# Appendices

## Appendix 1: Sequence Planning

| | | | |
|---|---|---|---|
| **UE** | ***Cognitions***<br><br>**Students…** | ***Caused by the following actions***<br><br>**Students…** | ***…intitiated by (actions and media)***<br><br>**Teacher…** |
| **Day 1 / Unit I (School)** | - reactivate their prior knowledge of climate and reflect on their own conceptual understanding of the climate system | - work on the pre-test and construct a concept map on their own without predefined terms, only with "climate" as the center<br>- then construct a joint concept map on the topic of climate together with the other students, whereby 11 terms are given, which must be used and may be extended | - illustrates the technique of concept mapping by an example and makes the students do a "dry run" to warm up with the method<br>- hands out a test, which also includes a blank sheet with the term "climate" in the center<br>- Encourages students to construct a large concept map together (using a flipchart and a marker) and supports the interaction process. The construction is based on 11 terms that are "parked" next to the concept map and are gradually integrated. |
| **Day 2 / Unit II (School, laboratory)** | - work out difference between weather and climate in class<br>- work independently in small groups to identify critical attributes of weather and climate phenomena<br>- Conduct experiments in these steps:<br>(1) formulate one hypothesis each,<br>(2) conduct the respective experiment and observe the physical processes closely,<br>(3) reflect on initial hypothesis in relation to the observation,<br>(4) formulate what process in the weather or climate the phenomenon represents, and<br>(5) put down on paper their own explanation of the phenomenon | - use of a Power Point presentation that allows for "hypothesis-observation-revision" logic<br>- This is done on the basis of seven experiments in five steps with the help of the experiment materials and the worksheets | - uses prepared power point presentation with supporting visual material<br>- provides hands-on activities and worksheets on seven the phenomena: low pressure areas, the greenhouse effect, reflection and absorption, the formation of currents in water, condensation, the heat capacity of water and the dependence of electrical voltage on the angle of incidence of a light source<br>- arranges the experimental materials in such a way that the students have to make their own arrangements<br>- instructs students in advance on handling and safety regulations<br>- accompanies the process, ensures that everything runs smoothly |

| | | | |
|---|---|---|---|
| **Day 2 / Unit III (School)** | - recapitulate initial assumptions and perceived phenomena with the help of the other students<br>- place the seven phenomena in a clear context with climate factors. | In class, small groups present their initial assumptions, observations, and explanations, and organize all seven observed phenomena into a graphic of the climate system | - provides a large graphic of the climate system with the system elements sun, atmosphere, greenhouse effect, ocean currents, land, biosphere and humans, to which the individual phenomena from the experiments must be attributed<br>- Summarizes results and explanations after they have been first done by the students<br>- discusses states of matter and uses particle model to distinguish between warm and cold water |
| **Day 3 / Unit IV (Klimahaus Bremerhaven)** | - explore, perceive sensory and experience climates of different climatic zones of the earth<br>- focus on specific scenes, objects and texts<br>- identify particularly influential climatic factors of a particular zone by referring back to the previous day's experiments<br>- reflect on living conditions in a particular climate and the adaptive behavior of flora and fauna<br>- form the concept of "tipping of the climate" by means of one interactive station each | - explore independently in small groups different climate zones of the earth staged in the climate house<br>- name the climatic factors that are particularly influential in a particular climate zone and match these to yesterday's experiments using the climate system illustration<br>- Select two objects or installations particularly interesting to them in “their” climate zone and capture them in a photo<br>- Collect information about the objects and independently plan the presentation of the climate zone in class<br>- consult the graphs and texts on the "overturning" of the climate of the Sahel a few thousand years ago and draw conclusions from the example to climate in general | - provides worksheets and clarifies uncertainties, organizes the small groups (composition voluntary)<br>- explains schedule, structure of the exhibition and worksheets in advance<br>- supports the small groups in working on the worksheets at certain points of the exhibition |
| **Day 4 / Unit V, School** | - reflect on their exhibition experience<br>- consolidate what they have experienced and learned<br>- reflect on what they have experienced with regard to specific questions.<br>- explore the relevance of what they have experienced for anthropogenic climate change | - report as a small group to other students about “their” climate zone with the help of photos and collected information<br>- discuss in class the effects of anthropogenic climate change in these climate zones and its causes | - provides retreat space in the exhibition, which allows undisturbed collaborative work<br>- moderates group presentations and subsequent discussion |

| | | | |
|---|---|---|---|
| **Day 5 / Unit VI (School lab)** | **Experiment 1: *Domino process***<br>- recapitulate experience that a single event can set a whole chain of events in motion, form the term "domino process" from the context of the game and work out its physical and systemic conditions<br>**Experiment 2: *Coupled pendulum***<br>- Conclude that coupled events do not always have to run in only one direction and construct the term "feedback" from the experience with the pendulum.<br>**Experiment 3: *Sand avalanches***<br>- Conclude that the pile of sand regulates itself without intervention, in that the small avalanches regularly counteract a too steep accumulation. Construct the term "self-regulation" based on this example.<br>**Experiment 4: *Metastable trough***<br>- Recall the term "metastable" in the context of the trough model and form the term "tipping point" | In each of the experiments described below, students investigate an issue by a) verbalizing and noting assumptions about the effect, b) conducting the experiment, c) verbalizing and noting their observations, d) reflecting on their initial assumptions, and e) if appropriate, making associations with other experiments and phenomena.<br><br>**Experiment 1: *Domino process***<br>Students first build simple domino series and then alternate the domino chain by a) inserting stones of very different sizes and b) building the chain in a branched way.<br>**Experiment 2: *Coupled pendulum***<br>Students use a frame with two hanging pendulums loosely connected by an elastic spring. Students pull one of the pendulums slightly outward and then release it so that it swings in the direction of the other pendulum. Students observe the gradual change in the deflection of the pendulum that is pushed and the effect on the pendulum that is coupled to it.<br>**Experiment 3: *Sand avalanches***<br>Students have an oblong glass filled with sand and a protractor in front of them. Students insert the glass into the protractor and slowly rotate the glass completely around several times in sequence. They observe the angle formed by the sand as the glass rotates.<br>**Experiment 4: *Metastable trough***<br>Students are presented a small marble run in a Plexiglas box with shallow and deeper depressions. They carefully place a ball in the upper well, then grasp the box with both hands and gently push it back and forth. They observe the behavior of the ball as they gradually push harder and harder. | Teacher assigns small groups to carry out the experiments, hands out worksheets and explains how to use them.<br>A helper assists at the individual stations by moderating the group discussions, supervising the completion of the worksheets and answering the students' questions. |

| | | | |
|---|---|---|---|
| **Day 6 / Unit VII (School)** | - recall initial assumptions and perceptions about the four models<br>- independently relate each of the models to a particular system behavior: Chain reaction, feedback (and resulting) self-organization, or tipping point.<br>- draw parallels from these system behaviors to known phenomena in their everyday life (not yet to climate) | One student per small group presents the group's initial assumption to the other classmates, describes the observation made on a model, and finally reads out the conclusion that was noted about this behavior. The small group then expresses everyday examples in which such behavior can be observed. Further everyday examples are collected in class. | - supports the students' memory with a Power Point presentation in which each model is illustrated again by videos and photos. Summarizes students' findings and explanations |
| **Day 7 / Unit VIII (School)** | - recall conclusions of the last lesson regarding the terms chain reaction, feedback (and resulting) self-organization, tipping point.<br>- in groups of 2, they independently relate one of these terms to processes in the climate system<br>- are forced to present their own work results in a comprehensible way and to clarify the connection between climate and the respective model.<br>- further elaborate on the concepts of chain reaction, feedback, self-organization and tipping point in the climate context | - work out a concept (cycle, chain reaction or tipping point) on the computer using texts, pictures and videos that specifically touch on the climate<br>- prepare their results for presentation in class<br>- present their research findings to the class using the presentations they created in small groups. Answer questions and discuss them with classmates | - provides computer workstations and data on a server<br>- a short presentation guides each small group through the work assignment<br>- supervises independent work of the students and is available for questions<br>- encourages students to verbalize their findings<br>- Displays the short presentations created by the students for all to see |
| **Day 8 / Unit IX (School)** | - work out and reconstruct the climate history of the earth.<br>- define the concept of natural climate change<br>- find out methods for measuring climate fluctuations | - watch excerpts from the documentaries "Climate Makes History" and "Water and Ice" and look for evidence of how climate has changed throughout Earth's history and how it can be studied using ice and sediment cores.<br>- make links between film and the hands-on models *domino process*, *metastable trough* and *sand avalanches* | - organizes the showing of the relevant video clips and encourages students to watch the videos under specific questions.<br>- Moderates subsequent class discussion |

| | | | |
|---|---|---|---|
| **Day 9 / Unit X (MARUM lab at Bremen University)** | - elaborate critical attributes of climate history and climate research<br>- emotionally empathize with working conditions of a climate scientist<br>- actively explore methods of climate research, including sensory perception, close observation, and categorization of sediment samples based on critical sensory properties<br>- recognize relevance of specific actions in climate research<br>- reflect experiences with climate research<br>- reflect on current experiences against the background of previous knowledge of climate change and reflect on their out-of-school experience | - follow a slide show of a climate researcher about climate history and climate research<br>- talk with the researcher about her experiences<br>- independently prepare sediment samples by sampling a core and washing it<br>- observe samples with the naked eye and under a microscope<br>- make a drawing of the visible properties of the observed sediment<br>- present own observations and interpretations to the group<br>- discuss how current climate change differs from natural historical climate variations | - course is led entirely by the climate scientist and her two lab assistants<br>- climate researcher concludes the session by asking students if there is a difference between historical climate variability and current climate variability |
| **Day 10 / Unit XI (School)** | - collectively form the concept "model" by identifying critical attributes of a model car<br>- abstract the attributes of a model<br>- then in turn apply these attributes to a climate model<br>- form solution hypotheses based on their knowledge acquired so far in the sequence and test them | - consider together, using a model car as an example, what distinguishes this model from a real car.<br>- Identify general properties of a model through discussion.<br>- discuss on this basis about what a climate model could be<br>- use a tablet to familiarize themselves with the Monash Climate Model<br>- discuss and practically explore how different climate factors need to be combined in the model to produce a specific climate<br>- form solution hypotheses based on their knowledge acquired in the sequence so far and test them | - uses a Power Point presentation that visually contrasts a model car and a real car. Collects together with students distinguishing attributes in a bullet point list<br>- provides tablets<br>- assists students in accessing the Monash Simple Climate Model website<br>- practices together with students the use of the online functions of the model |

| | | | |
|---|---|---|---|
| **Day 11 / Unit XII (Universum Science Center)** | - activate concepts of solar radiation angle, heat capacity, current etc. Sharpen these concepts and establish systemic connections between them.<br>- form an idea of dynamic processes in the global climate<br>- form an idea of possible effects of increasing $CO_2$ content in the atmosphere on global average temperatures and land ice cover<br>- work out and become aware of the relevance of their own actions in climate change<br>- formulate and evaluate technological solutions to limit global warming | - follow a demonstration of the animatable data globe<br>- enter into a dialogue with a geologist and use their own knowledge<br>- work on tasks concerning temperature development, global $CO_2$ distribution and ice melt using the data globe as an information resource and climate simulation. Collect notes on the following questions:<br>• Is the temperature rising at the same rate everywhere on Earth?<br>• Where does most $CO_2$ enter the atmosphere and why?<br>• How is $CO_2$ distributed throughout the year?<br>• According to the scenario, which areas, countries or islands will be under water in the future?<br><br>- search for and describe means of sustainable energy supply and mobility presented by text, video or objects in the technology exhibition<br>- focus on three specific objects, document them photographically and make notes on their energy-saving effect with the help of the accompanying texts | - geologist demonstrates construction. She involves students in the technical handling from the very beginning.<br>- then supports the students with questions to construct the different globes or data sets (angle of incidence of the sun and its shift in the course of the year, the global ocean current system and the heat capacity of the oceans in the global climate system) themselves by bringing in appropriate experiences from the course. She e.g. asks:<br>• What does the yellow belt across the globe represent?<br>• Why does this area fluctuate throughout the year?<br>• Why does the warming of the oceans "lag" two months behind the highest position of the sun?<br>• What do you see here, what are these swirls?<br>• Why are the swirls of different colors?<br>• How do such ocean currents develop?<br>• What do ocean currents do?<br><br>- explains what a simulation is, using the example of the global average temperature developing in relation to the increasing atmospheric $CO_2$ concentration<br>- points out at certain points what be relevant later for the processing of the research assignments<br>- teacher provides worksheets, clarifies uncertainties, organizes small groups (composition voluntary), supports them at certain points of the exhibition in working on the worksheets |

| | | | |
|---|---|---|---|
| **Day 12 / Unit XIII (School)** | - recall what they experienced at the science center and formulate their experiences in a way that is understandable to others<br>- work out the term "energy efficiency" together<br>- define the term "efficiency" and distinguish it from "Energy conversion efficiency"<br>- evaluate the energy efficiency of documented objects and mobility solutions encountered at the exhibition<br>- identify energy inefficient everyday problems<br>- recognize global warming as a challenge (likely) to be solved.<br>- form solution hypotheses and formulate solution steps,<br>- recognize relevance of own actions for global warming and discuss possibilities of own intervention | - orally present their work results from the universe to each other in small groups<br>- with reference to the worksheets, jointly compile research results on the term " Energy conversion efficiency"<br>- follow short teacher-centered documentation on energy conversion efficiency and read textbook texts on the subject<br>- use picture cards to identify everyday energy problems, collect possible more energy-efficient alternatives for action and discuss them with other students | - moderates the group presentations.<br>- explains the term "Energy conversion efficiency" by means of graphics<br>- provides a large concept map and a different colored sharpie |
| **Day 13 / Unit XIV (School)** | - recapitulate the term "climate system" and elaborate on it in relation to all four areas of competence (describing basic climate factors, explaining the system's dynamics, making climate forecasts and assessing action plans<br>for dealing with climate change) | - play a quiz together:<br>- discuss in a team whether different statements about the climate are true or false and collect arguments for their opinions. | - moderates discussions and point distributions<br>- summarizes findings from the quiz again at the end |
| **Day 14 / Unit XV (School)** | - recapitulate the term "climate system" and elaborate on it | - fill out post-tests<br>- class as a whole continues the large concept map from day 1 with a different colored Sharpie and discusses, changes and adds entries | - moderates the continuation of the concept map and encourages the students to clarify their statements and the terms used by asking questions.<br>- summarizes findings that the teaching-learning sequence has tried to convey |

## Appendix 2: Conceptual development toward a systemic view of the climate: Qualitative category guide

| | | |
|---|---|---|
| **1.1 Description of Climate Factors** | **...describes the idea of which elements determine the climate** | |
| 1.1.1 PL1 | Neither the major factors of the climate system nor their relationships can be reconstructed. | *L: What does a volcanic eruption have to do with the climate?*<br>*S1_w: ...Um… the smoke is very deadly. (261018_class conversation, pos. 204)* |
| 1.1.2 PL2 | Influencing factors of the climate system can be named but may be incomplete or are only constructed with assistance. Basic relationships between factors are constructed superficially. | ***L:*** *[…] have we forgotten anything? [climate elements]*<br>***S1_w:*** *Atmosphere. But I'm not entirely sure it has to do with the atmosphere. When the sun shines… the gases...um...our atmosphere heats up. (261018_ class conversation, pos. 230-231)* |
| 1.1.3 PL3 | Major factors of the climate system and their relationships can be reconstructed autonomously and applied to a certain climate zone, e.g. ice, ocean and sun for the polar zone or sun, atmosphere, ocean, plants for the tropical zone. | ***I:*** *Can you remember the elements that determine the climate?*<br>***S1_m:*** *First, there are vulcanoes that emit greenhouse gases. There are also plants and trees that convert CO2 into oxygen. Then there are the oceans with salt water and the glaciers, which unfortunately are currently melting. And there are the people who build factories and pollute the air... Apart from that, there is the atmosphere, the sun and precipitation. (291118_Interview S2_w + S1_m, pos. 24)* |
| **1.2 Basic Scientific Concepts** | **...describes the notion of scientific concepts related the climate such as greenhouse effect, reflection, absorption, water cycle, ocean currents etc.** | |
| 1.2.1 PL1 | A basic concept relevant to climate and/or weather is not explained coherently; instead, preconceptions become apparent. | ***I:*** *What causes wind, S2_w?*<br>***S2_w:*** *Eh... oh dear, trees? (140319_PostInterview_S2_w + S5_m, pos. 226)* |
| 1.2.2 PL2 | A basic concept relevant to climate and/or weather can be explained in a largely coherent manner, but the explanation remains vague and/or is assisted. | ***I:*** *And what is the result of having no plants?*<br>***S2_m:*** *We don't have clean air anymore. Because plants clean the air by means of photosynthesis. (291118_Interview S2_m + S3_m, pos. 69)* |
| 1.2.3 PL3 | A basic concept relevant to climate and/or weather can be explained in a technically coherent manner and distinguished from similar terms. | ***S1_m:*** *[...] Earlier the sun passed through the atmosphere, then it hit the earth, then it either went back into space or it hit the earth again from the atmosphere, but now the sun's rays often don't leave the atmosphere, and so the earth warms up. (291118_Interview S2_w + S1_m, position 73)* |
| **1.3 Weather/Climate Distinction** | **...describes the idea of how weather events and climate are related to each other.** | |
| 1.3.1 PL1 | Weather = Climate: Weather is considered to be synonymous with climate. Weather occurrences are not interpreted as part of a long-term climate development. | ***L:*** *Do you know examples that show that our climate is changing, S12_m?*<br>***S12_m:*** *For example in the summer... the sun shines more often and the temperature goes up, that's how you can tell. (261018_ class conversation, pos. 21)* |
| 1.3.2 PL2 | Independent, without statistical reference: Weather is not equated with climate, but the idea is still diffuse, e.g. does not include that long-term climate is composed of individual weather data. | ***S12_m:*** *Climate is made up by the weather. And um weather is when you already know when that is. (261018_ class conversation, pos. 76)* |

| | | |
|---|---|---|
| 1.3.3 PL2 | Independent, with statistical reference: There is a clear idea that weather and climate are independent concepts, but that long-term climate is composed of individual weather data averaged over decades | ***S20_m:*** *So, climate includes a longer period of time, whereas the weather exists for a day or a couple of weeks [...] And the weather can change very quickly, I'd say, but climate is just... [2s pause, S2 thinks], it normally does not change drastically or all of a sudden [...] The climate has already existed for a very long time. (PostInterview_S14_w + S20_m_210918, pos. 83)* |
| **1.4 Ideas of Cause-Effect** | **... describes the development from the idea of merely direct cause-effect connections to the development of the idea that one cause can result in multiple consequences, which may well occur at a temporal and spatial distance.** | |
| 1.4.1 PL1 | Direct, monocausal: simple idea that one cause in the climate causes only one direct, immediate effect. | ***I:*** *What would happen if we there was no ice on earth anymore?* ***S2_w:*** *It would become... even warmer because the ice.... well, it's cold. And so it cools down the Erath a little. (140319_PostInterview_S2_w + S5_m, pos. 52-53)* |
| 1.4.2 PL2 | Vaguely multicausal: idea that one cause in the climate can result in several effects, but the relationships cannot be scientifically substantiated. | ***S5_m:*** *Wasn't it that the climate change also causes stronger wind? //* ***I:*** *Why would that be? //* ***S5_m:*** *I'm not sure right now but I got that idea because I heard it somewhere before. (140319_PostInterview_S2_w + S5_m, pos. 222)* |
| 1.4.3 PL3 | Indirect, multicausal: idea that one cause in the climate can have several direct and indirect effects, which may differ from their cause in strength, be delayed in time and/or happen elsewhere. | ***I:*** *What else contributes to a warming climate?* ***S2_m:*** *Well, if the ice surface is gone it cannot reflect the sun light anymore. Um, it's dark and that's why the sun light gets absorbed and it makes the water heat up. Then perhaps the gulf stream stops and causes some other countries become colder because the stream does not supply them anymore with warmth. (200319_PostInterview_S2_m + S3_m, pos. 139-140)* |
| **1.5 Concept of Regulation** | **...describes the idea of how and why the climate is regulated** | |
| 1.5.1 PL1 | Anthropocentric and without system reference: assumption that climatic processes are being regulated for human survival. | ***I:*** *Do you remember roughly what it is [a system]?* ***S24_m:*** *Yes, a system is something like a computer that runs. [...] the trees are there for us to have oxygen, [...] so that we can live here. So, water, atmosphere and sun. Without the sun or something, we would die quickly. (PostInterview S17_m + S24_m_210918, pos. 133)* |
| 1.5.2 PL2 | Not anthropocentric, but not completely founded in a natural system: assumption that climatic processes exist independently of humans, but system reference is not established. | ***I:*** *How would you explain to someone what it means that the climate organises itself?* ***S19_m:*** *I would tell them that the climate just... cannot be influenced and just always somehow changes. So, it's never entirely stable. (PostInterview_S19_m_200918, pos. 39-40)* |
| 1.5.3 PL3 | Autonomous, founded in a natural system: clear conception of the self-regulatory capacity of a complex, natural system, which can, however, be disturbed by excessive human influence. | *I: And what happens in the Arctic with the sun and the ice – normally? What would be the normal climate if the ice didn't melt?* ***S1_m:*** *Um, I think it would always melt a bit, but new ice would always appear, too. [...] there has always been global warming, for thousands of years, but that's been so slow that animals and plants could get used to it. (291118_Interview S2_w + S1_m, pos. 56-57)* |
| **1.6 Concept of Dynamics** | **...describes the development from a sequential idea (simple, linear) to thinking in terms of a dynamic network of many elements that influence each other in non-linear ways. This includes an understanding that effects are seldom proportional to their causes.** | |
| 1.6.1 PL1 | Linear, static: simple idea of a sequence with a beginning and an end, both temporally and spatially. Elements in climatic processes are not considered in connection with but detached from each other. | ***L:*** *What is a system?* ***S7_m****: A sequence? (231118_ class conversation, pos. 126-127)* |

| | | |
|---|---|---|
| 1.6.2 PL2 | Linear, dynamic: idea of a process in one direction involving several elements that are connected in the sense of a domino effect. Idea that processes always proceed at a steady pace. | ***S4_m:*** *And the warmer it gets, the heavier the rain and the stronger the storms! And the stronger the storms, the more rain, destruction! Again and again. (291118_Interview S4_m + S5_m, pos. 76)* |
| 1.6.3 PL3 | Cross-linked, dynamic: Idea of a dynamic network of many elements that influence each other in the sense of positive and negative feedbacks; ideas of cycles instead of starting and ending points. Idea of non-linear processes (e.g. exponential growth), which result in limited predictability of a system's development. | ***S3_m:*** *If there are already large masses of water that are exposed and then the sun shines on them, it gets warm even under the ice, and then it all melts away faster, so it accelerates. (170119_Interim interview S2_m + S3_m, pos. 115)* |
| **1.7 Complexity of Problem Analysis** | **...describes how complex a person perceives problems or which actions and interventions seem reasonable to them to mitigate climate change.** | |
| 1.7.1 PL1 | Simple: assumption that a climate-relevant problem is clearly solvable with one strategy and thus there is no understanding of side effects or the relative insignificance of a measure. | ***T:*** *What does sustainability mean?*<br>***S7_m:*** *I think it also means, um, that we should do more for the environment, I don't know anymore, but that we should ride our bikes more or something. [...] (220218_ class conversation, pos. 25)* |
| 1.7.2 PL2 | More complex, but without system reference: it is not assumed that a climate-relevant problem is clearly solvable by only one strategy. There is a vague understanding of side effects, but these are not justified with a complex interaction in the system. | *S8_m: (commenting on the statement "Global warming mainly brings advantages for Germany. For example, we can go swimming earlier and more often".) Well, when it's summer, it's very warm and then the ice melts more and more. And when the ice melts, a lot of water comes and floods everything. (010319_class conversation, pos. 155)* |
| 1.7.3 PL3 | Complex, with system reference: conception of interconnected problems that cannot be solved simply by one strategy. This is justified with a complex interaction in natural and/or social systems. Or: Solutions are offered that take complexity into account. | ***S5_m:*** *Coal-fired power plants are generally [...] bad, because when you burn coal, carbon dioxide is released into the atmosphere and it makes the atmosphere denser and less sunlight can go out [...]. Nuclear power plants: Um, there are two sides to that. On the one hand, they are a bit better and healthier for the environment, because it's only water vapour. On the other hand, when they break down [...] radioactive rays may escape and poison trees, people, animals; cause them to die. [...] That's what happened in Chernobyl, for example, there was water nearby and it evaporated and all the rain and stuff came even over here to Germany. (140319_PostInterview_S2_w + S5_m, pos. 187)* |

## Appendix 3: Student Pre-/Post test

**Dear student,**

With this questionnaire we would like to learn more about you and your views regarding the climate. All questions are open and the answers are anonymous. No one will be able to link the results of the test to you. However, to enable us to relate the results of the questionnaire to the worksheets in the coming days, please provide a code.

**Your code**: The first two letters of your mother's first name followed by the first two letters of your father's first name (alternatively grandpa or brother) and the first two letters of your place of birth. Here is an example: Mother Maria, father (or grandfather or brother) Michael and place of birth Olbia = MAMIOL

Please fill in your code here:

| | | | | | |
|---|---|---|---|---|---|
| | | | | | |

I'm a girl　　I'm a boy　　I prefer not to say

I am ______ years old.

**How much are you interested in the following topics? In each row, mark the value on the scale that best applies to you. Here 1 is "not at all interested" and 5 is "very interested".**

| | 1 | 2 | 3 | 4 | 5 |
|---|---|---|---|---|---|
| Natural Science | | | | | |
| Technology | | | | | |
| Animals | | | | | |
| Nature | | | | | |
| Politics and humans | | | | | |

**What are you favourite subjects? Choose three.**

| | | | |
|---|---|---|---|
| Math | Religion/Ethics | Economy | Sports |
| German | Natural Science | Art | Other |
| English | Social Studies | Music | ____________ |

**How do you learn best? Choose all aspects that are important for you.**

| | | | |
|---|---|---|---|
| watch videos and look at pictures | touch, play and experiment | move and be physically active | be on my own and think in piece |
| listen to someone speaking | share and discuss experiences | read information | think analytically and logically |

**1. One often hears the word "system"**

a) What do you think is the meaning of this word?

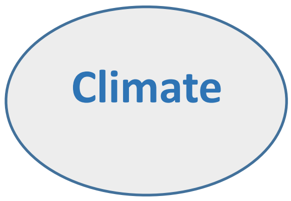
b) What ist a climate system?

c) The climate has the property of organising itself. What does this sentence mean? Can you give an example?

**2) Sun, plants, ice, atmosphere, oceans, ocean currents, clouds, land, humans, greenhouse effect, climate zones**

a) Put these terms into the form of a concept map on the topic of "climate". You have space for this on the next page. Concept map means: draw connections between these terms and use arrows to clarify causes and effects. Please write on the arrows precisely *how* terms are related.

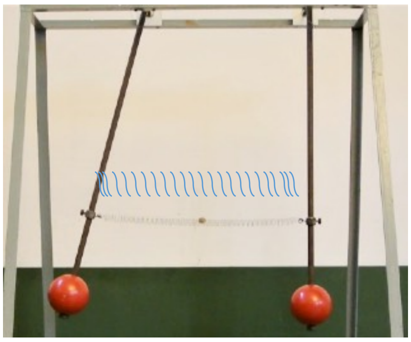
b) Add more words that relate to the climate. Don't forget to relate these to the existing terms in the map.


Climate

**3)** [No picture rights. For comic strip see https://the-avocado.org/2020/01/25/the-comic-strip-club-sat-1-25-2020/. Last accessed 21 January 2023.]

The guys in the comic are talking about a contradiction: cold temperatures are supposed to occur despite global warming. Do you think this can happen? If so, what could be the reason?

**4a)** If you were to tip the very smallest stone (on the far right) towards the second stone and let go - what do you think would happen?



**4b)** Two pendulums are connected by a light spring. What happens if you pull one of the pendulums to the side and let it go?

**4c)** In front of you is a glass box with a built-in marble run. The ball lies still in a pit.

Imagine pushing the glass box back and forth, first slowly and steadily and then jerkily. What would probably happen?

**5)** What could the situations 4a, 4b and 4c have to do with the climate?

a)

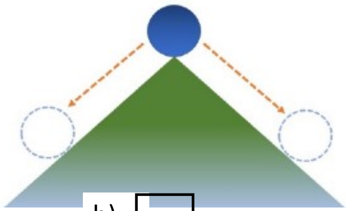
b)

c)

**6)** Which of these situations do you associate with the word "stable", which with the word "unstable"? Write an "s" for stable and an "u" for unstable in the boxes below the pictures. Give a brief explanation of your decision below!

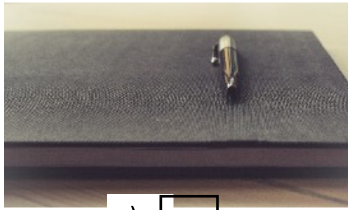
[Adobe Stock 60370106]

a)



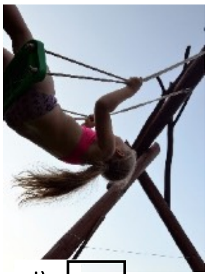
b)

[1249-pxhere.com, creative commons]



c)

[Wikimedia Commons]



d)

[883269-pxhere.com, creative commons]

e)

[1067819-pxhere.com, creative commons]

f)

**6 b)** What have the words “stable” und “unstable” to do with climate and weather?

## Appendix 4: Interview guide for interim and post-interviews with student groups

**Reproduction of the activities of the teaching-learning sequence**

- Can you remember the last out-of-school learning environment we went to?
- What was it about there? What were our lessons about?
- Which exhibits / experiments / pictures / videos / conversations do you remember most?
- Was there anything that impressed or surprised you? If so, what do you think was the reason?

**Reconstruction of content-related connections between activities**

- Which of the things we had discussed before could you use in the Climate Discovery Centre/School lab/ Science Centre and what was completely new for you?
- Was there a connection between what you saw and experienced at the Climate Discovery Centre/School lab/Science Centre and last week's class?
- *How* did we pick up on the experiences in the Climate Discovery Centre/School lab/Science Centre in class?

**Note**: In the post-interview (interview 3), the last two questions are replaced by:

- What was the dramaturgy of the content of our entire course?
- Can you assign the cards to the learning environments and put them in an appropriate order? [Cards are handed out in no particular order saying “Elements of the climate”, “How the climate system works”, “Climate history”, “Climate models”, “Climate future”, “Mitigate Climate change”, “Climate Discovery Centre”, “School lab”, “Science Centre”.]

**Reconstruction of subject-related interconnections**

**A) Interview 1, end of Phase 1, after visiting the climate discovery center**

- What are the elements of the climate, which influences are important?
- How do these influences interact? Can you give examples? [Graphic of the climate model is shown that was already used in class.]
- The Equator (i.e. the Cameroon area) and the Sahel are close to each other, so the solar radiation is quite similar. Why is the climate in Cameroon nevertheless different from that in the Sahel?
- What influences are there in the polar climate and how do they interact?
- If the ice is melting more in the Arctic, how does this influence the climate relationships in the polar zone?
- Did you find it difficult to make connections between the experiments and the climate? What did you recognize, for example?
- In nature, differences usually balance each other out. Can you give a few examples that you explored in the experiment?

B) **Interview 2, end of Phase 2, after conducting experiments at school and visiting the School lab**

- You recently did experiments at school. Which ones do you remember?
- What did we aim to show with them?
- What do you think is a system? And in what way is our climate a system?
- Which rules of a system became visible in the experiments? [Show pictures of the analogue models]
- What is shown here? Why is there a plus and a minus? [show two graphs comparing negative (stabilizing) feedback processes in the Polar Zone vs. a self-reinforcing process, the ice-albedo feedback]

- Has the climate always been like this in the history of the Earth? Why can the climate sometimes change quite abruptly?
- On the one hand it is said that we are on the way to an ice age, on the other hand we talk about global warming. Can you explain this?
- Did you find it difficult to relate the experiments to the climate? What did you recognize immediately, what was more difficult?

**C) Interview 3, end of phase 3, after handling the Monash simple climate model and the data globe**

- [Show image of Monash Simple Climate Model] We did something on the computer here. What were we dealing with there?
- What is a climate model and what is it for? What should it include?
- How does knowledge from the past of the climate help us to look into the future?
- What would happen if there was no more ice on Earth? What would happen if we no longer had an atmosphere on Earth?

- What do you say to the following statements?

  "We often hear that our harvest is at risk if there is too much drought. But that wouldn't actually be so bad, because we could move cultivation to greenhouses or import fruit/grain."

  "Wind turbines are no better for the climate than generating energy from coal."

  "When we humans produce $CO_2$, the effect is not necessarily immediately visible or noticeable."

  "There's nothing we can do about the greenhouse effect anyway; nature will make up for it on its own."

**Evaluation and Motivation**

- Did you have the experience of recognizing things / elements during our activities and conversations? How was that? Was it a good feeling or was it rather boring?
- Did our activities in the last weeks / in the course of the whole course contribute to you seeing the climate differently than before?
  - ➔ If yes: What do you see in a different way now? And what was it that changed this view?
- Did you do anything in your free time during the last two weeks as a result of our activities?
  - ➔ If yes: Did you tell anyone about it? Did you google something, read about it, talk to someone about it?
  - ➔ If no: Why not?

**Appendix 5: Concept Map Evaluation System adapted from Clausen and Christian (2012)**

| Element | Example | Score |
|---|---|---|
| applied climate system element* | Atmosphere | 1 |
| two terms actually causally linked are only connected by a line → evaluated as a simple statement | Evaporation --- Rain | 2 |
| further statements connected by a line | Trees --- Land | 2 |
| dependency constructs | Plants -- need -- Sunlight | 3 |
| Causal relations expressed by an arrow | Sun ---> Climate zones | 5 |
| Feedback | Greenhouse Effect <----> Humans | 10 |
| Incorrect statements | Nuclear power station ---> amplifies Greenhouse Effect | 0 |
| partially correct statements | more greenhouse gas in atmosphere --> less sunlight escapes | scores ½ |

**Appendix 6: Evaluative codings according to all seven categories across three phases of the sequence. NA = category was not coded**

| | Phase I | | | | Phase II | | | | Phase III/IV | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | *PL 0* | *PL 1* | *PL 2* | *PL 3* | *PL 0* | *PL 1* | *PL 2* | *PL 3* | *PL 0* | *PL 1* | *PL 2* | *PL 3* |
| Description of climate factors | 2 | 4 | 23 | 8 | 0 | 7 | 5 | 14 | 1 | 4 | 7 | 3 |
| Basic scientific concepts | 2 | 26 | 38 | 25 | 0 | 5 | 14 | 12 | 1 | 15 | 22 | 11 |
| Weather/climate distinction | 0 | 8 | 11 | 0 | 0 | 1 | 6 | 0 | 0 | 2 | 2 | 2 |
| Idea of cause-effect | 1 | 17 | 24 | 9 | 0 | 2 | 10 | 14 | 2 | 11 | 31 | 19 |
| Concept of regulation | NA | NA | NA | NA | 0 | 4 | 8 | 11 | 0 | 0 | 1 | 10 |
| Concept of dynamics | 0 | 5 | 14 | 5 | 0 | 7 | 25 | 16 | 0 | 5 | 24 | 6 |
| Complexity of problem analysis | NA | NA | NA | NA | 0 | 1 | 4 | 2 | 0 | 4 | 43 | 32 |