F: Prøv at gå ned til den der og tryk ALT-B, sådan så du får den udregnet.
M: Det kan jeg ikke. Jeg er ikke engang på offline lige nu. Plus min word kan heller

ikke, for den crasher hver gang jeg gør det.
F: Hva'?
N: Jeg prøver.
M: Min word crasher every time.
N: Vent venligst. Wordmath starter op.
F: Ja, så regner den det ud.
M: Hvad består den af. 69% Nitrogen og 30% oxygen. Hvad skal resten være?
F: Har du fået det?
M: Vores sidste 1%, hvad skal den bestå af, boys? Q6.4
N: Kan du se den der?
F: Ja, okay ... det skal bestå af ... neon.
M: Okay, neon?

—- [0.49:29] RESULTATET AF EN UDREGNING TIL HABITABLE ZONE ER IKKE SÅ GODT - MERE FOKUS PÅ TEMPERATUR NU!
N: (markerer resultat af formel, som blev 0.4519 ... W) Wow ... F: Jesus Christ, du kan ikke køre en solcelle på ... no way en habitable zone kan være så langt væk. Q1.2
M: Now, hvorfor ikk'?
F: Fordi at ... fordi der er ... en halv watt per kvadratmeter ... så langt væk. Vores sol, det er sådan noget 500, pr kvadratmeter, vores eh, der er sådan noget ... du kan ikke ...
M: Det er lige meget, jeg ender bare med lidt mere CO2, ikk', så den har den der greenhouse effekt, ikk, så bliver det varmt. Q6.4.1.2,
F: Hvad, nej, det er ikke det ... det er ikke det. Q7.3
M: Hva' så?
F: Vi snakker om ... jeg snakker om, hvadethedder, du kan ikke køre solceller på den ... på, på overfladen.
M: Prøv hør, vi bruger ikke solceller. Så bruger vi energi fra vores planets kerne. Ikk'.
N: Aha!
M: Eller, eller ... eller, jeg skulle lige til at sige, jo ... Vindmøller!
F: Dude, habitable zone kan ikke være ...
M: Jo. Det kan det jo godt, F. Det kan godt være at det ikke er optimalt for DIG.
(De griner)
N: Åh, overvej hvor ...
M: Habitable betyder at der kan være flydende vand, F.
N: Gutter, vi skal have en evig nat/dag. Nej, en evig nat side og en evig nat ... Q2.3.1
M: Så er den tidally locked ... N., det betyder at den ene side bliver burned to crisp.
N: Najnajnajnaj
M: Jojojojojojoo... det betyder det, så kan du kun leve i midten ... hvor du, hvor du kigger sådan
N: Det jeg bare havde tænkt mig var sygt, for så kunne det være ... hvor man kunne lave mega vibes på den ene side af planeten, hvor det var helt mørkt, sådan så alt det var lyset op af stjerner og sådan noget ... og på den anden side ...
M: Jo, men det ville bare være burned to crisps. Fordi du blev ved med at ... det er noget den bliver ved med.
N: Najnajnajnajnaj.
M: Jo! Jo, den gør (griner). Jeg sværger, det kommer den til at gøre.
N: Hvordan er månen så ikke brændt ned, hva'?

F: Det gør den også! Den brænder på den ene side og ... der er virkelig koldt på den anden. Nå nej!
M: Nej, den flyver jo rundt om os, det er jo ikke ... N. ... (De griner)
F: Men den er også ...
M: Men Merkur! Merkur, den er tidally locked, og den er brændt ned, ikk. Den ene side, om dagen på Merkur, ikk', der er det like plus 300 grader, om natten sådan minus 150 eller sådan noget, ikk'.
F: Du kan ikke have en ... altså, det bliver alt for varmt på den ene side, i forhold til den anden.
M: Ja. Det er kun sådan lige i midten hvor du lige ville kunne leve.
N: Men ...
F: Du kan kun leve der hvor der er solnedgang eller solopgang.
N: Men hvis det er, hvis vores orbit er de der 1000 år eller sådan noget, 1000 år på et år ikk'
M: Ja, mere.
N: Ja, meget værre ... så ender vi jo med at skulle have ret lang tid på den ene side.
M: Nejnej nejnej ... det er jo ikke det. Det er jo årstiderne. En dag, det er jo hvor meget den roterer rundt om sig selv. ... Du kan bare have en dag på 24 timer.
F: Nej! Nå, ja på den måde.
M: Joo
F: Jojo jaja, det et rigtigt nok
N: Gutter, gutter, gutter, der er 20 minutter
M: Fuck.
N: Vi tænker det her alt for godt igennem.
M: Ja
F: Jeg vil gerne have ... 5 gange så lang tid til at lave den.
M: hehe ... så må man lave den efter skole.
N: Det er rigtigt.
M: MMmMm.
F: N., kan du prøve at regne den der ud igen?
N: Okay.
F: Nu har jeg prøvet med 600 AU.
M: Hvad står der, 69% Nitrogen og 30 procent oxygen ... 0,05 ... men ... så du var ikk' ... altså, var det lige meget med det der ... Q6.4
N: Nu siger den det der.
F: What, det er jo een watt ... pr kvadratmeter.
M: F., det er bare din ... prøv hør, vi bruger ikke solceller der.
F: Har jeg ... har jeg ikke ret, har jeg sådan der, har jeg fucket et eller andet op.
M: Vi bruger ikke solceller.
F: Åh nej, hvis jeg har lavet det her forkert (markerer formlen for luminosity) ... det min egen ... prøv at regne det her ud, det burde være for solen, det burde være omkring 500 det her, 600 måske. ... Ved du hva', jeg regner den ud på min ... eh ... Q1.2.1
M: Jeg tænker på, at det burde måske også være lidt mere, hvis du tænker på, hvor thick den her stjerne er. Fordi overvej hvor meget den må skinne, hvis vi regner med at den er 30 lysår væk. Der skinner den med minus ... altså, sådan så du vil kunne se den om dagen, ikk'. Og vi er ikke engang et lysår væk.
F: MmHmmm.

M: Fordi en ... prøv se ... light year in AU (skriver) ... et lysår er 63.000 astronomiske enheder, vi er 900 AE væk, ikk'. Og du kan se den om dagen, når vi er 30 lysår væk, ikk. Prøv at gang 63.000 med 30. ... gange 63 nul nul nul gange 30 (regner), ikk' ... Så, vi vil kunne se den om dagen! 1,8 ... eller 1,9 millioner astronomiske enheder væk. Og vi er 900. Så jeg tror altså at der er noget galt der, F. Q1.3.5
F (skriver i søgefelt: "hvor meget lys blokerer")
M: Men det kan også godt være at jeg bare tænker forkert ...
F: Nå nej (sletter søgefelt igen) ... Det passer måske meget godt, det passer måske meget godt det, det handler om ... fordi denne her, den giver 1300, ikk', men det er den samlede, al den elektromagnetiske, eh, hvadethedder, ehm stråling, og der snakker vi jo også gammastråling og alt hvad der bliver blokeret af vores magnetfelt, ikk'.
M: Øøøh. Ja, atmosfære?
F: Ja, vores atmosfære, jo. Hvis det kun er halvdelen af energien, eller under halvdelen af energien, der rammer jorden, det giver måske meget god mening.
M: Ja. Jajajaja ... (arbejder videre med sin tekst) 0.04 CO2 ... resten neon, som N. wishede. ... Hvad, Neon ... Q6.4
N: Så kan man sætte strøm til loftet, og så lyser den.
M: (griner)
F: Hvad er det atmosfæriske tryk. Lidt over.
M: Ehm ...
F: Årh, vi skal også lave den der plakat, mand! Q3
N: Ja ... det er den der skræmmer mig lidt.
M: Jah ... (arbejder lidt videre ...) ... atmosphere ...
N: Uh! Har vi tidevande?
M: Tidevande? Aj, ikke uden en måne. Så skal vi have en måne.
N: Ah okay.
F: Kan vi lave et billede af den inde i Space Engine og sætte den ind på en plakat? Q3.1
M: Ehm, ja. Men det kommer vi ikke til at kunne nå i dag.
F: Nej, det er rigtigt. (Er inde på Space Engine, et software på computeren)
M: Men vi kommer alligevel ikke til at kunne nå at blive færdig med den der plakat i dag. Eller jo, jo, hvis det er noget vi gør efter skole. Så kan vi godt, F..
F: Skal vi så prøve at lave ... vi prøver at lave en planet, så tager vi et billede af den.
M: Ja. Vi kan lave den inde i Space Engine. Men ... skal lige se her ... excitede Nitrogen ... og ioner. Hvis man har nitrogen, hvis du har masser af ... vent, hvad, det burde ... no ... vent. mmm. Vent, jeg skal lige, "how to ... ". Hvad er det nu lilla på engelsk ... purple. Q7.1.1
F: Den der med albedo, det er også sådan noget der, hvor meget ... eh, den der.
M: Hvad for noget ... hvad for noget lys ...
F: Er afstanden 900 AU? Q1.3.5
M: Ja, 900 AU.
F: Men what, det er langt væk. Jeg forstår det ikke. Det er jo ikk, det er ikke ...
M: Det er ikke hvad.
F: Jeg forstår det ikke, det er jo ikke nok til altså ... hva' bliver dens ... hvaddethedder, dens magnitude for sådan noget, det burde jo gerne være det samme som solen eller hvad.
M: Eh, nej, det er ikke sikkert. Kan du ikke selv regne det ud, eller hvad, F? Q7
F: Men hvordan finder vi så ud af hvad dens overfladetemperatur er? Nå, det er ... her.

M: Ehm, (læser): “Hvad er dens atmosfæriske tryk?”. Jeg siger, prøv hør, atmosfæren, ikk’, “består af 69% nitrogen og 30% oxygen. 0.04% CO2 og resten neon”, og så har jeg sagt at “det atmosfæriske tryk er 5% større end jordens“. Så den er altså lidt mere “thick”. How does that sound? Q6.2
(Stilhed)
M: Hallo, hallo, hallo?
F: Hvad siger du?
N: Det lyder meget godt.
M: Fordi, så er det også sådan når den har mindre tyngdekraft, så skal den også kunne holde fast på atmosfæren, så den skal være lidt mere ... lidt mere, hvis den nu ikke kan holde fast på det hele, det alt sammen. Q5.3
F: Overfladetemperaturen af den, hvad var det? Q7
M: Hvordan ser overfladen ud. Okay, N., har du skrevet nogen ting til den? Q8
N: Ja, jeg har her.
M: Ja, nice. ... læser “Vores planets geografiske opbygning er meget forskellig. Den har både høje klipper, da tyngdekraften er ... kan de blive 0, ... Er det virkelig sådan? Kan man sige det? At de kan blive ... sådan ... eller er der et regnestykke til det? Q8.2, Q5.3
F: Det ved jeg faktisk ikke, men det er lidt sådan min hjerne tænkte.
M: Ja ...
N: Men altså, det kunne da godt være, hvis jeg bliver hevet i halvt så meget, så kan jeg jo nå dobbelt så langt.
M: Mm. Ikke nødvendigvis. Det er fordi du er ... det kommer an på hvad du er lavet af jo.
N: Menneske.
M: (griner) .. du skal jo ... dine knogler, det er jo ikke sikkert at de kan blive ...
N: Nej, men lad os sige at jeg løber en tur, der er ikke nogen vindmodstand. Så lige pludselig, så er der modstand, så kan jeg jo ikke løbe lige så langt.
M: nej nej, men det er jo ikke sikkert at det er lige præcist 0,25 gange ... det var bare det jeg prøve at sige.
N: Nej, det er rigtigt.
M: Ehm ...
N: Og Mount Everest er nok ikke det højeste, der kunne nok godt være noget større.
M: Ja.
N: Eller det er der ...
M: (læser) “Forandrer overfladen sig med tiden?”
N: Jeg siger ja fordi ... eroderinger er inevitable.
M: Okay
N: hvis vi skal regnes, så bliver jeg nødt til at ændre det. Men så skal jeg lige til at skrive, ikk’ - at der ikke er noget tidevand, fordi der ikke er nogen måne.
F: Hvad er afstanden, der er 900 gange ...
M: Ja ... vi har ... åh: “Regner det med syre eller diamanter?” Q6.5
N: Aj, vi behøver ikke, det skal være habitable, så det skal bare være sådan du ved ... vind.
M: Kan det ikke regne med .... Kan det ikke regne med sådan ... aj, kan vi ikke sige at der er sådan nogle organiske, der er sådan nogle dyr, ikk’, som lever oppe i skyerne, som ... og det er sådan nogle plante-agtige dyr, som producerer sådan noget juice, så det regner med juice. Q6.5.1

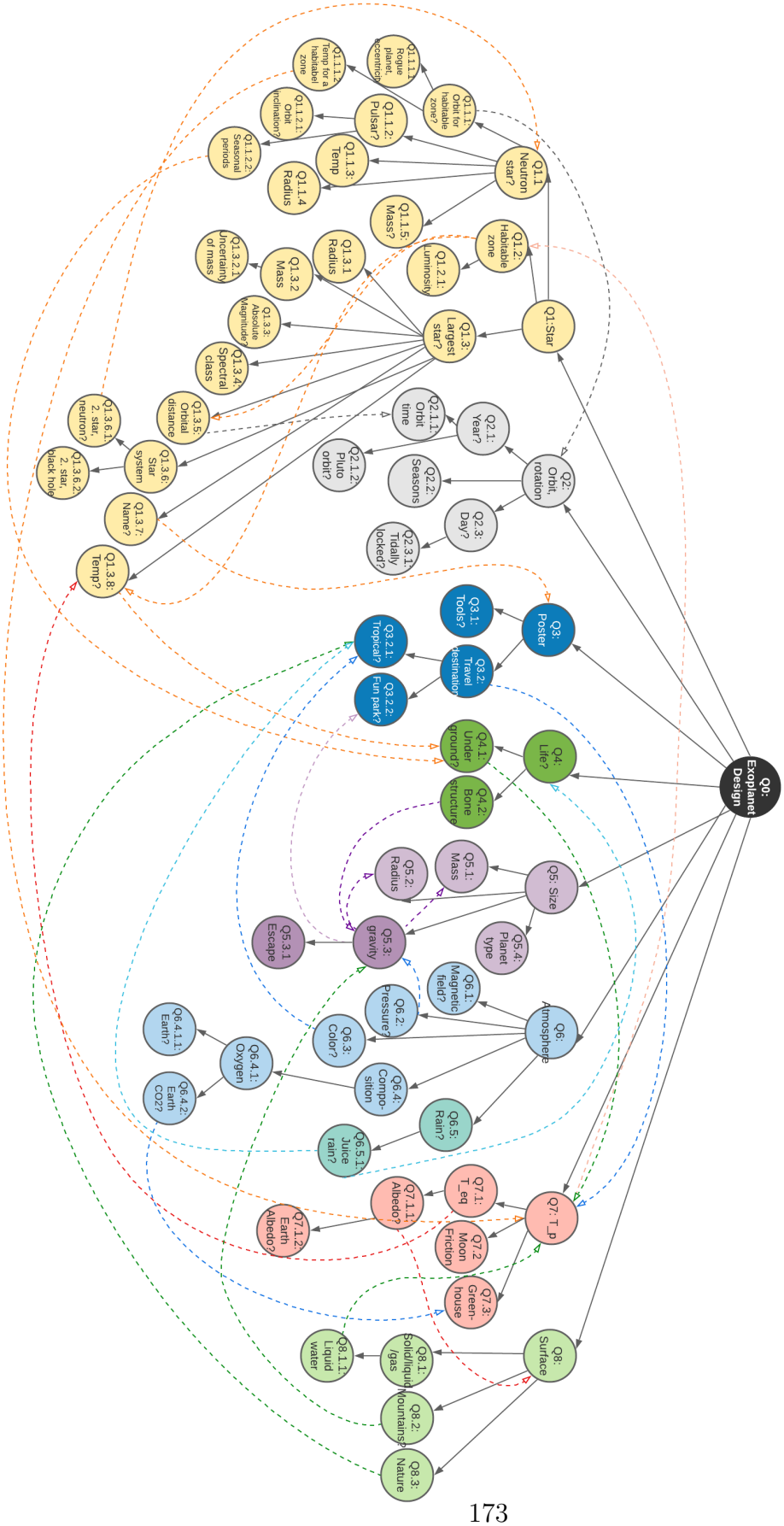
(Let grin)
N: Det skulle være realistisk mand, men fair nok.
M: Ah okay, fair nok.
F: hehe.
M: Hvem siger at det ikke er realistisk?
(Der grines)
M: Det er jo bare lige tropical paradise, ikk', så hvis du vil ... så hvis du vil have, så sidder du der på stranden og så begynder det at regne, så kan du bare tage din drink kop ud. Q3.2.1
N: (griner)
F: Jeg ved ikke, N. vil du lige ... vil du lige regne den her om ... nå, ja åh, okay, har du regnet den ud? Ja, okay.
N: Det har jeg gjort, mand. En chiller.
F: Ved I hvad vores verdens temperatur er?
M: Verdens temperatur?
F: Heh, overfladefladetemperaturen er 1 kelvin! Q1.3.1,
M: øøøøh. Q7
F: Nej!
M: No
N: Uuuuh ...
M: Nono nono no. Is that true? ... Aj, det kan ikke .. nej, det kan ikke passe, F.. Det kan ikke passe.
F: Nå, det er stjernens radius, jeg ved ikke lige ... ehm, jo jo, det er rigtigt nok, stjernens radius. Q1.3.1
M: Det kan ikke passe, det kan ikke passe, det kan ikke passe at den er 0,1 Kelvin!
F: Jo!
M: Det er næsten absolute zero. Så meget kan den ikke ... så tæt på det kan den ikke være.
F: Nej, så kan det godt være at den ... så regner vi jo ikke med ... alt muligt for alle mulige andre stjerner og sådan noget ...
M: Nej nej, men så tæt på, det kan ikke ... det kan den simpelt hen ikke. Det tror jeg ikke på.
F (Markerer formlen/udregningen)
M: Er den det? Hvad nu hvis du satte den til 500 Q1.3.5
Astronomiske enheder? Hvad ville det så være? Fordi, det er altså ret meget tættere på.
F: Men er en astronomisk enhed ikke 150 gange 10^9 meter?
M: Eh ... det ... jo, sikkert. Jeg tænker ...
F: Prøv at regne denne her ud nu, N.
N: Hvor henne?
F: Den er samme sted.
N: Den er ikke lige opdateret for mig, så jeg venter lige.
F: Nå, ja.
(Alle arbejder lidt i stilhed)
F: Albedo, det skal vel være ... Q7.1.1
(Lidt mere arbejde)
M: Så! Nu regner det med juice. Jeg har en god forklaring.
N: Hvad for en juice, though?

M: Det regner med juice, som har en ... hvad for en smag? Hvad er jeres yndlingsjuice? Q6.5.1
N: Appelsinjuice.
M: ... som har en appelsin ...
N: Vi kunne også godt gøre det multifrugt, fordi det ...
F: Hvad er temperaturen? Q7
N: ... er alle juicer. Alle frugterne på planeten, der ...
M: ... okay, ja, ... multifrugt ... juice ... smag (skriver) ... "Hvor lang er en dag?" ... ehm ... "Vores" ... vil vi gerne have ... kan vi ikke have en dobbelt så lang dag? Fordi så er der både mere tid til at nyde den når det er dag, og mere tid til at nyde den når det er nat. Q2.3
F: Jeg forstår det ikke, der er et eller andet galt med den der temperatur. Q7.1
M: Jeg tror heller ikke at det er 0,1 kelvin. Kan vi ikke bare sige at det er ... sådan ... at vi siger at det ca. er sådan ... et eller andet ... noget der minder om Jordens.
F: Men vi skal jo regne det ud jo!
M: Er det det der står i den første?
F: Det står der.
M: Okay. Ehm ... hvad hvis du ændrer en af faktorerne.
F: Hvis jeg sætter et gange tegn der og hvis jeg sætter et gange tegn der ... prøv at regne den ud igen.
M: ... jeg kan ikke ... (læser) "Hvor varmt eller kold er der ... stjernens temperatur" ... prøv at sætte afstanden ned til ... Jamen, jeg tror bare at hvis det er sådan noget som 100 ... altså ... Q7.1
F: Majoris ... habitable zone ... Q1.2
(Længere pause, ca. 1 minut, hvor de hver især arbejder)
M: Her står der ... jeg skal lige se her ... Åh, vent ...
F: Hvad skal afstanden være i?
M: Afstanden? I meter.
F: Ja, men den er også i meter ...
M: Ja, men altså ... der står bare her, "for VY Canis Majoris the habitable zone is between roughly 600 and 1200 AU". Så prøv at sæt os ... hvis du nu sætter ... et eller andet ... sæt os ... sæt os ... i stedet for ... ja, sæt os 500 lysår væk, hvad giver det så?
F: Lysår?
M: Nej, ikke lysår, ups ... jeg mente ...
F: AU
M: Ja (griner), lysår, det ville ikke hjælpe noget ... hvad giver det, hvis du gør det?
F: Prøv at regne ... altså, prøv at trykke ctrl-B på den.
M: Det kan jeg ikke.
F: N.
N: Jo. Hvad for en. Den samme?
F: Ja, den samme.
M: Hvad giver det?
N: 0.25.
M: 0.25. Er det kelvin?
N: Ja
M: Prøv at sætte det til 100 AU, hvis det så stadig giver sådan noget lavt, så kan det simpelt hen ikke passe, så er der noget galt. Q1.3.5
F: Det kan det godt, fordi ...

M: aj.
M: Prøv at hør, hvis den ... det kan den ikke.
F: Prøv at se her ... vi siger 50 AU.
M: 50, altså, du vil jo nærmest burn up in ... Prøv hør, skal jeg lige finde space engine og se hvor stort det der er, hvis jeg ... er 50 AU væk.
F: Jeg ændrede den til 50 på ... nej ...
M: Vi skal ind om 5 minutter btw.
N: Jah
F: Prøv at regne den ud igen, N.
N: Hvad hedder det ... den skal lige opdatere ...
M: Men ... F., jeg tror at den der ... det der ... nej, fordi ... nej. Nevermind, faktisk.
F: Jeg tror at en af vores værdier er forkert.
M: (sukker)
F: åååh, det ser ud til at der er for mange nuller på! Den ene af værdierne er der for mange nuller på.
M: Bro ...
F: Nej. Nej, det er der ikke. Det er der ikke.
N: Hvad for en er det du snakker om, det afsnit kan jeg ikke rigtig ...
F: (tæller), 1,2,3 ... 1,2,3 ... 1,2,3 ... nej, der er ikke for mange nuller på ...
M: Okay her ... VY Canis Majoris. Okay. Se her.
N: Candis.
M: Candis ... VY Candis Majoris.
N: Hvad er det for en regnestykke du snakker om?
M: Distance ...
F: Det deroppe ... igen ... den samme som før.
N: Men har du ændret i den?
F: Ja.
N: Fordi den ændrer sig ikke for mig.
M: Okay, den har faktisk nogle planeter her, inde i spillet. Eller ... øh, hvad du ville kalde det for. Ehm, den her, den er ... skal lige se her ... okay, der er en 50 ... ehm ...
F: Jeg forstår ikke hvorfor den giver en temperatur på så lidt ... skal vi ikke prøve at spørge hende om hjælp?
M: Jo. Ved du hvad, det kan faktisk godt passe. Den er bare thick på himlen. Nej, vent, hold on ...
F: Skal jeg ...
M: Jo, vent vent, vent lige, det er fordi ... Canis Majoris, hvad er dens temperatur? Q1.3.8
F: Den er 3 hundrede ... nej, 3400
M: 3400 ... Ja! Det ... den er jo meget ... den er stor, men den lys.., altså, den er ikke så varm. Det kan godt ... det kan godt passe faktisk. Fordi herinde i spillet, ikk', der er en der er 50 AE væk, den har 88 grader.
F: 88.
M: Ja.
F: Jamen hvad ... hvad er dens albedo?
M: Ehm ... Albedo ... det ved jeg ikke, der står bare at greenhouse effekt giver den +51 grader. Q7.3, Q.7
F: Okay, men hvis vi nu siger Jorden f.eks. ikk', prøv lige at regne den der ud igen,

N., hvis du kan.
N: Jeg lukker lige dokumentet og åbner det igen. Det ser ikke ud til at den ændrer sig nemlig.
M: Og den ... okay, den her har en atmospheric pressure på 41 ... det er det jeg siger, greenhouse effekten giver den 51. .. Ehm, så ... Q6.2
N: Prøv lige at kopier det du har skrevet og sæt det ind lige ovenover eller sådan noget ... fordi, den ændrer sig ikke.
M: Den er bare ...
N: Jeg kan stadig ikke se det. (Ændringen i Formlen) ... jeg prøver lige at åbne og lukke igen ...
M: Men til gengæld ... den der er længst væk ... vent, nu skal jeg lige prøve at se ... ja ... det er lidt mærkeligt though ...
M: Ehm ... denne her ... der er bare også en her, ikk' ... den er 600 AU væk, og den har 167 temperatur ...
N: F., det opdaterer ikke ...
M: Nej, det ... det kan godt passe ... nej, F., ved ca. ... her er der faktisk en der minder virkelig meget om jorden her ... okay, så ... 6 ... 700 væk, ikk ... 700 AU væk ... der burde være på minus 200. Faktisk. ... hvorfor det der så siger ... hvorfor den på google så siger det der andet, det er sådan lidt ... ja. Q1.3.5
F: Hvad siger du?
M: Jeg sagde bare at den ... der var en der hvor den bare var 6 .. eller 700 hvad hedder det, astronomiske enheder væk, der havde den minus 200 grader.
F: Det giver et kommatal. Det giver et kommatal, hvis vi sætter 50 lysår væk. Jeg forstår ikke det giver kommatal.
M: 50 lysår? Du mener astronomiske enheder.
F: Astronomiske enheder, ja. ... Jeg hopper ind i General.
— [01:12:19] (Alle vender tilbage til det fælles rum)

F SRP, group 1


Q0: Exoplanet Design
Q1:Star
Q1.1: Neutron star?
Q1.1.1: Orbit for habitable zone?
Q1.1.1.1: Rogue planet, eccentricity
Q1.1.1.2: Temp for a habitabel zone
Q1.1.2: Pulsar?
Q1.1.2.1: Orbit inclination?
Q1.1.2.2: Seasonal periods
Q1.1.3: Temp
Q1.1.4 Radius
Q1.1.5: Mass?
Q1.2: Habitable zone
Q1.2.1: Luminosity
Q1.3: Largest star?
Q1.3.1 Radius
Q1.3.2 Mass
Q1.3.2.1 Uncertainty of mass
Q1.3.3: Absolute Magnitude?
Q1.3.4: Spectral class
Q1.3.5: Orbital distance
Q1.3.6: Star system
Q1.3.6.1: 2. star, neutron?
Q1.3.6.2: 2. star, black hole
Q1.3.7: Name?
Q1.3.8: Temp?
Q2: Orbit, rotation
Q2.1: Year?
Q2.1.1: Orbit time
Q2.1.2: Pluto orbit?
Q2.2: Seasons
Q2.3: Day?
Q2.3.1: Tidally locked?
Q3: Poster
Q3.1: Tools?
Q3.2: Travel destination
Q3.2.1: Tropical?
Q3.2.2: Fun park?
Q4: Life?
Q4.1: Under ground?
Q4.2: Bone structure
Q5: Size
Q5.1: Mass
Q5.2: Radius
Q5.3: gravity
Q5.3.1 Escape
Q5.4: Planet type
Q6: Atmosphere
Q6.1: Magnetic field?
Q6.2: Pressure?
Q6.3: Color?
Q6.4: Compo-sition
Q6.4.1: Oxygen
Q6.4.1.1: Earth?
Q6.4.2: Earth CO2?
Q6.5: Rain?
Q6.5.1: Juice rain?
Q7: T_p
Q7.1: T_eq
Q7.1.1: Albedo?
Q7.1.2: Earth Albedo?
Q7.2 Moon Friction
Q7.3: Green-house
Q8: Surface
Q8.1: Solid/liquid /gas
Q8.1.1: Liquid water
Q8.2: Mountains
Q8.3: Nature

G Poster Presentation and feedback notes

Group 1:

FMN-577 (Test group).
Star size and temperature like VY canis Majoris.
17 solar masses 3490K.
150 AU away for an okay temperature.
The star is alone.
Eq temp, 289K, 20 C.
Surface temp a bit hotter because of greenhouse effect. Plants and vegetation.
The future of vacation, travel destination.
Lots of mountains and skiing. Water and fun (badeanstalter).
Neon in the atmosphere - blue skær.
69% Nitrogen, 30% Oxygen 0.04 CO2, Neon the rest. Pressure is 5% higher than on earth.
Earth Radius, 0.75 mass, so smaller surface density.
Mountains and trees are higher.
Tropical environment, raining with juice.
1 earth day. Year ... 540 earth years.
Used space engine for the image.
–
Feedback: star temperature is lower than the sun, but distance is 150 AU, how come?
Answer: Because the radius is ridiculously large, 988 mil km
Feedback: Cool with the atmosphere. planet size same as earth, but less mass, how can it have a lower mass?
Answer: Maybe more surface and less iron core, inside is less dense.

Group 2:

Acies-852A: star 2.5 solar masses, 8000 K temp.
Earth is "frodig", same levevildkår as Earth, distance 2.5 AU from star.
Tidally locked, always the same side. A belt in the middle where there is liquid water and live.
Same density as earth and radius x3. Surface gravity x3.
Greenhouse effect, a bit warmer climate.
Atmosphere: N 71%, O 23%, other gasses to greenhouse, but similar to Earth.
Surface, belt. frodigt bacause one size towards the sun, one side away. Rain forest because of the air circulation, also rain.
Surface as Earth with mountains and sand, liquid water of salty water. Uneven surface on half of the side and dry and even on the side that is towards the sun. Maybe a little life on the warmer side. Maybe seasons depending on the orbital form. Maybe life could live in the few months where it was hot enough on the colder side.
Orbital period is about 3 times Earth, have not calculated (Keplers).
Feedback: Tidally locked, how can that be? Whick planet in our solar system has it?
Answer: Mercury.
F: Yes and how is the surface?
A: Gold.

F: Yes, and mercury has no atmosphere. But will an atmosphere influence this?
A: High pressure on the hot side and low pressure on the cold, so there will be atmospheric turbulance / circulation in the middle (circulation). Strong winds.
F: Tidally locked. Why?
A: Don't know.
F: Explains gravitational locking as the Moon and Mercury. Do you think that your planet could be locked like this?
A: No, probably too far away.

Group 3:

Bespin: Gas planet. Double star system, 2 solar masses F star, planet revolves around this. M star, 0.2 solar masses.
Distance 275 mill km, 1.8 AU.
F star is 7000 K, M star is 30000 K.
Planet is 9.4 Earth radius and 28 Earth masses, twice the mass and size of Uranus. No surface because gas planet.
Surface gravity 0.4g. Much lower than Earth. Human beings could have n easier time jump around on the floating cities.
Earth-like atmosphere. N, O, CO2, H2O. H2O can be used for drinking.
Cities in a hight that has around 1 atm pressure.
Caramel coffee color from the skies below the cities. Sky is blue above and pink on sunset.
20 C temperature and greenhouse effect that heats up to 28C.
Day is 12 hour long. Year is 1.7 earth year (Distance is 1.8 AU, mass is 28).
Axial tilt is 17 degrees, so there are small seasonal changes.
Feedback: Why are there clouds with caramel and coffee colored clouds.
Answers: Thick clouds because the atmosphere is thicker.
Feedback: White clouds on Earth, so if the atmosphere is the same, the color of the clouds should be the same. Have you considered the orbital form?
A: Not circular all the time because of two planets. But not too eccentric because the other star is small.
F: 1.8 AU ... but it's quote big. What is it called?
A: Hot Jupiter.

Group 4:

Diantara. Planet mass is 24 Earth masses.
Surface gravity 6x earth. Only smaller things on the planet, cannot grow large. Minature form.
Star is 5 times size of the sun and 10.000K.
Planet is 3AU away, so that we can have a temperature about 24 C. Orbital period is 9 years and rotation, length of day is 48 hours. Long day means a larger temperature variations during day and night. Temperature difference will create storms.
Average temp is a bit higher than earth, so we have more clouds and more thunder.
Atmosphere 50% Nitrogen, 30% Oxygen, 20% other compounds. Not too poisonous. normal water rain.
Surface is covered with red stones and water. Even surface due to the large gravity.

Feedback: So planet is 24 times earth mass. Is this a rocky planet or a gas planet then?
A: Rocky.
F: So a really big rocky planet ... but only 6 times surface gravity? Will it be nice to be on?
A: No ...
F: No, I don't think so either. Not tourist friendly. Why are the stones red? What can the planet consist of? Which planet in our solar system is also reddish?
A: Mars.
F: Yes, which compound could make other compounds red?
A: Copper?
F: That would become green ... but Iron. Iron can make rust which would be red. And that could also make the planet more massive.

Group 5:
Filur 80085b: inspired by the filur ice (Danish). Planet mass is $6.01 * 10^2 4$ kg.
Radius is 6527 km.
Distance to the sun is 1.524 AU.
Seasons: Filur has an axial tilt as Earth, so there are seasons. 423 days orbit time.
Star is 1.5 solar masses, 5500 K.
Relatively low atmospheric pressure.
The planetary look is due to vulcanos (red parts), and a large area covered with rust and iron.
Thin atmosphere and low temperature. The tempeature is -50C.
Variation between 138K (-135C) - 300K (20C)
Surface gravity 3.71 m/s^2.
Feedback: 6000 Km radius is Earth like. So what should the mass be to get a higher surface gravity?
A: The higher the mass, the higher the surface gravity.
F: Yes. So if the size is as big as Earth, so what makes it heavier?
A: The iron.
F: Yes. And the atmosphere. Not much, but are there any clouds?
A: No.
F: Makes sense. What could the yellow color be?
A: Maybe some sulfur covering the surface.

Group 6: Dabbler-420:
Planet mass 1.155 Earth mass. Distance 1.3 AU. Radius 1.5 Earth radius.
Density is 1800 kg/m^3.
Orbital period: 391 days.
Surface gravity 5.04 m/s^2, so half of Earth.
Temperature 27 C due to atmosphere.
Exotic water planet. Sulfur on the surface. Blue-yellow color.
Star, Dappler, is 1.5 solar masses, 7500 K, type A star.
Luminosity is 5 solar luminosty. Radius i 1.26 solar radius.
1 day is 30 hours. Year is 391 days.
Two moons, because that would look cool.

No atmosphere. But a little bit sulfur acid in water.
Feedback: A lot of calculations. No atmosphere, but it's a water planet. How can a water be kept on the planet?
A: Not 100% water, a dense core.
F: You said density is 1800 kg/m3, do you remember Earth's density?
A: About 5000 kg/m3, so a our planet's density is a lot smaller.
Therefore surface gravity is also about half.
F: Okay, good. So the liquid water in no atmospheric pressure. How is it Mars?
A: It evaporates.
F: Yes. So how come your planet have water?
A: Maybe the planet is in its early stages. We have a lot of sulfur and therefore no life on the planet and it's just going through the early stages such as Mars before water evaporated.

	Group 1	Group 2	Group 3	Group 4	Group 5	Group 6
Name	FMN-577	Acies-852A	Bespin	Diantara	Filur 80085b	Dabbler-420
Type	Rocky	Super-Earth	Gas	Rocky	Rocky	Water world
M_s	17 M_s	2.5 M_s	2 M_s (and 0.2 M_s)	5 M_s	1.5 M_s	1.5 M_s
R_s	988 mill km					1.26 R_s
T_s	3490K	8000K	7000K F-star (and 3000K M-star)	10.000K	5500K	7500K A-star
System	Single	Single	Double	Single	Single	Single
R_p	1 M_E	3 R_E	9.4 R_E	2 R_E	6527 km	1.5 R_E
M_p	0.75 M_E	1 M_E	28 M_E	24 M_E	$6.01 \cdot 10^2 4$ kg	11.55 M_E
Surface gravity	0.75g	3g	0.4g	6g	3.71 m/s^2	5.04 m/s^2
Orbital distance	150 AU	2.5 AU	275 mil. km / 1.8 AU	9 AU	1.524 AU	1.3 AU
T_p	289K / 20° C	cold and hot side, warm middle	20(−28° C)	A bit higher than on Earth	Avg -50° C (135° C-20° C)	27° C
Greenhouse	Yes, CO_2	Yes	+8° C			Maybe
Surface	Mountains, fresh water, tropical nature	Lush middle belt with mountains, sand, liquid salty water	Gas, no visible surface	Red stones and water. Even surface due to large gravity pull.	Volcanoes, red iron surface in places	Water planet with sulfur, gives it a blue-yellow color
Atm. Pressure	1.05 atm		1 atm		Thin	
Atm. composotion	69% N_2, 30% O_2 0.04 CO_2, rest is Neon	71% N_2, 23% O_2, greenhouse gasses, similar to Earth	Earth-like N_2, O_2, CO_2, H_2O	50% N_2, 30% O_2, 20% other		
Weather	Juice rain	Wind circulations across middle belt, Water rain		Water rain, storms, cloud, thunder due to 48 hours temp. variations		
Year	540 yrs	3x Earth		9 yrs		391 yrs
Day	1 day	Tidally locked	12 hrs	48 hrs		30 days
Seasons			17° tilt	Maybe	Tilt and Earth-like seasons	
Special features	Tropical travel destination, skiing, jumping park	Hot day-side and cold night-side, middle belt with water and possible life	Floating cities above caramel clouds	Due to large gravity, things cannot grow large on the planet. Miniature forms	Looks like a Danish "Filur" ice cream	Plenty of sulfur acid in water makes no life possible, two moons
Poster	Space engine		Hand painted			

Table 2: Keywords from poster presentations from group 1-6

	Group 1	Group 2	Group 3	Group 4	Group 5	Group 6
Feedback and main examples of questions	T_s vs. distance and T_p. What can Earth size planet lower mass?	Why tidally locked? Influence of temperature differences in an atmosphere?	Color of clouds if atmosphere is Earth-like, Orbital eccentricity?	Why can give red stones? How does it fit the high density?	What gives the planet its density and what gives it the yellow color? Are there clouds?	How is water kept on surface with almost no atmosphere? What can make the density so low?

Table 3: Feedback to posters

H Survey after exercise

Var der noget ved øvelsen du særligt godt kunne lide?

1. Jeg kunne godt lide at vi selv kunne lave en planet, og det eneste der var vigtigt at vi kunne begrunde hvorfor planeten er sådan.
2. Det var mega fedt at skulle finde på en planet og så selv design den.
3. Jeg fandt det interessant at lære om planeter ude fra vores system.
4. Nej
5. At man designede sin egen exoplanet og kunne få lov at være kreativ med plakaten
6. 1 At man selv måtte vælge grupper.
   2 At der var matematik involveret.
   3 At det var en Åben opgave"
7. Det var en sjov opgave hvor vi kan selve vælge de forskellige ting en exoplanet kan have.
8. Ja, elsker at vi selv får love til at lave noget kreativt, som fx design vorse egen exoplanet.
9. de dele hvor man skulle tænke logisk frem for at regne
10. Kreativiteten
11. Jeg kunne godt lide at vi fik lov til at sætte vores kreativitet løs, men der var dog nogle krav man skulle forholde sig til. Dette gjorde et mere overskueligt, men på samme tid en sjov opgave
12. Det at vi selv skulle prøve at lave vores planet og danne et miljø, hvor liv kunne leve
13. Ja, men det var den del øvelsen gik ud på hvor at man skulle opfinde eller lave sin egen planet hvilket var en sjov opgave.

14. Jeg kunne godt lide det at vi selv skulle prøve at lave en planet det gjorde så vi fik et bedre indblik i forholdne mellem en sol og planet
15. vi fik lov til at lave vores eje planet og skal tænke over meget de beslutninger påvirke planten på
16. ja, der, hvor vi skulle snakke sammen med de forskellige elever fra klassen.
17. Jeg syntes det var sjovt at være kreativ og selv finde på de opgaver vi skulle løse.
18. At vi skulle være meget kreative men samt bruge noget teori til at lave vores egen exoplanet
19. Jeg kunne godt lide kreativiteten ved opgaven. Altså at også havde meget frie hænder
20. exoplanet
21. Ja, synes det var spændene og sjovt at finde på sin egen planet
22. Jeg kunne godt lide konceptet om at designe en planet, det er derfor at jeg meget godt kan lide "Universe Sandbox" da man kan lave hvad man vil derinde.

Var der noget du/I synes at I manglede?

1. Der var ret meget man skulle finde ud af på en meget kort tid, så det ville enten være mere tid eller en bestemt ting man skulle finde ved en planet.
2. Mere tid, det ville være fedt at kunne gå mere i dybden med tallene så det kunne give 100% mening. Tage/designe mega cool billeder.
3. Ud over at det nok ville havde været bedre hvis vi var i skolen så nej.
4. Lidt mere tid
5. Måske en liste med realistiske værdier for planten (masse, radius, temperatur) osv. for de forskellige typer af planeter, så man havde noget at gå ud efter
6. Ik rigtig
7. ikke rigtig fordi det var mest op til os, om hvordan vil vi lave vores eget planet
8. Mangelde ikke meget. Men det kunne være sjovt med en stor projet som Design.
9. næh
10. Mere tid
11. Jeg kan ikke rigtig komme i tanke om noget
12. Det kunne være fedt hvis vi havde et program man kunne bruge, som ville være gratis, og som vi kunne bruget til at lave planeten visuelt. Der findes programmer, men de nok rimelige dyre
13. ikke rigtigt

14. Nej syntes ikke der var noget der manglede
15. nej
16. ikke noget nej
17. Vi manglede nogle informationer om hvor langt væk planeten skulle være fra dens stjerne.
18. Vi manglende nogle informationer om hvor langt væk vores planet skulle være fra stjernen
19. det er måske friheden der også kan blive for meget, altså måske også lave nogle begrænsninger
20. nej ikke rigtigt
21. nej
22. At gå i dybden, men det er forståeligt.

Var der noget du/I syntes var svært?

1. Med tiden vi havde var det lidt svært.
2. Forstå Albedo. Jeg havde aldrig hørt om det før.
3. De nye formler tog lidt til at lære. Var ikke det nemmeste at bruge dem i regnestykkerne.
4. At komme på alle de forskellige dele, og få dem til at stemme overens med hinanden
6. Ik rigtig
8. Ja, det var svært at finde ude af alle de ting som en planet indeholder. Det svært at huske på alle variabler som hænger sammen, og det var svært at finde ude af alle de ting som en planet indeholder. Det svært at huske på alle variabler som hænger sammen, og de har en betydning.
9. enhederne til formlerne
10. Beregningerne
11. Nogle af formlerne kunne godt være lidt forvirrende at sætte sig ind i, for de skulle også give mening ift. alt det andet man har sagt at planeten skulle bestå af, have eller hvad der foregår på planeten
12. At bruge formlerne, og vide hvad man skulle gøre for justere forholdene på exoplaneterne
13. måske at regne på de forskellige størrelser der skulle være realistiske.
14. Nej
15. nope

16. ikke noget nej
17. Beregningerne.
18. Beregningerne
20. ikke rigtigt
21. Nej
22. Ikke rigtigt.

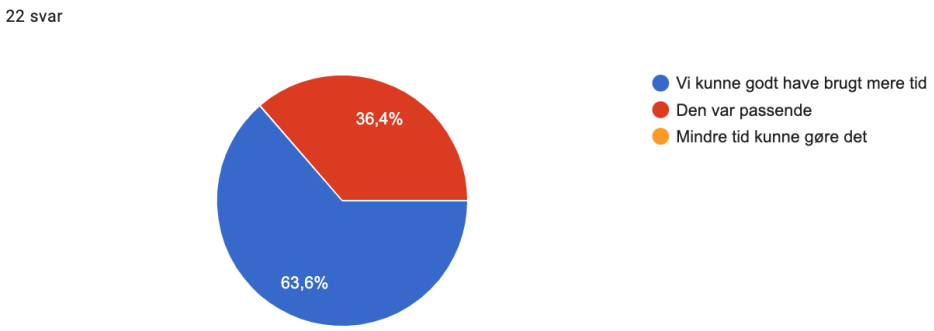


Figure 32: Did you find the amount of time fitting? We could have used more time / it was okay / less time could have worked

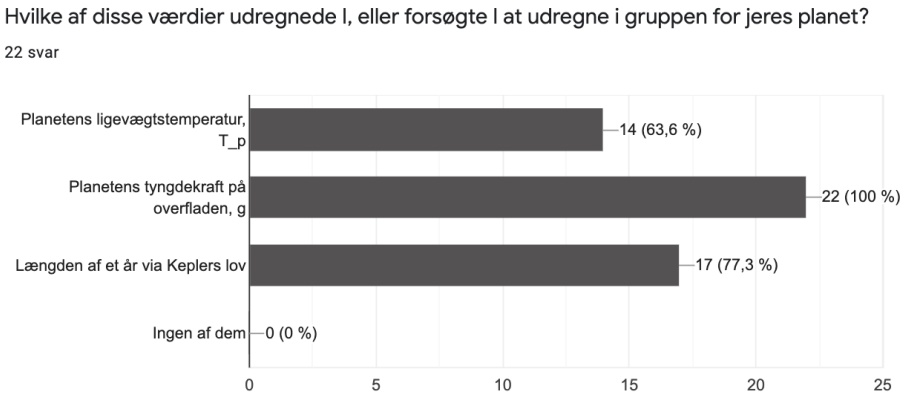


Figure 33: Which of these values did you calculate? 1) The equilibrium temperature, 2) Surface gravity, 3) Length of the year with Kepler's law, 4) none of them

Har du evt. kommentarer til jeres udregninger?

1. Nej.
2. Vi kunne ikke lige finde ud af det til at starte med, men vi skulle lige lave komma til punktum osv.

3. Det kan være lidt besværgeligt når man er usikker på hvilke tal man arbejder med.
4. Nej, det syntes vi ikke var nødvendigt
5. De var komplicerede og der manglede lidt hvilke enheder vi skulle bruge i formlerne.
9. næh
10. Kunne være fedt at blive undervist lidt i dem først
12. De var nok ikke helt rigtige, men de var svære at bruge som sagt
13. nej
14. Nej
17. ja
18. Nej
19. Ikke rigtigt.

Havde I andre overvejelser, end dem der var angivet i opgaven, og hvis ja, hvilke?

- Vi kiggede meget på hvorfor planeten har den farve vi gav den.
- Ja, om vi kunne udregne den habitale zone omrking vores stjerne. Med det, kunne vi så regne alt mulig andet. Dog fik vi informationen fra internettet.
- Ikke rigtigt.
- Det tror jeg ikke
- Nej ikke rigtigt
- nej
- Nej vi fulgte opgave beskrivelsen
- vi tænkte på en gas og klippe planet
- Vi prøvede f.eks. at udregne stjernens habitabile zone, men udregningen gik lidt forkert.
- tror ikke jeg havde, kan ikke huske det
- nej, synes det ville være bedre med mere tid
- Om det var muligt at have syre regn.

Brugte I, eller forsøgte I at bruge, andre formler, end dem der var angivet i opgaven? (og hvis ja, hvilke og til hvad?)

- Det gjorde vi ikke, for vi troede at det kun var det vi skulle lave.

- Ikke rigtigt.
- F=m*a Det var nogenlunde det tror jeg
- tror jeg ikke
- Ikke umiddelbart
- Nej vi havde ikke ligefrem mod på det. :-)
- ja men kan ikke lige huske dem
- Vi brugte nogle som vi fandt på nettet
- nej
- ja den for den habitabile zone
- ja det gjord jeg
- Nej
- Vi brugte en metode til at finde ud af hvad ligevægtstemperaturen på planeten ville være.

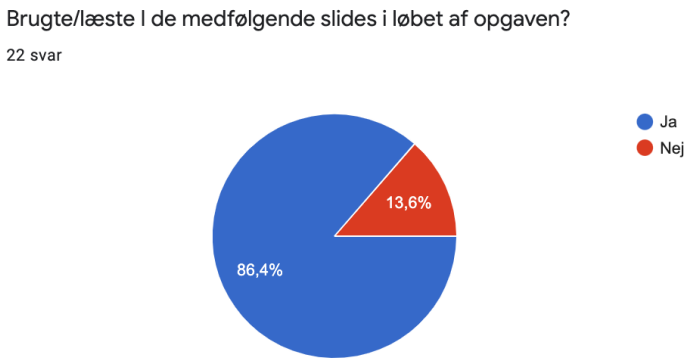


Figure 34: Did you use/read the slides?

Hvilke(t) program(mer) eller redskab(er) brugte I til at lave jeres poster?

- Vi brugte microsoft paint.
- Vi benyttede os af space engine til at lave planeten og tage billedet. Photoshop til at colorgrade og skrive tekst.
- Kan ikke huske det.
- Ingen idé
- Jeg tegnede og malede den i hånden (det var vildt sjovt)
- papir og akvarelfarver

- pixlr.com
- Photoshop, google, inspiration fra NASA plackter.
- power point
- Photoshop
- Vi tegnede det i fri hånd på et stykke papir.
- Google drawing
- ved jeg ikke da jeg ikke lavede den, men det var nok photo shop.
- paint
- https://lommeregneren.dk/ photoshop og word
- Photoshop
- Vi brugte google drawings
- Google drawing
- Vi brugte photoshop og space-engine
- paint
- Ved det ikke, jeg lavet ikke posteren i min gruppe
- Photoshop.

Har du andre kommentarer?

- Nej.
- Det var et super fedt forløb!
- Nej.
- :D

- Det var en supersjov opgave og den side fra NASA, hvor man kunne “besøge” exoplaneter, var ret fed at klikke rundt på.
- Star Wars episode 7, 8 og 9 er ikke canon
- næh
- Håber du fik de svar du havde brug for
- nej
- Nej
- nej
- Nej
- nej
- Nej.

I Improved Exoplanet Design package, high school

Improved student guide

Exoplanet Design

Create your own world!

Classroom Activity

Material List:

- Drawing tools: Either digital or pen and paper
- Access to internet or books

Outline

Welcome to the future! Tired of staying home? Travel the galaxy! Create your own new world for leisure holiday and new adventures.

No matter where you go in the Universe, you cannot escape the rules of physics. Therefore: learn as much as you can about the physics behind exoplanets and their host stars, and then use your creativity to design your own exoplanet in groups. Finally, you present your planet and hear about other creations.

As an extra thought, you can consider what kind life could live on these planets and how they could adapt to (perhaps extreme) conditions of the planet. Could humans have evolved to survive on the planet?

Procedure:

Work in groups of 3-5.

1. **Gather inspiration**

   - Look at example travel posters for real exoplanets at https://exoplanets.nasa.gov/alien-worlds/exoplanet-travel-bureau/ and explore the surface of some of the planets. This is what your end product could look like.

   - Visit NASAs interactive "Eyes on exoplanets": https://eyes.nasa.gov/apps/exo You can "Filter by planet type", where you can view planet, system and star or you can choose "Browse planets" in the top menu.

   - Use the presentation for further explanations, examples and inspiration.

2. Property of the star

The properties of the host star, and the orbital distance to it, are essential for conditions of your planet, especially for the planet surface temperature, and hence the habitability. Consider the following star properties:

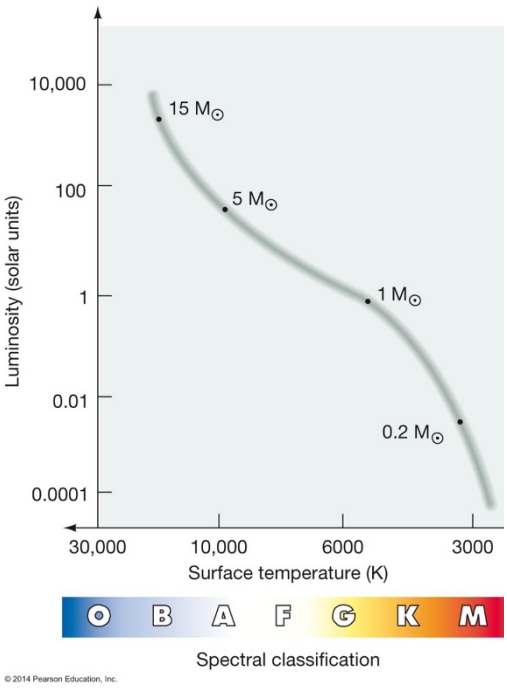
a. The surface temperature of the star, $\boldsymbol{T_s}$. Use Kelvin as units. Note, that the more massive your star is, the higher temperature it will have. You can find examples for the connection and values for the temperature, mass and spectral classes of stars in the figure below.

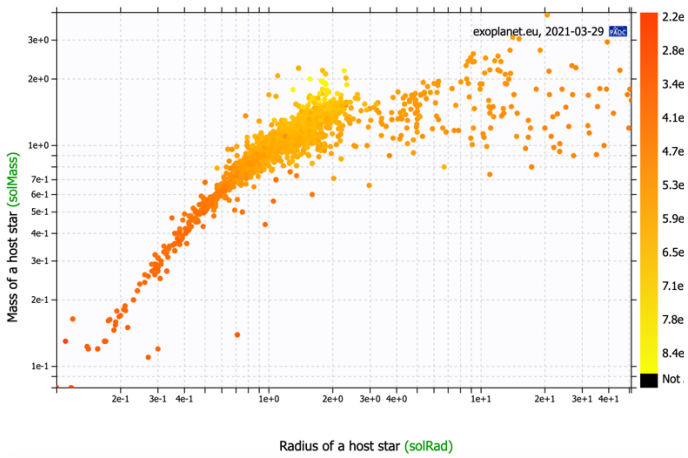
b. The mass of the star in solar masses, $\boldsymbol{M_s}$, based on the temperature and the HR-diagram below.

c. The radius of the star, $\boldsymbol{R_s}$ in km. First, find the approximate value in solar units from the plot below or using exoplanet.eu/diagrams, then calculate it in meters. You can also use astro.unl.edu/mobile/HRdiagram/HRdiagramStable.html to see relation between stellar temperature and radius.

d. The average orbital distance, $\boldsymbol{a}$, from the star to the planet. Find this distance in both AU and km, where 1AU is the average distance from Earth to the Sun and approximately ~ 150 million km.

(extra) Is it a single star or a double or triple system? (Like the Alpha Centauri system). We won't use this in our calculations, but it's important to note that many stars out there are double systems, and it might affect the orbit and habitability of the planet, not to mention the view. A planet usually revolves around one of the stars, but it is also possible for a planet to revolve about both.





HR diagram (©2005 pearson prentice hall inc) and radius-mass relation between stars (exoplanet.eu).

3. Find the surface temperature of your planet

You will need the star properties from the previous part for this.

a. First, calculate or estimate the equilibrium temperature of the planet. This is roughly given by the equation below. Use the values you have found above, and for now set the albedo, $\boldsymbol{A_B = 0}$. We will return to this value in part 5.
Use the same units for R_s and a.

$$T_{eq} = T_s\,(1 - A_B)^{1/4}\sqrt{R_s/2a} =$$

Even if you don't calculate the exact value, the equation tells us that:

i. The lager the radius and temperature of the star, the higher temperature we get on our planet
ii. The larger the orbital distance is to the star, the lower the planet temperature

b. A greenhouse effect can raise the temperature. We will consider this in part 6.

c. A habitable planet has a temperature in the range of 0-100C. Is your planet habitable? Play with the values above or find another for why or how it could still be a travel destination.

4. Type of planet:

a. Is your planet Terrestrial, a Super Earth, Neptune-like or a gas giant?
b. What is its size in Earth radius? (e.g. 0.5 R_E for a planet half the size of Earth)
c. What is the mass in Earth masses? (e.g. 2 M_E for a planet twice as massive as Earth)
d. Find from these values the surface gravity of your planet, relative to Earth:

$$g_{relative} = \frac{M_p}{R_p^2} =$$

When we use relative values, we call the gravity on Earth for 1g. Your relative value will then be given in units of g. An example from the above you would get:
Example: $g_{relative} = \frac{M_p}{R_p^2} = \frac{2M}{(0.5\,R)^2} = 8g$ - 8 times the gravity of Earth.

(extra) You could consider what density your planet would have with those values and why.

5. Planet surface

a. Is the surface solid, liquid or gas?
b. Does it have lakes, is it even or is it filled with mountains?

From the type of surface, you can try to deduct the ratio of light reflected by the planet. This is the albedo, A_B, which can have a value of 0-1, and is used for the equilibrium temperature in part 2: the higher the value, the more light the planet reflects back and the colder it will be. You can refine your calculation of T_{eq}.

(extra) You might also consider if the surface changes over time. Are there any tectonic plates or volcanoes?

6. The atmosphere and weather

a. Does your planet have an atmosphere?
b. What is the atmospheric pressure? Is it relatively thin or thick compared to Earth?
c. What does your atmosphere consist of?
d. Are there any greenhouse gasses such as CO_2, CH_4, and other more complex molecules? (use this to explain a possibly higher surface temperature in part 2)
e. How is the weather? Are there cloud formations and is there rain, perhaps with diamonds or acid? Are there any storms?

(extra) Does your planet have a magnetic field and why? (it helps keeping the atmosphere, although it is not crucial – compare with Venus, Earth and Mars. Only Earth has a magnetic field)

7. Calendar

a. How long is a year? The year, or orbital period, *T*, depends on the orbital distance, *a* – the further away from the star, the longer the year. You can use Kepler's 3rd law, if you have the orbital distance from previously:

$$T^2 = \frac{a^3}{M_s} =$$

b. How long is a day? How fast does the planet rotate around its own axis? Could it be tidally locked and hence always have one day side and one night side? (such as Mercury)

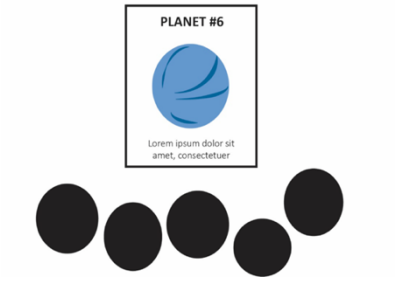
(extra) Are there any seasons? Consider axial tilt and eccentricity. An axial tilt is the reasons for seasonal changes on Earth. If the planet has a very eccentric orbit, this could also result in seasons, which is the case on Mars, while Earth's orbit is too circular to influence.

8. Poster

Create a poster with your planet as a travel destination as seen on NASAs page. Be as creative as you like with physics as your framework. Also, name your planet.

Assessment:

Present your poser and planet for the rest of the class. Receive and give feedback.



Further Resources/Activities:

- This activity can be related further to other subjects:
  - Biology: Consider what kind of life there could evolve on your or any of other groups planet. Life on Earth has evolved to adapt to its conditions. How would life look, if it were to adapt to different, perhaps more extreme (from our point of view), conditions?
  - Geology: Consider how the planetary structure and surface could have evolved over time by comparing with the geological evolution of Earth.
  - Design and communication: Refine your poster, create a story setting, an travel agency ad, or a poster for the life form.

Improved teacher guide

Exoplanet Design

Create your own world!

Classroom Activity

Overview

Age Range:

High school (15-18)

Prep. Time:

15 mins

Lesson Time:

2x 1,5 hours

Cost per activity:

Little or none

Includes the use of:

Computer with internet
+ digital or real drawing tools

Outline

Students will learn about exoplanets. Working together in groups to design their own planets, using both physics and their imagination to decide on what sort of conditions would be present.

They will then practise their presentation skills, explaining what they have created to the rest of the class.

Pupils will Learn:

- Exoplanets have a diverse range of conditions, based on a range of factors.
- How the host star, the planetary system and some planetary properties will influence the conditions and the physics behind.

Lesson Plan:

Overview of the time required to complete lesson.

Description	Time	Notes
Day 1: Introduction to exoplanets	20-30 min	Use ExoplanetPresentatin.pdf
Day 1: Exoplanet design	1 hour	Students work in groups to design their exoplanet conditions

The online observatory collaboration consists of the following partners:
Baldone Observatory, Brorfelde Observatory, Cardiff University, Harestua Solar Observatory, Helsinki Observatory

Day 2: Poster design	30 min	Students work in groups to design their exoplanet travel poster
Day 2: Presentations and Assessment	1 hour	Poster presentation from each group and feedback.

Introduction to the subject:

Use the Presentation to introduce the students to the subject.

The presentation can also be used as a resource for the students if time is sparse, so that only a few main points are presented, and the students get more time for the exercise itself.

Show a quick example on how to use https://eyes.nasa.gov/apps/exo as a resource.

Day 1:

- Divide into groups of 3-6 students

If the activity is done by hand, provide each group with the materials required to make a poster. It can also be done digital, if the students wish to and have access to some software (such as Photoshop, GIMP, MS paint, Space Engine, Canva.com or other).

Tell the groups to design their own exoplanet following their student guide, which includes:

1. Gathering inspiration from NASAs travel posters and Interactive Eye program (part 1).
2. Using physics and imagination to plan the exoplanet properties (part 2-7).

The exercise has many factors to consider, and the students might want more time. Either they must prioritize what to consider, or it can be a home assignment to finish up the planet design.

Day 2:

3. Start the day by letting the groups finish up the assignment with a poster to present the planet as a travel destination (part 8).
4. Time to present the poster. Let each group present, and prepare a few questions for each of them, as described in the assessment.

Assessment:

Examples of questions for the students to consider when giving feedback:

- Why does your planet have the density that it has? Consider its elements and structure (core and layers)
- Why does your planets have the surface colors that it has? Which elements or processes could have caused it?

- Does your orbital distance, star mass, temperature, radius, and planet surface temperatures make sense?
- Is the planet habitable for humans as we are? Or how could we adapt over the years?
- Are there seasons on your planet and what causes them?
- Could this planet be discovered and observed from Earth and how?

Further Activities:

This project could be part of an interdisciplinary project with either biology (with focus on evolution of life on Earth and how life on the designed planet could possibly evolve), geology (with focus on the planet structure, and the surface evolution), and design and communication (with more focus on the poster and presentation).

Background Material/Knowledge:

Students are expected to know the planets in our solar system, about other stars and the main sequence, and know Kepler's third law.

EXOPLANET DESIGN

CREATE YOUR OWN WORLD

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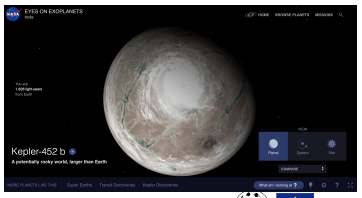
INTRODUCTION

What you will learn:

- Exoplanets have a diverse range of conditions, based on a range of factors.
- Some of the physics behind those conditions.

An exoplanet is a planet outside our solar system (orbiting another star).

- We have found thousands of such planets through different methods, e.g. transit method, radial velocity (wobble), microlensing and direct images.
- Some of these planets could have conditions for possible life.
- Use NASAs visualisation app online discover different exoplanets: eyes.nasa.gov/apps/exo - click on individual stars to see their system and planet(s) or choose "Browse planets".



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INTRODUCTION

I.3 Improved presentation

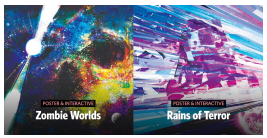
What you will need:

- Drawing tools: Either digital or pen and paper
- Access to internet or books

Welcome to the future, where it's possible to travel the galaxy. What other worlds are out there? In this exercise, you will learn about the physics of exoplanets and create your own new world based on physics and imagination. You will then create a travel poster for your destination.

Check NASAs Exoplanet Travel Posters for inspiration on planets and their possible surface.

Halloween version



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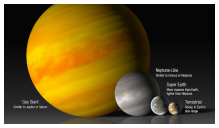
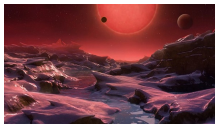
DAY 1

ON THE FOLLOWING PAGES YOU WILL LEARN ABOUT SOME OF THE CONSIDERATIONS BEHIND EXOPLANET CONDITIONS AND THE PHYSICS BEHIND.

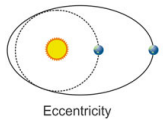
THE HOST STAR AND ITS INFLUENCE ON PLANET TEMPERATURE



PLANET TYPE, SIZE AND SURFACE GRAVITY



PLANET SURFACE AND ATMOSPHERE



PLANET "CALENDAR"

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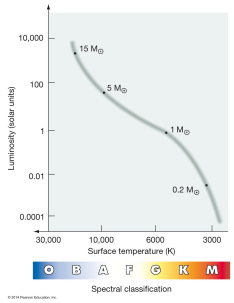
HOST STAR

Which kind of star does the planet orbit around and in which distance? This will have essentially influence the planet temperature and surface.



HR diagram ©2005 Pearson Prentice Hall inc

Considerations:

- What is the mass of the star, M_s? [solar masses]
- What is the surface temperature of the star, T_s? [K]
- What is the radius of the star, R_s? [km]
- What is the orbital distance, a? [AU and km]

You will need **T_s**, **R_s** and **a** to calculate the surface temperature of the planet and **M_s** to find the orbital period ("year"). **T, R and M are not independent of each other**!

Single star or part of a double or tripple system? Cool sunsets?

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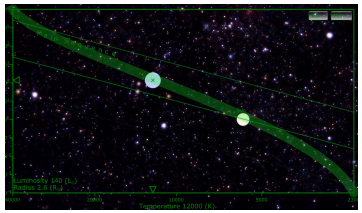
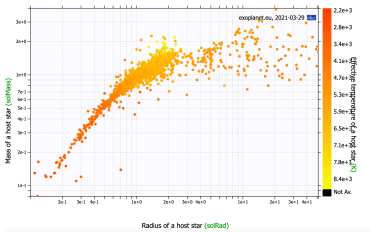
HOST STAR

Tools for finding relations between star temperature, radius and mass,

Interactive HR-diagram: https://astro.unl.edu/mobile/HRdiagram/HRdiagramStable.html
Use it to find a relation between temperature and radius for your star.

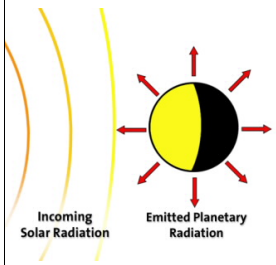


For host star mass and radius relations, use: http://exoplanet.eu/diagrams/ or see example plot here (also included in the exercise):



PLANET EQULIBRIUM TEMPERATURE

The planetary equilibrium temperature is a theoretical temperature that a planet would have if it was a black body being heated only by its star.



$$T_{eq} = T_s(1 - A_B)^{1/4}\sqrt{R_s/2a}$$

- T_{eq}: Planetens equilibrium temperature
- T_s: Star temperature - T_{eq} is directly proportional with T_s
- R_s: Star radius - T_{eq} is square root proportional with R_s
- a: Orbital distance - T_{eq} is inversely proportional with square root of distance, a

- A_B: Albedo - how much light does the planeten reflekt, value between 0 and 1.
  0: all light will be absorbed by the planet (planet will get maximum heat from star)
  1: all light will be reflected, e.g. none of the heat from the star will warm the planet

The albedo is strongly dependent on the material, hence the surface composition of the planet.

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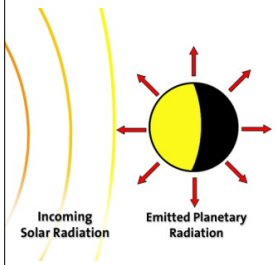
PLANET EQULIBRIUM TEMPERATURE

Background knowledge: How is this temperature derived? For students, who have learned about luminosity of stars.



We define the equilibrium temperature as the temperature at which absorbed power of the planet equals radiated power from the planet.

Black body radiation from the star: $L_* = 4\pi R_*^2 \sigma T^4$

$$P_{abs} = P_{rad} \quad \Rightarrow$$

$$\frac{L_* R_p^2}{4a^2} \overbrace{(1 - A_B)}^{\text{Absorbed fraction}} = \overbrace{4\pi R_p^2}^{\text{Surface Area}} \overbrace{\sigma T_{eq}^4}^{\text{Flux}} \quad \Rightarrow$$

$$T_{eq} = \left(\frac{L_*}{16\pi\sigma a^2}(1 - A_B)\right)^{1/4} \quad \Rightarrow$$

$$T_{eq} = \left(\frac{4\pi R_*^2 \sigma T^4}{16\pi\sigma a^2}(1 - A_B)\right)^{1/4} \quad \Rightarrow$$

$$T_{eq} = T_*(1 - A_B)^{1/4}\sqrt{R_s/2a}$$

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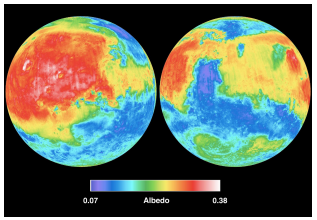
AIBEDO EXAMPLES

The planetary equilibrium temperature is a theoretical temperature that a planet would have if it was a black body being heated only by its star.



Mars Albedo. jpl.nasa.gov/images/mars-albedo

Surface	Typical albedo
Fresh asphalt	0.04[5]
Open ocean	0.06[6]
Worn asphalt	0.12[5]
Conifer forest (Summer)	0.08[7] 0.09 to 0.15[8]
Deciduous forest	0.15 to 0.18[8]
Bare soil	0.17[9]
Green grass	0.25[9]
Desert sand	0.40[10]
New concrete	0.55[9]
Ocean ice	0.50 to 0.70[9]
Fresh snow	0.80[9]

Planet	Bond Albedo
Mercury	0.088 [25] or 0.068
Venus	0.76 [26] or 0.77
Earth	0.306 [27]
Mars	0.250 [28]
Jupiter	0.503±0.012 [29]
Saturn	0.342 [30]
Uranus	0.300 [31]
Neptune	0.290 [32]

https://en.wikipedia.org/wiki/Albedo

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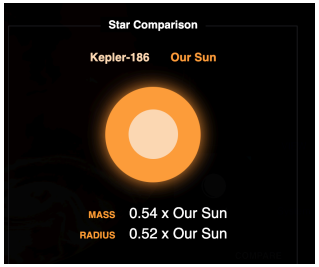
PLANET EQULIBRIUM TEMPERATURE EXAMPLE

Example of the equilibrium temperature calculation.
Case: Kepler-186f https://eyes.nasa.gov/apps/exo/#/planet/Kepler-186_f



T_s = 3000 K (M-star)
R_s = 0.52 R_s = 361,920 km
a = 0.432 AU = 64,626,280 km
A_B = 0.2 (average guess)

$$T_{eq} = T_s(1 - A_B)^{1/4}\sqrt{R_s/2a}$$

$$= 3000K(1 - 0.2)^{1/4}\sqrt{\frac{361920km}{64626280km}} = 212K = -61°C$$

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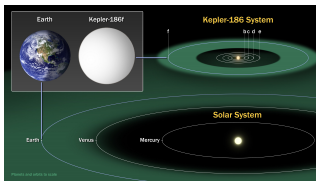
PLANET EQULIBRIUM TEMPERATURE II

The planetary equilibrium temperature is a theoretical temperature that a planet would have if it was a black body being heated only by its star.

$$T_{eq} = T_s(1 - A_B)^{1/4}\sqrt{R_s/2a}$$



- Summary of the equation:

1. A higher star temperature T_s, and radius, R_s, will result in higher temperature on the planet
2. A higher orbital distance, a, will result in lower temperature. Inverse square law meaning that a planet twice the distance will receive 4 times less heat.
3. A higher albedo A_B will give a lower equilibrium temperature

Habitable zone: A planet will be in the habitable zone if liquid water can exist. What temperaures would we need for a habitable planet?

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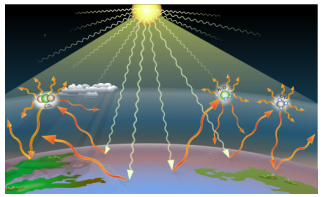
TRUE TEMPERATURE OF THE PLANET

The equilibrium temperature is only hypothetical. What other factors than the star can influence the true temperature on a planet?



- The equilibrium temperature of Earth according to the equation should be 255K (-18 C). **So why is the average temperature much higher?**
- **Green house effect!** Gasses such as CO2 and CH4 will reflect some of the reflected light from the surface back.

We cannot know an exoplanets true temperature and conditions just yet, since we cannot observe the atmosphere of smaller (non Gas-giants) planets.

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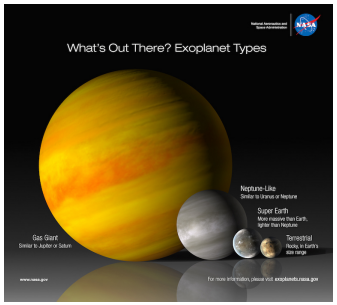
PLANET TYPE AND SIZE

Size and mass of the planet depends on its composition and structure and will influence the surface gravity.



Different types of exoplanets:

- **Terrestrial**: Rocky Earth-like planets or smaller
- **Super Earth**: Large rocky planets, larger than Earth, smaller than Neptune.
- **Neptune-like**: Planets such as Neptune or Uranus
- **Gas Giant**: Enormous gassous planets such as Saturn, Jupiter or larger. Many gas giants has been found very close to their host star in other solar systems. Those are called **Hot Jupiters**.

For this exercise it is easiest to use Earth units for the mass and radius to get relative values. You can also use absolute values in kg or meters.

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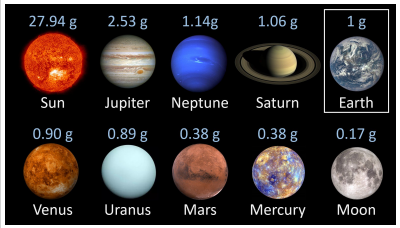
PLANET SURFACE GRAVITY I

What is the surface gravity of the planet? E.g. how much does it pull you down?

In absolute values, the surface gravity is: $g = G\frac{M}{R^2}$

Where $G = 6.674 \cdot 10^{-11} m^3\ kg^{-1} s^{-2}$, mass in [kg] and radius in [m].



g_Earth = 9.8 m/s^2
g_Moon = 1.6 m/s^2
g_Mars = 3.7 m/s^2
g_Jupiter = 25 m/s^2

If we use relative values, then g_relative = 1 for Earth, and the the relative gravity of a planet is then found by using mass and radius in Earth units:

$g_{relativ} = \frac{M}{R^2}$ - Example for Mars: $g_{relativ} = \frac{0.107 M_E}{(0.53 R_E)^2} = 0.38g$

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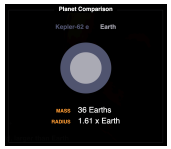
PLANET SURFACE GRAVITY EXAMPLES

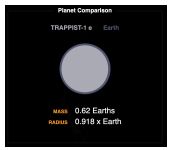
2 examples with exoplanets from https://eyes.nasa.gov/apps/exo/



Kepler-62e

$$g_{relativ} = \frac{M}{R^2} = \frac{36 M_E}{1.61^2 R_E^2} = 13.9g$$

A super-Earth with almost 14 times surface gravity compared to Earth!
Note: The found mass is n absolute max value derived from the observations. A realistic estimate under the assumptions of rocky composition is 4.5 Earth masses, which will result in a surface gravity of 1.74g.



Trappist-1e

$$g_{relativ} = \frac{M}{R^2} = \frac{0.62 M_E}{0.918^2 R_E^2} = 0.74g$$

An Earth.like planet with a lower mass and surface gravity.
Trappist-1 system has several interesting rocky planets in the habitable zone. The system is 42 light years away from us.

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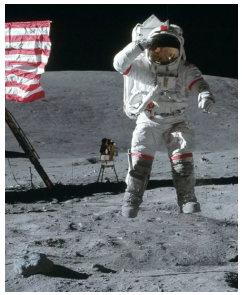
PLANET SURFACE GRAVITY II

The implications of the surface gravity.



The surface gravity of the moon is about 1/6 of Earth, so a step will become a jump. If you weight 60 kg on Earth, your weight will be 10 kg on the Moon.

If **Kepler-62e was truly 36 Earth masses**, your 60 kg would become 834 kg. An estimate of 3.4 Earth masses would make you 104 kg. Maybe it would be a bit hard to get up in the morning. Or maybe you would get super strength.

Our bodies are adapted to surface gravity of Earth, so the way we are build ad the way we move is a product of evolution on Earth. Consider how human life could be on a different planet, how we might evolve or how other life could have evolved and look like in a different gravity field.

Mars has a surface gravity of just above 1/3 of Earth, so our muscles would not get the same exercise if we lived on Mars.

Consider both short term and long term implications.

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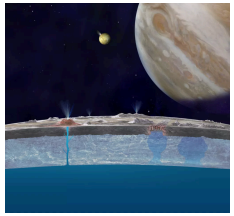
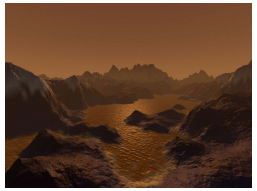
PLANET TYPE AND SURFACE

What is the surface composed of and what does it look like?



Europa, Jupiters moon
Sea under surface



Titan, Saturns moon with lakes of liquid methane

- **Rocky planet:**
  - Solid: Land, mountains, carbon, metals, ices
  - Liquid: Water, lava, other compounds
    There exists planets which could be covered only by water: Water worlds.

You might also consider if the surface changes over time. Are there any tectonic plates or volcanoes?

- **Gas- or is-gigant:** no solid surface, very thick atmosphere

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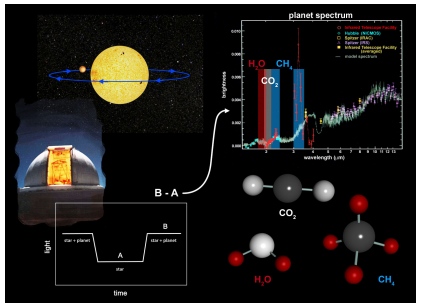
PLANET ATMOSPHERE

Transit method and spectroscopy are used to discover elements in planetary atmosphere, but current telescopes are only good enough for large atmospheric layers of gas giants. James Webb Space Telescope (JWST), will give more precise measurements of atmospheres of terrestrial planets.



- **Does your planet have an atmosphere?**
  - What does it consist of?
  - Is it thick like Venus' or almost thin like Mars?
- **What is the resulting weather?**
  - Are there cloud formations and is there rain, perhaps with diamonds or acid? Are there any storms?
  - Is there a greenhouse effect?

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PLANET ATMOSPHERE II

Atmospheric compositions, examples from our Solar system.

Object	Mass (kilograms)	Carbon Dioxide	Nitrogen	Oxygen	Argon	Methane	Sodium	Hydrogen	Helium	Other
Sun	3.0×10^{30}							71%	26%	3%
Mercury	1000			42%			22%	22%	6%	8%
Venus	4.8×10^{20}	96%	4%							
Earth	1.4×10^{21}		78%	21%	1%					<1%
Moon	100,000				70%		1%		29%	
Mars	2.5×10^{16}	95%	2.7%		1.6%					0.7%
Jupiter	1.9×10^{27}							89.8%	10.2%	
Saturn	5.4×10^{26}							96.3%	3.2%	0.5%
Titan	9.1×10^{18}		97%			2%				1%
Uranus	8.6×10^{25}					2.3%		82.5%	15.2%	
Neptune	1.0×10^{26}					1.0%		80%	19%	
Pluto	1.3×10^{14}	8%	90%			2%				

Source: https://www.nasa.gov/sites/default/files/files/YOSS_Act_4.pdf

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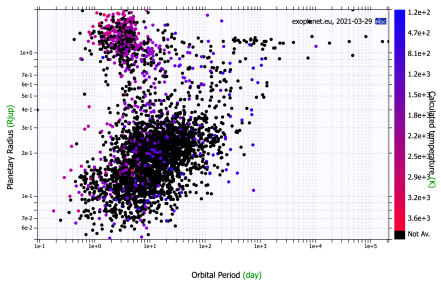
PLANET CALENDAR

The movement of the planet will influence the sense of time periods.



- **Planeten orbital period: How long is a year?**
  - Larger orbital distance gives larger orbital period or "year". Use Kepler's third law $T^2 = a^3/M_s$
  - This is something we can derive from observations via transit or radial velocity method.
- **Planeten rotation: How long is a day?**
  - The planet rotation around its own axis will give periodic variation of light from the star on the surface.
  - Some planets close to their star are tidally locked, meaning same side is always facing the star.

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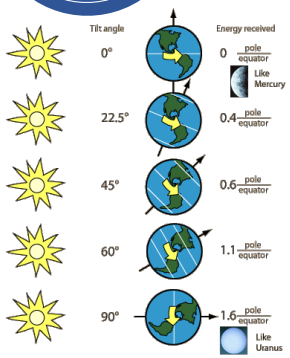
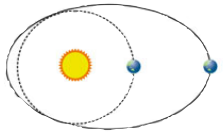
PLANET CALENDAR II

How about seasons?



- The axial tilt of a planet will give Earth-like seasons. It will essentially influence the temperature relation between the poles and the equator. http://hyperphysics.phy-astr.gsu.edu/hbase/Astro/orbtilt.html
- Eccentricity: If a planet has a more eccentric orbit, the difference in orbital distances will also result in seasonal changes in temperature. This is the case on Mars, while the orbit of Earth is too circular for the differences in distance to matter.



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EXOPLANET DESIGN

Now it's your turn!

eyes.nasa.gov/apps/exo
exoplanets.nasa.gov/alien-worlds/exoplanet-travel-bureau

Use the above links and other resources on the internet for inspiration, and design your own exoplanet using the described considerations and physics. You might not have time for all considerations, but do as many as you can, and remember to reason and argue for how your choices could be realistic!

Write a description of the planet and design a travel poster as seen in the examples. Be as creative as possible within the given framework and time and don't forget to name your new planet! It's time for new adventures …

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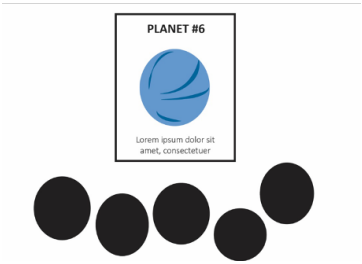
DAY 2: ASSESSMENT

Next time: Presentation of your planets. What other worlds has been created as a future travel destination in the safe space of your imagination?



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FURTHER WORK

This activity can be related further to other subjects:

- Biology: Consider what kind of life there could evolve on your or any of other groups planet. Life on Earth has evolved to adapt to its conditions. How would life look, if it were to adapt to different, perhaps more extreme (from our point of view), conditions?
- Geology: Consider how the planetary structure and surface could have evolved over time by comparing with the geological evolution of Earth.
- Design and communication: Refine your poster, create a story setting, an travel agency ad, or a poster for the life form.

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