PULCHRA

Participatory Urban Learning Community Hubs through Research and Activation

The PULCHRA Handbook of Educational Materials

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Content

Executive summary

This document is the PULCHRA Handbook of Educational Materials. It comprises the PULCHRA Collection of Educational Materials, which contains work sheets, instructions for experiments, links to smart phone apps, and other types of material. The collection is intended to be amendable like a loose-leaf collection. The materials are meant as building blocks. Thus, they can be combined in multiple ways. In its introductory section, the handbook provides an example of a one-week project course, based on the concept of a Learning, Exploring and Activity Path (LEAP).

Version History

Version	Date
0.5 First draft for partners	2020/07/17
1.0 Delivery	2020/08/28
1.2 Update	2020/09/16
1.3 Correction of overview table	
1.4 Correction of errors	2020/12/08
1.5 Correction of overview table	2020/12/17
1.6 Language corrections, updates	2021/02/02
1.7 Fixed links in P28	2021/02/08

1 Introduction to the handbook

This handbook provides information on educational resources developed and compiled within the PULCHRA project. PULCHRA aims at strengthening “Science in the City” by building “**P**articipatory **U**rban **L**earning **C**ommunity **H**ubs through **R**esearch and **A**ctivation”. Responsible citizenship requires more than ever the competence to distinguish fact from fiction. Sufficient competence in evidence based reasoning and science based approaches is essential for all members of the society. Because democratic systems need societal participation, building pathways to activate people irrespective of age, level of education, family background, gender or religion are important pillars to maintain coherent and cooperative communities. The Open Schooling concept, pursued by PULCHRA, facilitates building an inviting and participatory platform, with schools as community hubs to stimulate students and citizens to take an active role in their respective community. Activities carried out by students will have a direct link to the challenges faced by the local community, to different subjects taught in school as well as to different age groups. Thus, schools become a focal point of community integration.

The core of the PULCHRA activities at schools focus on the wider topic of “Cities as urban ecosystems”, where a city is understood as a kind of living organism, where processes from the natural environment, the build environment, and the socioeconomic environment interact and thus have to be investigated in an integrated way. The UN Sustainable Development Goals (SDG), particularly Goal 11 “Sustainable cities and communities”, as well as the UN Habitat’s ”New Urban Agenda” provides a suitable overarching frame for the development of a concrete, science based pathway towards urban sustainability, which facilitates participation and learning by doing, and which utilizes schools as community learning hubs. The broadness and generality of the SDG’s requires that the complexity of the problems at hand are broken down to manageable but still coherent pieces, which invite the contribution from different disciplines, facilitate cooperation of different stakeholders, utilize a diversity of methodological approaches. By this means, an understanding of connectedness and interdependence based upon perceptions in local spatial and temporal context and ultimately demonstrates the relevance of local action with regards to regional and global wellbeing.

Against this background, the SDG’s have been translated to “City Challenges” (Table 1), which serve as examples, inspiration and stimulus to develop a school-specific agenda and profile. In this context, the educational goals of competence building and learning are linked to the societal goals of responsible citizenship, stewardship for the physical, societal and cultural environment, and active participation in developing our society. Thus, the teaching materials presented in the PUCLHRA Collection of Educational Materials are by no means complete or final. They shall be understood as a starting point and an open platform, inviting completion, contributions and new ideas by teachers, experts and researchers.

Table 1 UN Sustainable Development Goals (SDGs) assigned to PULCHRA's City Challenges. More information on the City Challenges can be found on the PULCHRA website (https://pulchra-schools.eu).

City Challenge	SDGs
1. Powering cities without harming the climate	7 Affordable and clean energy; 9 Industry, innovation and infrastructure; 12 Responsible consumption and production; 13 Climate action
2. Buildings for the future city	9 Industry, innovation and infrastructure; 11 Sustainable cities and communities; 12 Responsible consumption and production; 13 Climate action; 15 Life on land
3. Regenerating urban space to connect people in a healthy environment	8 Decent work and economic growth; 9 Industry, innovation and infrastructure; 10 Reduced inequalities; 13 Climate action
4. From waste disposal to resource efficiency – Circular economy at the city scale	1 No poverty; 2 Zero hunger; 3 Good health and well-being; 6 Clean water and sanitation; 7 Affordable and clean energy; 9 Industry, innovation and infrastructure; 10 Reduced inequalities; 15 Life on land
5. Mobility patterns that support community development	8 Decent work and economic growth; 9 Industry, innovation and infrastructure; 12 Responsible consumption and production; 17 Partnerships for the goals
6. Innovation for social and environmental benefit	9 Industry, innovation and infrastructure; 12 Responsible consumption and production; 13 Climate action; 16 Peace, justice and strong institutions; 17 Partnerships for the goals

The materials, approaches and examples provided here focus mainly on City Challenges in the context of urban climate (City Challenges 2 and 3). Utilizing and developing the Open Schooling concept facilitates the transfer from a school challenge to a City Challenge as it reaches out beyond the immediate realm of the school to additional stakeholders such as researchers, administrators, companies, industry etc., who play an active role in finding a pathway to address these challenges. The societal relevance and the immediate connection to the own living environment makes these City Challenges particularly motivating to learn and experience the methods of scientific discovery. Thus, the materials presented here utilize particularly the approach of inquiry based learning in order to strengthen trust in the method of science, to provide experience in evidence based reasoning, to help understanding the difference between opinions and proven facts, and to foster environmental education.

This handbook consists of a teachers' guide (chapter 2) and an extendable collection of education material.. It is intended that additional material will be added to the collection as it is developed in the PULCHRA network of schools during the project's runtime and beyond. A description of procedures to evaluate the effectiveness of the teaching approaches is given in an accompanying document.

2 Teachers' guide

2.1 Introduction to the teachers' guide

The Teacher's Guide complements the PULCHRA Collection of Educational Materials with background information and an implementation example that aims at establishing a strong link between the educational goals of schools and the need for active citizenship. As a coherent, publicly visible and integrative concept, we propose establishing **L**earning, **E**xploring and **A**ctivity **P**aths (LEAP, see section 2.2), which provide a thematic coherence relating an overarching societal issue to local places. LEAPs are set up in the immediate school environment as well as in the city to provide a safe learning environment for students and at the same time a point of access to the local community and broader urban society. By this means, and which provide a thematic coherence relating an overarching societal issue to local places. The concept presented in this guide is intended to serve as a template for schools to develop their own specific teaching / learning approach. The LEAP concept implies both, a physical pathway along which a City Challenge (including e.g. the explanation of the urban climate character) can be experienced, researched and addressed, and a learning trajectory along which learning progress and opportunities for participation can be fostered. Thus, the LEAP concept integrates different elements: provide knowledge and facts, explore through experiments and observations, address different perspectives and disciplines, facilitate cooperation through sharing of observations and ideas, and utilize information and communication technologies and analogous education resources. The LEAP example presented here addresses different aspects of the SDG-based examples of City Challenges, which focus particularly on understanding cities as urban ecosystems and on urban climate. The resources presented in the PULCHRA Collection of Educational Materials are intended to inspire educators, students and citizens to engage in scientific discovery and societal participation. We very much encourage the use, adaptation and enhancement of these materials to other topics, user groups and learning environments.

2.2 The Learning, Exploring and Activity Path (LEAP)

2.2.1 Concept

A LEAP is a **L**earning, **E**xploring and **A**ctivity **P**ath. It addresses a range of issues and subjects which are particularly obvious at given places within a city. A LEAP should have a thematic coherence to address different aspects of a given issue (e.g. urban climate, role of water in the city, resource use and recycling, etc.). It is a real pathway along a set of learning-stations as well as a learning trajectory. Each station deals with a certain aspect of the LEAP's topic. Each station of the LEAP is identified with a QR-code tagged sign. The QR code provides a link to information on the station's topic. The digital nature of the information facilitates easy modification and augmentation to invite continuous development and adaptation to new City Challenges. Smartphones and other information and communication technologies serve as an activating element to the learners. Besides the digital resources, other types of learning opportunities can be offered at a station of a LEAP, which activate learners in various ways. Analog opportunities such as hands-on experiments or environmental observations are mutually complemented by digital ones like smartphone-apps for guided observations, or for access to data measured at the site, data from external sources like aerial photography, or data gathered by satellites. Figure 1 provides a graphical outline of the LEAP concept.

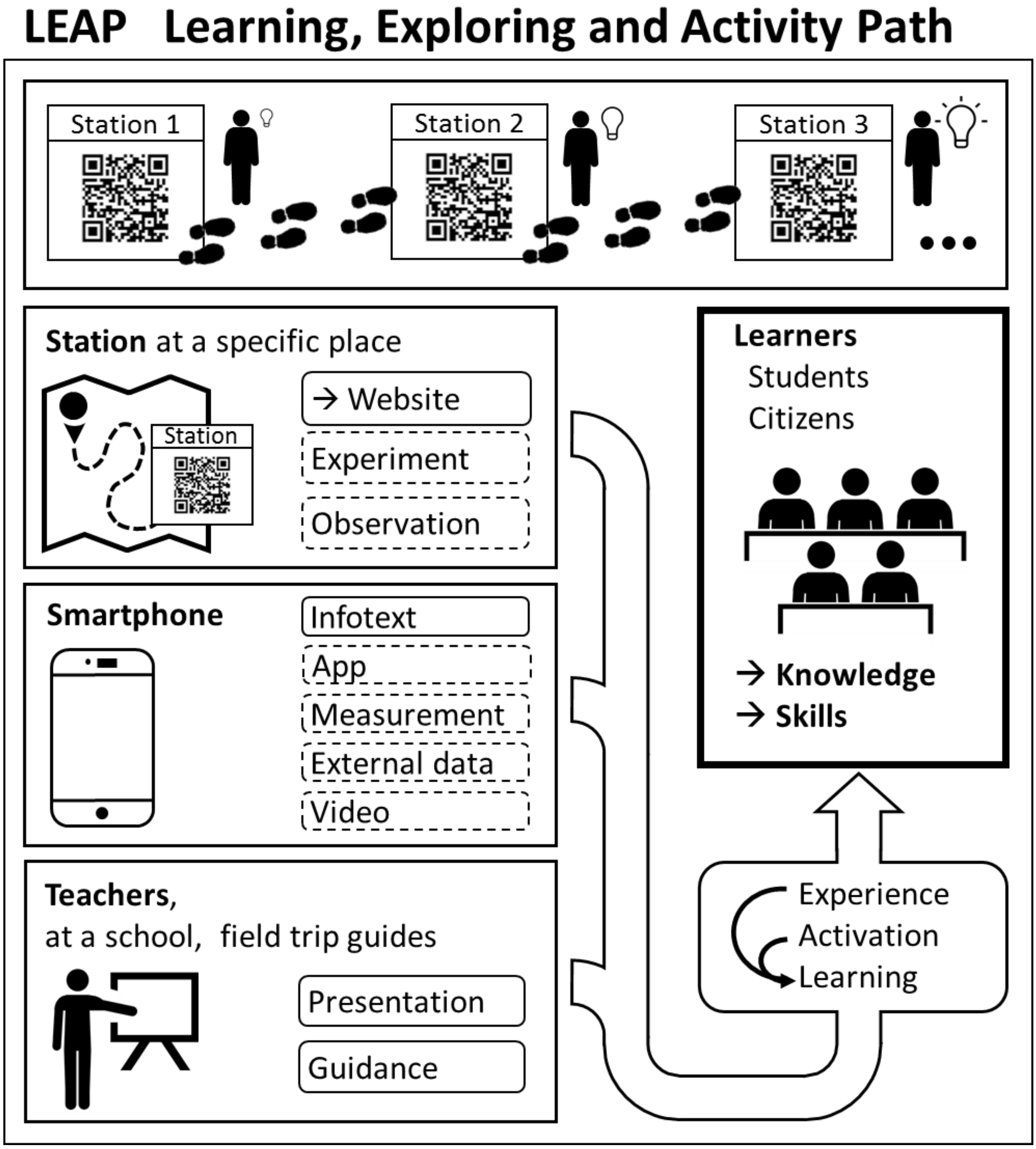

Figure 1 Visualization of the LEAP concept

The aim of this approach is to foster environmental education and education for sustainable development, to improve learning, to facilitate active participation and to strengthen citizenship by (1) connecting learning in the classroom with working outside the classroom, (2) facilitating cooperation (with local experts), (3) using digital learning approaches, smartphones and other information and communications technologies e.g. for environmental observation, and (4) doing hands-on experiments. Especially the latter will built direct experience and enhance trust in the method of science.

2.2.2 Implementation in the context of schools

Building upon the basic idea of a path, which can be followed by anyone at any time, there are ways to utilize the LEAP-concept in the context of schools. An existing LEAP can be part of a class as an out-of-school place to learn. In that case, there will be a tour along the LEAP guided by a teacher, scientist or any trained person. Since the stations do not necessarily follow a sequential approach and thus may be independent from each other, also only selected stations, whose topics suit into a certain teaching concept may be visited. Since a LEAP is modular, it is suitable for different teaching formats (e.g. regular classroom approaches, project weeks, project groups) and provides points of access to different disciplines reaching from natural sciences to social sciences (e.g. connections to political or economic aspects), arts (e.g. the colors / sounds of nature) and languages (e.g. bilingual teaching).

A LEAP may also be established as a result of a course or a project by the participants. The students deal with different aspects of a certain subject or City Challenge. Each aspect becomes the topic of a station of the LEAP. The locations should be selected in order to showcase the problem at hand and to be accessible to the participants. In the school context, the LEAP is preferably put into practice on the school grounds or in the surrounding of the school. This approach helps to develop a sense of ownership and makes the achievement visible to a broader audience.

The development of a LEAP implies competence building regarding the LEAP's subject area but also regarding the basic principles of the scientific method. In addition, experience in terms of integrative cooperation beyond disciplinary borders is built by addressing different perspectives such as the physical nature, the political and societal interrelations, the cultural context or even the artistic value of the location. Often locations have a specific cultural relevance, which are expressed in poems, music or other pieces of arts. Experiencing these in the given context and realizing the difference of the impression expressed by the artists and the current situation on-site is a perspective and potential of a LEAP station, which goes well beyond natural science. This integrative perspective strengthens the notion of equal relevance of the contribution of different disciplines and lowers the perception of mutual exclusiveness of artistic, scientific, cultural, social, or language skills prevalent in many students. Participating in method-based observations and analyses, following observational protocols (e.g. by using smartphone apps), evaluating experiments and reasoning based upon evidence heightens a sense of familiarity with the scientific method, builds confidence in the own ability to engage in science and helps develop the ability to distinguish evidence-based scientific results from opinions. An example for a school climate LEAP is presented in section 2.4.

2.2.3 Participation approach, stakeholders, external experts

The LEAP-concept offers opportunities in the context of participation and open schooling. The use of smartphone apps for environmental observations at certain stations of a LEAP results in a collection of data that can be scientifically evaluated. This represents one aspect of the Citizen Science approach, where citizens participate in scientific investigations. The opportunity to actively contribute to science is perceived as a particularly motivating factor and builds trust in science based upon own experience. In this context, schools are an essential societal multiplier. Including parents and the wider school community at events (opening, project presentation) connected to an existing or student-designed LEAP brings them into contact with the respective subject and fosters environmental education and education for sustainable development in society.

Applying the open schooling concept has the potential to enhance the learning effects of a LEAP. External experts from the local administration, economy, NGOs, or scientists can be included in the teaching process either as dialog partners concerning topics at a station, or as sources of information for students working on the creation of their own LEAP. Including external experts enables the students to obtain information beyond the provided learning materials. It can provide additional perspectives on the theoretical or conceptual information collected during the investigations on their respective topic. This can foster interdisciplinary thinking and generates a broader view on the topic. In addition, the students get into direct contact with people with interesting or influential professional tasks, which reduces the often perceived distance to decision makers and has the potential to show pathways for future professional development.

2.3 Organizational structure of the educational materials

To showcase the concept of open schooling using the example of a City Climate LEAP, the educational materials in this collection are organized along the following guidelines:

1. Provide clear and direct links to the competence building goals of science education standards with particular emphasis on
   a. fostering the understanding of scientific concepts and developing the ability for inquiry and evidence based evaluation,
   b. strengthening the learning of subject matter in the context of personal and societal perspectives,
   c. implementing inquiry based learning approaches to address the diversity of the students' skills, proficiency and abilities,
   d. strengthening the communication of science explanation in the classroom and beyond,
   e. investigating over an extended period.
2. Provide a clear structure
   a. that splits topics into small independent learning modules with a clear-cut content and a set of teaching materials,
   b. that assigns the modules to learning units,
   c. that identifies the contextual links to the City Challenges provided by PULCHRA,
   d. that enables easy extension through adopting additional teaching material developed by the PULCHRA network of schools or other institutions.
3. Provide clear instructions for activities, experiments, and digital learning tools, which are based upon scientific approaches. Thus, the method of science from a research question, via the research method, to data analysis, and from data analysis to evaluation and communication and discussion of the results becomes evident.

The PULCHRA Collection of Educational Materials is organized as learning modules, which represent separate learning activities. Each learning module conveys a certain content-related and/or methodical educational objective. It includes specific material, which can be exercise sheets, manuals for experiments, slides to be presented by teachers, or other type of media. A complete list of learning modules is presented in the beginning of the PULCHRA Collection of Educational Materials.

The learning modules are assigned to learning units, which are organized along the elements of the research process complemented by additional units to integrate this process into a course at a school. The learning units currently considered are listed in Table 2, others may be added as required.

Table 2 List of learning units

Learning unit	Description
Activation	Activation of the students
Basics of the scientific method	Fundamental concepts of research and of the scientific method
Planning Research	Setting the research agenda in terms of topic, research questions, hypotheses, research plans, and research methods
Setting Theoretical and thematic foundations	Preparing theoretical, methodical, and content-related knowledge
Exploration	Exploration of places
Theoretical inquiry	Theoretical considerations on a topic and gathering of information and data from existing resources
Measurements, experiments, observations	Practical gathering of data from measurements (experiments, observations) or simulations
Documentation	Documentation of research, its results and conclusions, including uncertainty and error considerations
Analysis and discussion	Organization of data/results, their analysis, evaluation, and discussion
Communication and presentation	Communication and presentation of the results of the inquiry, investigation, or research
LEAP	The "Learning, Exploring and Activity Path" as an outcome of a course
Reflection	Personal reflection of what was done
Evaluation of the course	Evaluation of the learning event

These modules are intended as building blocks in a coherent teaching approach, which is designed by the teacher. The learning units shall help to guide teachers to the required modules. Different modules may serve a similar purpose and scope. This redundancy is relevant to (1) address the different needs and skills of the students, (2) to showcase different methods, and (3) to cope with the time required or the difficulty of the tasks. Since the modules were designed to fit into existing course schedules, they may contain methodical or content-related elements that are connected to multiple learning units.

As the overarching thematic context of this guide, we chose the topic of “Urban Climate and Climate Adaptation”, which is directly related to the City Challenges No. 2 “Buildings for the future City” and No. 3 “Regenerating Urban Space to connect People in a Healthy Environment”. The timeliness as well as the interdisciplinary nature of these topics is obvious. While the LEAP concept we use here related particularly well to place based learning approaches, other City Challenges are not primarily place based in nature. City Challenge No. 4 “From waste disposal to resource efficiency – Circular economy at the city scale" is an example addressing primarily behavioral and economic aspects than spatial aspects. Thus, while the LEAP concept as a place based approach, is not the preferred option, the inquiry and evidence based concepts exemplified here may be transferred or serve as inspiration to develop the own teaching approaches. Sharing these approaches is strongly encouraged as the issues at hand and the educational approaches are numerous, and each educational approach requires suitable adaptation to the given learning environment.

While a City Challenge provides a coherent conceptual frame for a teaching project spanning over an extended period, individual activities and materials can also be used in the context of short teaching units. Thus, the learning units and the sequence of learning modules shown in section 2.4.1 shall provide an example for an extended project, which can be put into effect in the frame of research projects, workgroups, project weeks or in regular classes.

Most of the material in the PULCHRA Collection of Educational Materials was designed for grades 7 to 8. In order to simplify finding suitable material, each material is assigned a skill or difficulty level of 1 (low) to 3 (high), which is shown on the material itself and in the overview table in the beginning of the collection. By adapting the language and the aspiration level, these materials can be transferred to other age groups and skill levels.

2.4 A school LEAP

Most of the resources initially contained in the PULCHRA Collection of Educational Materials are designed and compiled for a course, where the students create a school LEAP. This can be for example a project week, or a series of periodic regular lessons. The learning project may consist of the phases listed below.

1. Introduction
   a. Group formation
   b. Introduction to the method of science:
      - What is research?
      - The scientific cycle
      - Research questions
      - Hypotheses
   c. Introduction to the project
      - LEAP
      - Topic of the City Challenge
2. Planning research
   - Exploration of the school ground
   - Site description
   - Identification of research questions
   - Putting forward hypotheses
3. Experiments and observations
   - Plants
   - Weather
   - Water
   - Soil
   - Documentation of results
4. Analysis of results
5. Presentation

- Written characterization of the site
- Description of the experiment or observation method
- 2.4.1Presentation of results
- Statement on the confirmation or refutation of the hypothesis
- Physical implementation of the LEAP

6. Reflection
    - Research diary
    - Daily reflection
    - Reflection of the total course

The initial collection of educational materials contained in this handbook is an example for this type of course with the central topic "City Climate LEAP". An example for a one-week project course is presented in the following section. Besides imparting knowledge on clime, the course covers an introduction to the method of science and its main elements.

Since the PULCHRA Collection of Educational Materials is continuously extended, the identifiers of the materials' (P-numbers, see below) are not connected to the order in which the materials may be used in a learning unit. Additional material added to the collection, however, is not intended to be limited to the concept of this course.

2.4.1 Exemplary structure of a one-week project class on the City Climate LEAP

This section presents an example of the application of the education material. The course was held in the context of a project week at a school in Germany. It shows the structure, the schedule and a list of required materials. The latter also includes general material like a projector. Each day has a certain intention mentioned as the Take-Home-Message of the day. The course was designed for students in the seventh grade.

There are two main goals of this course:

1. Create basic knowledge on the interdependencies of soil, vegetation, weather and water in the context of climate and especially temperatures.
2. Foster the trust in the scientific method through hands-on experience with research.

Each day of the project week (Table 3 - Table 7) is compiled from modules of the PULCHRA Collection of Educational Materials. The learning goals are given as take-home messages in each table. Since this course was held at a school in Germany, times are set according to the rules of that school and need to be adjusted.

The modular concept of the PULCHRA Collection of Education Material is exemplarily shown in day one of the course where two alternative sequences are presented. Teachers can choose one of these depending on the teaching goals and the students' abilities. Alternatively, both suggested sequences can be combined resulting in an extension of the course's scope.

Table 3 Example of a one-day course as part of a project week.

Day 1		
Take-Home-Message	Everybody can do research. Research arises if one tries to answer a question by observing, measuring, experimenting, or questioning. In doing so, it is important to make the research transparent and comprehensible to others. This is done by documenting the materials used, the activities done, the data acquired and the process of analysis and interpretation in order to make the research reproducible by others.	
Time	**Topics**	**Materials required**
08:35 – 09:00	Arrival, team building - Based on questions, the students position themselves along a rope, which represents a measuring scale	- Rope or wallpaper roll - P1-L: questions
09:00 – 09:35	Work on the question “What does research mean?” (similar to a think-pair-share method) - Think: Students fill in questionnaires on basic questions regarding research and question other students or teachers - Pair: Students compare their results in small groups - Share: The groups compare their results in the plenum	- P2a-e: What is “research”? -
09:35 – 10:05	Elaboration of the research cycle - Students assign examples to the phases of the research cycle - Students find own examples for the phases - Students put the phases in an order to form a cycle	- Scissors, glue stick - P3: The research cycle
Break		
Version 1		
10:50 – 11:00	Introduction to the LEAP project	- P6, P6-L: The project "LEAP" (with final slide 1) - Laptop, projector
11:00 – 12:00	Students form groups of three or four (the “home groups”, number of groups equals number of places) Students explore and map the school ground and highlight differences in land-use	- P12, P12-L: A map of our school - A GPS-device per group (e.g. a smartphone)
12:00 – 12:30	Presentation of the research questions	- P10, P10-L: Setting the research agenda
12:30 – 12:50	Students return to the school ground and write a description for each place (one group per place)	- P11: Places at our school
Break		
13:40 – 14:30	Students write a description for each place (continued)	
Version 2		
10:50 – 11:00	Introduction to the LEAP project	- P6: The project "LEAP" (with final slide 2) - Laptop, projector

11:00 – 11:25	Properties of research questions	- P29 Suitable research questions
11:25 – 12:50	Students form groups of three or four (the “home groups”, number of groups equals number of places) Students explore the school ground and look for places where something can be discovered about the LEAP’s topics	- P7a-d Places at our school
Break		
13:40 – 14:30	Students develop research questions on the LEAP’s topics	- P9a, P9-L Research questions - magnets or sticky tape, blackboard and chalk or white board and pens
14:30 – 15:15	Reflection period - Students create a research diary and make a first entry - What have you gained?	- P26: My research diary - P27a: Evaluation of the research day

Table 4 Example of a one-day course as part of a project week.

Day 2		
Take-Home-Message	Research has a specific structure. It starts with a hypothesis. Hypotheses can be tested, e.g. by doing an experiment.	
Time	**Topics**	**Materials required**
08:35 – 09:35	Students learn what a hypothesis is and what makes a good hypothesis	- P4 Hypothesis formulation - Laptop, projector
09:35 – 10:35	Students explore „their“ place (home groups) more closely and create a hypothesis about their research question	- P7 or P11 from day 1
Break		
10:50 – 11:30	In a Gallery Walk, students talk about their results with the other groups	- P5-L: Exchange of results: The Gallery Walk
11:30 – 12:30	In an experiment, the students investigate the water permeability of soils	- P13: The Water Challenge - Sand, silt, clay, gravel, plastic bottles, measuring cup, stop watch, water
12:30 – 12:40	Reflection period - Students write the daily entry into the research diary - Joint conclusion of the research day	- P26: My research diary - P27a: Evaluation of the research day

Table 5 Example of a one-day course as part of a project week. Breaks have to be organized individually.

Day 3		
Take-Home-Message	There are different ways to test a hypothesis. One can do experiments or simply carefully observe things and document these observations.	
Time	**Topics**	**Materials required**
08:35 – 09:00	Students are divided into groups (home groups) and familiarize themselves with the description sheet, they will fill in the following day with the results of the experiments.	- P24a-e: Our school – a Learning, Exploring and Activity Path
09:35 – 15:00	Students pass through the five stations in groups and carry out various observations, measurements and experiments.	- P20-L: Route card - P8, P14-P18, P36: Experiments and Observations
15:00 – 15:15	Reflection period - Students write the daily entry into the research diary - Joint conclusion of the research day	- P26: My research diary - P27a: Evaluation of the research day

Table 6 Example of a one-day course as part of a project week. Breaks have to be organized individually.

Day 4		
Take-Home-Message	To pass on our research results to others, the results need to be structured.	
Time	**Topics**	**Materials required**
08:35 – 09:00	Students (home groups) collect experimental and observational results of “their” station from all groups	- P8, P14-P18, P36: filled in, of all groups - P21, P22: Analysis of results and comparison
09:35 – 15:00	Preparation of the description sheets and presentations - Students write first drafts of texts for the description sheets (when required, use the phrasing assistance P24h) - Students check and correct their description sheets - Students write the final version onto the description sheet which is laminated thereafter - Students prepare and practice their presentation	- P24: Our school – a Learning, Exploring and Activity Path: description sheets and ancillary material - P21, P22: Analysis of results and comparison, completed - P25: Evaluation sheet for presentations - laminator
15:00 – 15:15	Reflection period - Students write the daily entry into the research diary - Joint conclusion of the research day	- P26: My research diary - P27a: Evaluation of the research day

Table 7 Example of a one-day course as part of a project week.

Day 5		
Take-Home-Message	We explored our school by research and learned more about our environment! I can do research myself at home by exploring my surrounding.	
Time	**Topics**	**Materials required**
08:35 – 10:00	Students practice their presentations	- P24a-e: Our school – a Learning, Exploring and Activity Path: completed description sheets
10:00 – 12.00	Joint "hike" on the LEAP with presentations by the students	
12:00 – 12:50	Reflection period - Students write the daily entry into the research diary - Joint conclusion of the research week	- P26: My research diary - P27a: Evaluation of the research week

PULCHRA

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<u>How to find material in the PULCHRA Collection of Educational Materials</u>

To simplify the search for materials, the table on the following pages gives a complete overview. It contains a list of all materials together with some important properties:

- Suggestions of contexts where the material may be used (City Challenges, learning units, topics). A link to the sustainable development goals (SDGs) of the UN can be established via the table of City Challenges (Table 1) in the PULCHRA Handbook of Educational Materials.
- Information on the kind of material and on didactic arrangements the material is intended for.
- Available languages, a rating of the level of difficulty, and an estimation of the time required.
- A short description of what will be done.

The materials are sorted according to their ID, which starts with a P for PULCHRA followed by a number. An “L” like in the example below denotes material for teachers. This ID is given in an info-box in the top right of each material. It is accompanied by additional information, which makes it faster to find the desired document. An example of an info-box is shown below:

Level of difficulty	City Challenges	Language	ID of the material

Level of difficulty	The PULCHRA Collection of Educational Materials is designed of students at ages between 12 and 18 years or grades from 7 to 12. The level of difficulty of the materials is assigned to three levels from 1 (low) to 3 (high): 1:  1-2:  2:  2-3:  3:  Some materials with organizational purpose haven no level of difficulty assigned. In the material, it is avoided to use terms like “difficulty” or “hard” in order not to make the students develop any prejudices about their ability to cope with a task. For the same reason, we do not use yellow or red colors in the level indicator.
City Challenges	In the second element of the infobox the highlighted numbers and letters refer to the City Challenges the material may be useful for. These are: 1. Powering cities without harming the climate 2. Buildings for the future city 3. Regenerating urban space to connect people in a healthy environment 4. From waste disposal to resource efficiency – Circular economy at the city scale 5. Mobility patterns that support community development 6. Innovation for social and environmental benefit Two additional symbols refer to further contents: D Didactic methods or teacher information, which can be applied for activation, communication or in the context of the LEAP concept. G Material on the general scientific method, which may be used for all learning events concerning the method of science Additional information on the City Challenges can be found on the PULCHRA website.
Language	The language of the material. An arrow at this position indicates that the languages are given in the material.
ID of the material	The ID of the material, which is used to refer to it throughout the PULCHRA Handbook of Educational Materials.

Overview of all Learning Modules assigned to City Challenges (CC), Learning units, and topics. Related UN Sustainable Development Goals (SDGs) are assigned in Table 1 of the PULCHRA Handbook of Educational Materials. The Learning Modules are identified by their ID and title. Additional properties of modules listed in the table are a category describing the kind of material, the type of material, the didactic arrangement, languages available, a difficulty level of 1, 2, or 3 (low, medium, high), and an estimated time required to work on the task. The activity associated with the material or its purpose is indicated in the last column.

Mod. ID	Title	CC	Learning unit	Topics	Category	Type of media	Didactic arrangement	Lang.	Diffi-culty	Dura-tion (h)	Description
P1-L	Questions for the start	**D** G 1 2 3 4 5 6	Activation	Didactic method	Teacher information	Text	Teamwork		1	0.5 - 1	Method to activate students and promote positive group dynamics
P2	The method of research	D **G** 1 2 3 4 5 6	Basics of the scientific method	Scientific method	Teaching material	Exercise sheet	Individual work, Teamwork		1	0.5 - 1	Students explore what research is
P3	The research cycle	D **G** 1 2 3 4 5 6	Basics of the scientific method	Scientific method	Teaching material	Exercise sheet	Teamwork		1	0.5 - 1	Students consolidate and test their knowledge on the research cycle
P4 P4-L	Hypothesis formulation	D **G** 1 2 3 4 5 6	Basics of the scientific method	Scientific method	Teaching material, Teacher information	Presentation	Teacher-centered		1	1 - 1.5	Students learn the properties of a hypothesis and practice to formulate one
P5-L	Exchange of results: The Gallery Walk	**D** G 1 2 3 4 5 6	Communication and presentation	Didactic method	Teacher information	Text	Teamwork		2	1	A Gallery Walk as a method to exchange information among groups
P6 P6-L	The project "LEAP"	**D** G 1 **2 3** 4 5 6	LEAP	Didactic method	Teaching material, Teacher information	Presentation	Teacher-centered		1	0.5	Introduction into the LAP concept and the topics of the School Climate LEAP
P7 P7-L	Places at our school	**D** G 1 **2 3** 4 5 6	Exploration	Didactic method	Teaching material, Teacher information	Exercise sheet	Teamwork		1 - 2	2	Students explore their school ground and identify places relevant for their topic
P8	Leaf colors	D G 1 2 **3** 4 5 6	Measurements, experiments, observations; documentation	vegetation	Measurement	Exercise sheet	Teamwork		1	0.5 - 1	Students determine leaf colors
P9 P9-L	Research questions	**D G** 1 **2 3** 4 5 6	Measurements, experiments, observations; documentation	Didactic method	Teaching material, Teacher information	Exercise sheet	Teamwork		1	1	Students select research questions
P10 P10-L	Setting the research agenda	D **G** 1 **2 3** 4 5 6	Planning research	Didactic method	Teaching material, Teacher information	Presentation	Teacher-centered		1	0.5 - 1	Research questions are presented and discussed
P11 P11-L	Places at our school	D **G** 1 **2 3** 4 5 6	Planning research	Didactic method	Teaching material, Teacher information	Exercise sheet	Individual work, Teamwork		1 - 2	0.5	Students create a site description for places at the school, which are connected to a research question

P12 P12-L	A map of our school	D G **1 2 3** 4 5 6	Exploration; Documentation	Land use	Teaching material, Teacher information	Exercise sheet	Teamwork		2	1 - 1.5	Students develop a mapping key and use it to map their school grounds
P13 P13-L	The water challenge	D G 1 2 **3** 4 5 6	Measurements, experiments, observations	Water	Measurement, Teacher information	Experiment	Teamwork		1 - 2	1 - 1.5	Students create a multi-layer soil from sand, silt, and clay and determine the permeability for water
P14	Properties of the water	D G 1 2 **3** 4 5 6	Measurements, experiments, observations; documentation	water, water quality, measuring	Measurement	Exercise sheet	Teamwork		1 – 2	1 - 1.5	Students determine properties of the water
P15 P15-L	Seasonal cycle of plants	D G 1 2 **3** 4 5 6	Measurements, experiments, observations; documentation	vegetation, phenology, trees, grass	Measurement, Teaching material, Teacher information	Exercise sheet	Teamwork		2	0.5 - 1	Students determine the phenological development state of plants in the seasonal cycle
P16 P16-L	Wind and temperature	D G **1 2 3** 4 5 6	Measurements, experiments, observations; documentation	weather, temperature, wind, measuring	Measurement, Teaching material, Teacher information	Exercise sheet	Teamwork		1 – 2	1 - 1.5	Students measure wind near to and far from building and temperature of air and ground using different methods
P17	Clouds and temperature	D G **1 2 3** 4 5 6	Measurements, experiments, observations; documentation	weather, temperature, clouds, measuring	Measurement, Teaching material	Exercise sheet	Teamwork		2	1 - 1.5	Students determine the current types of clouds and measure the temperature
P18	Soil identification	D G 1 2 **3** 4 5 6	Measurements, experiments, observations; documentation	soil	Measurement, Teaching material	Exercise sheet	Teamwork		2 – 3	0.5 - 1	Students determine soil properties
P19 P19-L	Surface cover and water	D G 1 **2 3** 4 5 6	Theoretical Inquiry	water, land use, infiltration, water budget	Teaching material, Teacher information	Exercise sheet	Teamwork		2	0.5	Students theoretically explore the ways of the water after a precipitation event
P20-L	Route card	**D** G 1 2 3 4 5 6	Measurements, experiments, observations	Didactic method	Teacher information	Text	n/a		n/a	n/a	Organization of parallel experiments of different groups
P21 P21-L	Analysis of results	D **G** **1 2 3** 4 5 6	Analysis and Evaluation; documentation	water, soil, weather, temperature, clouds, vegetation, infiltration	Teaching material, Teacher information	Exercise sheet	Teamwork		1 – 2	1 - 1.5	Students gather the results of the different groups and analyze them
P22	Analysis of results: Comparison	D **G** 1 2 3 4 5 6	Analysis and Evaluation	scientific method	Teaching material	Exercise sheet	Teamwork		1 – 2	1 - 1.5	Students compare the data gathered from the different groups
P23 P23-L	Temperature diurnal course and clouds	D G 1 **2 3** 4 5 6	Analysis and Evaluation	weather, temperature,	Teaching material, Teacher information	Exercise sheet	Individual work, Teamwork		2	0.5 - 1	Students evaluate temperature measurements and compare them to satellite images of clouds

				clouds, remote sensing							
P24 P24-L	Our school – a Learning, Exploring and Activity Path	**D** **G** 1 2 3 4 5 6	Communication and presentation; LEAP	Didactic method, scientific method	Teaching material, Teacher information	Exercise sheet, text, presentation	Teamwork		2	2 - 3	Students document and present their results
P25	Evaluation sheet for presentations	**D** G 1 2 3 4 5 6	Communication and presentation	Didactic method	Teaching material	Exercise sheet	Teamwork		1	0.25	Students rate the presentations of the other groups and vote for the best presentation
P26	My research diary	**D** G 1 2 3 4 5 6	Reflection	Didactic method	Teaching material	Exercise sheet	Individual work		1	0.25	Students reflect their personal research day
P27	Evaluation of the research day and week	**D** G 1 2 3 4 5 6	Evaluation of the course	Didactic method	Teaching material	Exercise sheet	Individual work		1	0.25	Students evaluate the research day and the research (project) week
P28-L	Smartphone Apps for environmental observations	D G 1 **2 3** 4 5 **6**	Measurements, experiments, observations	App	Citizen Science, Teacher information	Text	Individual work, Teamwork		n/a	div	Students/participants conduct environmental observations using smartphone apps
P28a	App: Weather observer	D G 1 **2 3** 4 5 6	Measurements, experiments, observations	App, weather	Citizen Science	App	Individual work, Teamwork		2	n/a	Participants document observations guided by an App
P28b	App: Cloud types	D G 1 **2 3** 4 5 6	Measurements, experiments, observations	App, clouds	Citizen Science	App	Individual work, Teamwork	عربي	2	n/a	Participants document observations guided by an App
P28c	App: Leaf damages	D G 1 2 **3** 4 5 6	Measurements, experiments, observations	App, vegetation, plant stress	Citizen Science	App	Individual work, Teamwork		2	n/a	Participants document observations guided by an App
P28d	App: Soil texture	D G 1 2 **3** 4 5 6	Measurements, experiments, observations	App, soil	Citizen Science	App	Individual work, Teamwork	عربي	2 – 3	n/a	Participants document observations guided by an App
P28e	App: Soil type	D G 1 2 **3** 4 5 6	Measurements, experiments, observations	App, soil	Citizen Science	App	Individual work, Teamwork		3	n/a	Participants document observations guided by an App
P28f	App: Animal tracks	D G 1 2 **3** 4 5 6	Measurements, experiments, observations	App, animals in the city, biodiversity	Citizen Science	App	Individual work, Teamwork	عربي	2 - 3	n/a	Participants document observations guided by an App
P28g	App: Land cover / land use	D G 1 2 3 4 5 **6**	Measurements, experiments, observations	App, land use	Citizen Science	App	Individual work, Teamwork		3	n/a	Participants document observations guided by an App
P28h	App: Plant phenology	D G 1 2 **3** 4 5 6	Measurements, experiments, observations	App, vegetation, phenology	Citizen Science	App	Individual work, Teamwork		2	n/a	Participants document observations guided by an App

P28i	App: River structural quality, short	D G 1 2 3 4 5 **6**	Measurements, experiments, observations	App, water, watercourse	Citizen Science	App	Individual work, Teamwork		1 – 2	n/a	Participants document observations guided by an App
P28j	App: River structural quality, advanced	D G 1 2 3 4 5 **6**	Measurements, experiments, observations	App, water, watercourse	Citizen Science	App	Individual work, Teamwork		3	n/a	Participants document observations guided by an App
P28k	App: Flow velocity	D G 1 **2 3** 4 5 6	Measurements, experiments, observations	App, water, watercourse	Citizen Science	App	Individual work, Teamwork		3	n/a	Participants document observations guided by an App
P28l	App: Rocks	D G 1 2 3 4 5 6	Measurements, experiments, observations	App, rocks	Citizen Science	App	Individual work, Teamwork		3	n/a	Participants document observations guided by an App
P29	Suitable research questions	D **G** 1 2 3 4 5 6	Planning research, Basics of scientific method	Scientific method	Teaching material	Exercise Sheet	Teamwork		1	n/a	Students develop research questions for their topic
P30	Building the Cool City Lab	D G **1 2 3** 4 5 6	Measurements, experiments, observations	water, water budget, infiltration, energy, vegetation, sealed surfaces, measuring	Experiment	Manual	Individual work, Teamwork		2	n/a	Students build the Cool City Lab
P31 P31-L	Why do surfaces have different temperatures and what does that mean for the city?	D G **1 2 3** 4 5 6	Measurements, experiments, observations	water, water budget, infiltration, energy, vegetation, Sealed surfaces, measuring	Experiment, Teacher information	Text	Individual work, Teamwork		2	n/a	Students use the Cool City Lab to investigate the effect of surfaces on fluxes of energy and water
P32-P34	… will be added later …										
P35	Building instructions for a radiation shield	D G **1 2 3** 4 5 6	Measurements, experiments, observations	measuring, temperature	Experiment	Manual	Individual work, Teamwork		2	n/a	Students build a radiation shield to enable outdoor measurement of air temperature
P36 P36-L	Infiltration	D G 1 2 **3** 4 5 6	Measurements, experiments, observations	soil, water, measuring	Experiment, Teacher information	Exercise sheet	Teamwork		2	0.5 - 1	Students measure the infiltration at different surfaces
P37	Powering Cities without harming the Climate: An introduction	D G **1** 2 3 4 5 6	Planning research, theoretical inquiry	Climate, energy, sustainability, urban area	Teaching material	Text	Individual work, Teamwork		1 – 2	n/a	Students deal with the basics of energy, investigate the interdependencies of energy and climate and explore potentials to save energy

P38	Innovation for Social and Environmental Benefit: An introduction	D G 1 2 3 4 5 **6**	Planning research, theoretical inquiry	Land use, mobility, energy, sealed surfaces, sustainability, urban farming, urban gardening, smart city	Teaching material	Text	Individual work, Teamwork		1 – 2	n/a	Students deal with urbanization and its positive and negative effects; they explore innovations like the ideas of the Smart City
P39-L	Buildings for the Future City - A pathway towards a City Challenge: The case of cool materials	D G 1 **2** 3 4 5 6	Planning research, theoretical inquiry	Sealed surfaces, city climate, water, water budget, infiltration, energy, vegetation, measuring	Teacher information	Text	Individual work, Teamwork		1 – 2	n/a	Students deal with the relations of surfaces in the city and city climate.
P40-L	Regenerating Urban Space to connect People in a Healthy Environment - From local action to regional impact	D G 1 2 **3** 4 5 6	Planning research, theoretical inquiry	Sealed surfaces, city climate, health, energy, vegetation, measuring, remote sensing	Teacher information	Text	Individual work, Teamwork		1 – 2	n/a	Students deal with the importance of collaborations in the city in order to adapt to climate change and keep temperatures at a bearable level.

Questions for the start

Material:

- Rope or roll of wallpaper with scale labels
- Questions

Method:

The rope is put on the floor in a way that there is room for all students along it. The teacher asks the questions listed below. For each question, the students position themselves along the rope according to the scale in order to personally answer the question. The students comment on why they chose the respective positions.

very few	0	very much
bad		good
not at all		a lot

1. Did you sleep well?
2. How do you feel today?
3. How well do you know the other students?
4. How much do you know about the projects we are going to carry out this week?
5. How much do you know about research?
6. How much do you expect to have learned about research by the end of the project week?
7. Are you looking forward to our project week?
8. …

What is "research"?

1. Answer the questions below on your own. Write down your answers in the marked areas.
2. Find a partner and question at least three other persons (students, teachers, …) together. Write down their answers in the boxes below.
3. After collecting the answers, meet with another group. Compare your results. Agree on a maximum of three important answers per question. Transfer these answers to the sheets P2b – P2e.

a) What do you think does the word "research" mean?

b) Who can do research?

c) How is research accomplished? (Which methods are there to do research?)

d) What rules apply when doing research? (What does a good researcher have to take care of?)

What do you think does the word "research" mean?

Write down your thoughts and ideas in the box below.

Who can do research?

Write down your thoughts and ideas in the box below.

How is research accomplished?
(Which methods are there to do research?)

Write down your thoughts and ideas in the box below.

What rules apply when doing research?
(What does a good researcher have to take care of?)

Write down your thoughts and ideas in the box below.

The research cycle

1. Form groups of three or four. Cut out the labels of the phases of the research cycle below und the examples on sheet P3b.
2. In your group, discuss which example belongs to which phase. Glue the matching phase labels and examples on the copies of sheet P3c, respectively.
3. Think of other examples for each phase and note them on the respective sheets P3c.
4. Which is the right order of the phases? Order the phases in a circle.

Idea / Assumption

Observe carefully

Write down observations

Question

Discuss results

Document results

Teamwork

Experiment / implementation

Examples

I found that the tap water at home sometimes is shimmering in a slight reddish color when the tap has not been used for some time. I wonder why the water shows that color.

I assume that the water changes its color due to certain small particles from the water pipe. I assume that there might be rust in the water.

We note down the results of each iron test in a table in order to be able to compare the results quickly.

I want to perform an experiment. I put water into a clean vessel. I test the iron content of the water with a test strip for iron.

More eyes see more: Together with two other researchers, we perform the experiment. We simultaneously test the water from several taps.

We wonder what the results can mean. We discovered that the iron content is quite high in some samples but not in other samples. We discovered that all samples with a high iron content are from the tap with the reddish water. The reddish color seems to result from the high iron content of the water. Our assumption that the color is caused by rust is right.

We write down our observations. We label each sample and note the result of the respective iron test down.

We carefully observe what the test strip shows. Its color changes depending on the iron content of the water. We compare the color on the test strip with the color code on the box.

Phases of the research cycle

Phase of the research cycle Glue the phase here	**Example** Glue the appropriate example here.

Your own examples

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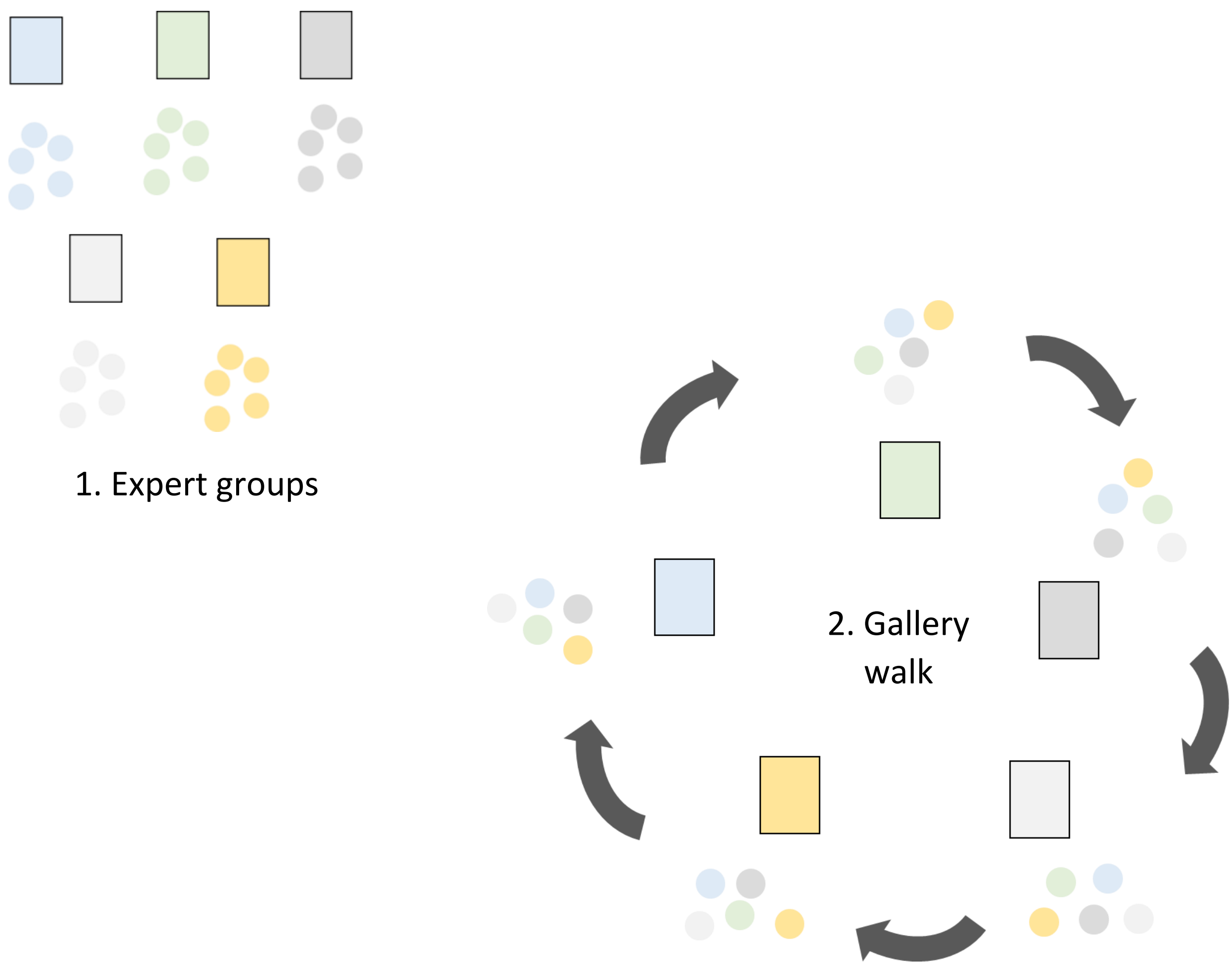
Teacher information: Hypothesis formulation

Material P4 is a presentation. It is therefore not included in this file but is available as a separate file (MS Powerpoint) accompanying the PULCHRA Collection of Educational Materials.

Teacher information: Exchange of results

Method: Gallery Walk

1. Each group presents their place description (P7) and their written hypothesis
2. The groups are now recomposed so that there is at least one member from each home-group in the new group. The number of new groups must not exceed the number of presentations.
3. Each new groups visits one of the place-presentations
4. A group member who has worked on the description and hypothesis introduces the group to this place.
5. When there are no more questions, all groups move on one station at a time until each place has been introduced.



Teacher information: LEAP and school ground exploration

This material introduces the students to the Learning, Exploring and Activity Path (LEAP) and invites the students to explore their school ground according to the topics of the LEAP, which are

- Water
- Plants / vegetation
- Weather
- Soil

Material P6 is a presentation. It is therefore not included in this file but is available as a separate file (MS Powerpoint) accompanying the PULCHRA Collection of Educational Materials.

The presentation P6 contains a short introduction to the LEAP concept as a series of stations. A slide introduces the list of topics. Here, it is required to make the connection between the topics and to mention the difference between weather (the current meteorological situation) and climate (the long-term average meteorological conditions).

The presentation includes two final slides, which prepare the transition to the next modules (see notes in the presentation). They belong to two different versions of a course suggested in section 2.4.1 of the PULCHRA Handbook of Educational Materials. Since the educational material has a modular concept, the slide can be chosen according to the intended sequence of modules or be skipped in case of other ideas on how to progress in class.

Order of modules:

Version 1 (with field mapping):

P6 (presentation with “final slide 1”) → P12 (mapping) → P29 (theory research questions) → P10 (prescribed research questions) → P11 (site description)

Version 2 (with selection of research questions):

P6 (presentation with “final slide 2”) → P29 (theory research questions) → P7 (site description and development of research questions) → P9 (Selection of research questions)

For more information on the LEAP concept, please refer to the PULCHRA Handbook of Educational Materials, Section 2.2.

Teacher information: Places at our school

This material is meant to stimulate students to explore their surroundings. Concerning their specific topic they are requested to find places at the school where they can learn about it and to write down or decide on research questions. This participatory approach invites students to intensively deal with their surroundings and to experience that they personally have a connection to the problem brought up by the City Challenge.

This method can be adjusted to a lot of different topics.

Material P6 connects this to the LEAP.

Places at our school – Topic: Water

At this place, you can discover something about the topic water: ____

Description of the place (What can you see, hear, feel, …?)	Sketch (rough draft) of the place:

Tick which research questions could be investigated at this place. If you have a question of your own, write it down.

- ☐ What is the quality of the water?
- ☐ Which color is the water?
- ☐ ____

Places at our school – Topic: Plants

At this place, you can discover something about the topic plants: ____

Description of the place (What can you see, hear, feel, …?)	**Sketch (rough draft) of the place:**

Tick which research questions could be investigated at this place. If you have a question of your own, write it down.

- ☐ What do the plants look like right now and how does this change over time?
- ☐ To what degree is the soil covered by plants?
- ☐ ____

Places at our school – Topic: Weather

At this place, you can discover something about the topic weather: ____

Description of the place (What can you see, hear, feel, …?)	**Sketch (rough draft) of the place:**

Tick which research questions could be investigated at this place. If you have a question of your own, write it down.

- ☐ Can clouds be used for weather forecasting?
- ☐ How and why does the temperature differ between different places?
- ☐ ____

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Places at our school – Topic: Soil

At this place, you can discover something about the topic soil: ____

Description of the place (What can you see, hear, feel, …?)	**Sketch (rough draft) of the place:**

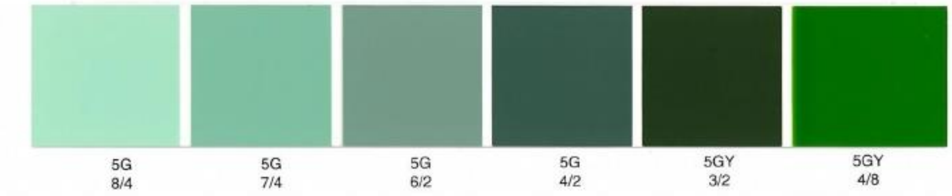
Tick which research questions could be investigated at this place. If you have a question of your own, write it down.

- ☐ Which kind of soil do we have?
- ☐ How wet is the soil?
- ☐ On which surface can water best infiltrate (seep) into the soil?
- ☐ ____

Leaf colors

Use the color chart to determine the colors of three leaves of each of three different plants. Enter the color codes (e.g. 5G 8/4) in the table.

blue/green



yellow/green

brown/green

brown/red

		Color codes
Plant 1:	Leaf 1	
	Leaf 2	
	Leaf 3	
Plant 2:	Leaf 1	
	Leaf 2	
	Leaf 3	
Plant 3:	Leaf 1	
	Leaf 2	
	Leaf 3	
Date, time		

Research questions – Water

Discuss in your group which research question you find most interesting. Write down this research question in large letters in the box below.

Research questions – Plants

Discuss in your group which research question you find most interesting. Write down this research question in large letters in the box below.

Research questions – Weather

Discuss in your group which research question you find most interesting. Write down this research question in large letters in the box below.

Research questions – Soil

Discuss in your group which research question you find most interesting. Write down this research question in large letters in the box below.

Teacher information: Selection of research questions
The balloon method

Duration: ca. 30 min

Material: P9a-d (research questions), magnets or sticky tape, blackboard and chalk or white board and pens

Goal: Selection of a suitable question per topic.

Preparation: Draw the outline of a large hot air balloon on the blackboard or whiteboard. Fix (with magnets or tape) the worksheets P9a-d as "ballast" around the balloon. The balloon printed above can be downloaded from https://creazilla.com/de/nodes/2270-heissluft-ballon-silhouette for free in resolutions sufficient to print it largely.

Description: The students put themselves in the situation that they are sitting in the hot air balloon. But the balloon continues to descend because it is loaded with too many questions. In order for the balloon to rise again, the students have to exclude one question after the other and "throw it overboard". In the end, only one question should be left for each topic (one blue, one green, one grey and one yellow card). The following guiding questions can be used as criteria for evaluating a research question:

- There needs to be a way to answer the question.
- The question must be complex enough but not too complex
- Can we answer this question?
    - with the means available?
    - in the time available?

Teacher information: Setting the research agenda

Worksheet P10 is an example. A sheet like this is intended to be used if the research questions are specified by the teacher. In the list of questions, at least one place is assigned to each topic of the LEAP. The background colors of the boxes are used throughout the material in order to create a visual connection of all documents belonging to the same question.

The places and questions have to be adjusted to the specific situation at a school. School building and schoolyard are usually suitable to do observations on content like temperature, radiation, or clouds. A sports ground and its surrounding often has different surface covers and degrees of sealing which enables infiltration experiments. Similarly, a vegetated place will be found at each school. Observations on water do not require an open water body like a stream, river, pond, or lake. Instead, a place where water accumulates after rain events can be used to study the way of the water into the ground or back into the atmosphere.

Suggestions for extensions:

1. Prior to the presentation of research questions, the students can deal with research questions in general using sheet P29.
2. The research questions can be shown without places assigned. The students use their map (P12) to identify suitable places.

Research questions

The stream: What is the quality of the water?

The Park: What do the plants look like right now? How does this change over time?

The school building: Where is it warmer, close to the school building or in the schoolyard?

The schoolyard: How does cloud cover influence ground and air temperature on tarred surfaces?

The sports ground: On which surface can water best infiltrate (seep) into the soil?

Teacher information: Places at our school

The worksheets of P11 are examples. There must be one sheet for each place identified as suitable. Places are assigned to research questions previously presented by the teacher (P10). The background colors of the boxes are used throughout the material in order to create a visual connection of all documents belonging to the same question or place.

The places and questions have to be adjusted to the specific situation at a school. School building and schoolyard are usually suitable to do observations on content like temperature, radiation, or clouds. A sports ground and its surrounding often has different surface covers and degrees of sealing which enables infiltration experiments. Similarly, a vegetated place will be found at each school. Observations on water do not require an open water body like a stream, river, pond, or lake. Instead, a place where water accumulates after rain events can be used to study the way of the water into the ground or back into the atmosphere. School ground exploration and site description can also be applied to many other topics like energy consumption (where is it consumed) or circular economy (what kinds of waste to we have).

During the introduction to this module, the teacher can refer to the research cycle (P3) and can explain the importance of this step for the documentation of the research process.

Places at our school: The stream

What is the quality of the water?

Description of the place:	Sketch (rough draft) of the place:
(What does the stream look like? How fast is it flowing? Do you see plants or algae in the water? What is the color of the water? What about its transparency?)	

Places at our school: The park

What do the plants look like right now? How does this change over time?

Description of the place:	**Sketch (rough draft) of the place:**
(What plants can you see? How big are they? Do they have leaves/needles? Are the plants green?)	

Places at our school: The school building

Where is it warmer, at the school building or in the schoolyard?

Description of the place:	Sketch (rough draft) of the place:
(What does the school building look like? Are the walls rather warm or rather cold? Is the wind blowing at the school building?)	

Places at our school: The schoolyard

How does cloud cover influence ground and air temperature on tarred surfaces?

Description of the place:	Sketch (rough draft) of the place:
(What does the ground look like on the schoolyard? How warm or cold does it feel? What was the weather like during this observation (sunny, cloudy, …)?)	

Places at our school: The sports ground

On which surface can water best infiltrate (seep) into the soil?

Description of the place:	**Sketch (rough draft) of the place:**
(What different ground surfaces are found on and around the sports ground? What do these surfaces look like? Do plants grow there?)	

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Teacher information: A map of our school

Simply create your own land use map for your school according to the template shown below:

1. Enter your school's address at https://www.openstreetmap.org
2. Zoom in or out until your school building and, if applicable, adjacent areas are shown.
3. Save the image or use the screenshot tool (Snipping Tool in case of MS Windows) to copy the image.
4. Paste the image into worksheet P12, cut it to suit to extent of the grid and position it in the background so that the grid is in the foreground.
5. In the table and bullet point 2 of the instructions on P12, fill in the places the students are intended to find in the map.
6. Adjust the legend to the requirements of the surroundings of your school.

A map of our school (Example)

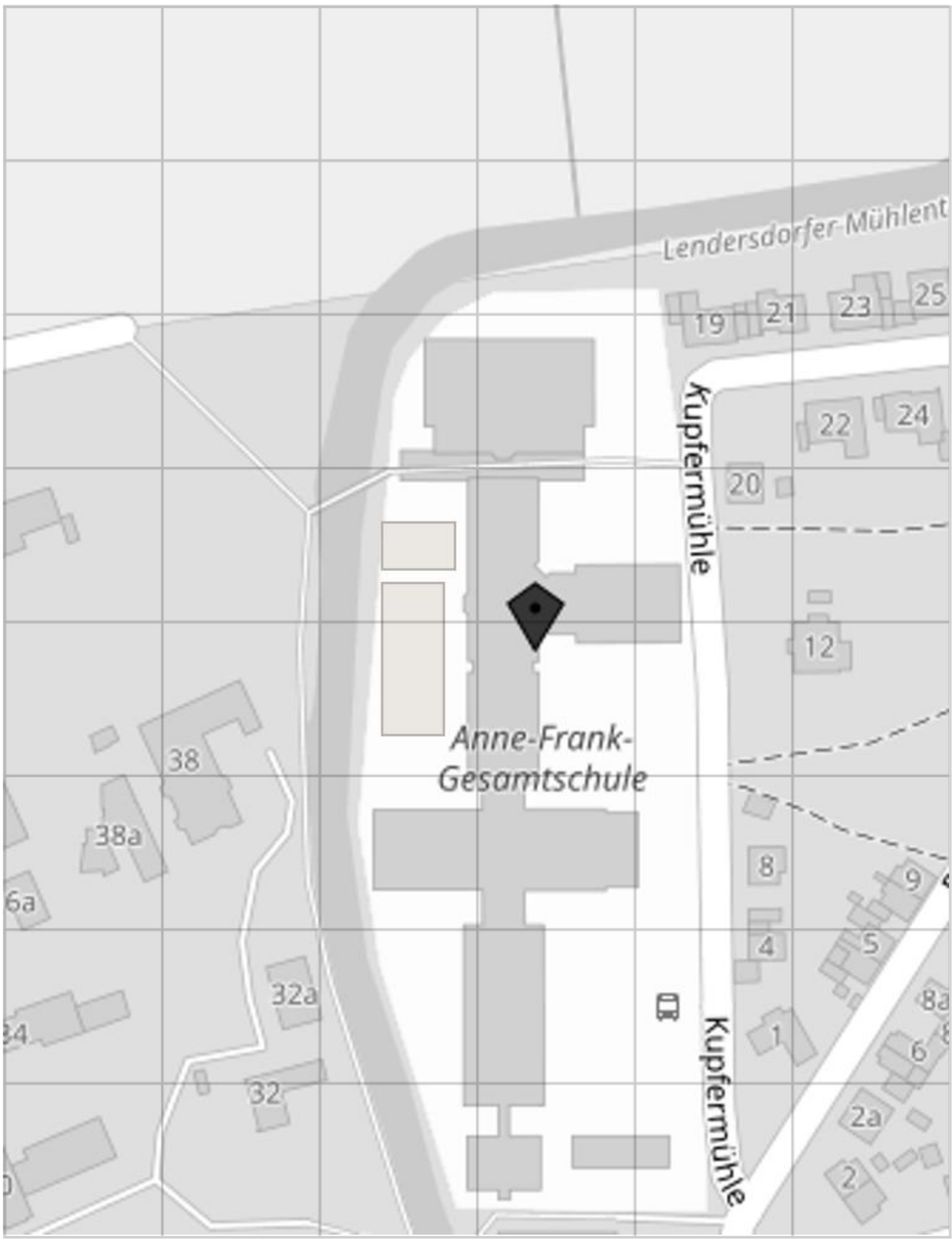
1. Explore your school grounds in groups of three or four
2. Move to the following places and label them on the map

bridge, gym, sports ground, bus stop, canteen

3. Fill in the coordinates of these places in the table.
4. Find out which area are used for what: Paint the areas of the map with the correct colors (see legend).

A B C D E F

1 2 3 4 5 6 7 8



Place	Coordinates

Legend

- Agricultural area
- Park/ green area
- Housing area (residential buildings)
- Public buildings (school, …)
- Tarred area
- Water body (river, stream, pond, …)
- Recreation or sports ground

A map of our school

1. Explore your school grounds in groups of three or four
2. Move to the following places and label them on the map
3. Fill in the coordinates of these places in the table.
4. Find out which areas are used for what: Paint the areas of the map with the correct colors (see legend).

	A	B	C	D	E	F
1						
2						
3						
4						
5						
6						
7						
8						

Place	Coordinates

Legend

- Agricultural area
- Park/ green area
- Housing area (residential buildings)
- Public buildings (school, …)
- Tarred area
- Water body (river, stream, pond, …)
- Recreation or sports ground

The Water Challenge!

Your Challenge: Create a soil with at least three layers. Which group manages to let one liter of water seep through their soil in the shortest time?

Required materials:

Soils:

- Sand
- Clay
- Silt
- Gravel

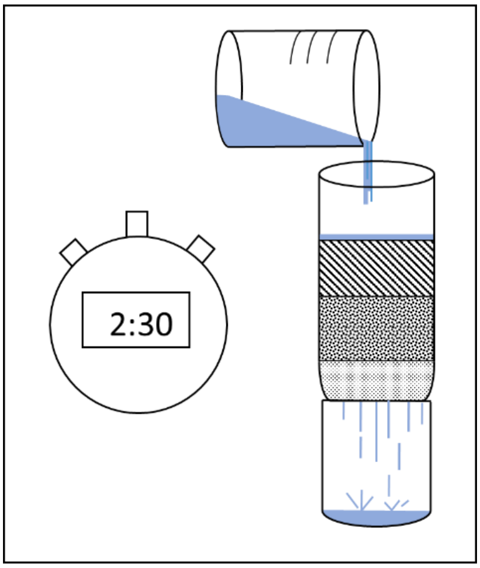
Bottle with cut-off bottom

Measuring cup

Stop watch

1 liter of water

Experimental set-up:



Procedure:

1. Write down your research question for this experiment.
2. Watch the properties of the different soil components. Write them down in the table. The following words might help you:

loose – firm – crumbly – fine – clumpy – heavy – light – coarse

Sand	Silt	Clay	Gravel

3. Now the task is to stack three layers of soil on top of each other. Write down a hypothesis, which layering and order of soils (in the bottle) will let one liter of water seep through it in the shortest time.

4. Fill the bottle as written down in the hypothesis up to the mark.
5. Wait until your teacher gives the start signal. Then, all groups pour the water into the bottle onto the soil and measure the time the water needs to seep through it.
6. The group where the water seeped through the soil in the shortest time wins.

Teacher information: Water Challenge

The water challenge has two main goals:

1. The students practice the scientific method and repeat the steps of the research cycle. This is meant as a contribution to fostering trust in the method of science by hands-on experience.
2. The students learn about different soils and their ability to hold water or let it percolate. This is important knowledge in the context of the water cycle and therefore very helpful when trying to understand weather and climate.

The students have to decide on a layering of the different materials. This is a hypothesis against the background of the research question “Which sequence of layers results in the fastest seepage of 1 l of water?” A complete test of the hypothesis will usually not be feasible in the context of a school course since all possible sequences would have to be tested. Therefore, the interpretation of the results may become ambiguous.

Practical advice:

1. First, the bottle should be filled with some material that prevents the soil from falling through the bottle’s neck. Some filter paper, for example, is suitable for this purpose.
2. As the soil saturates with water, not all of the filled liter will flow through. Therefore, a quantity of water must be determined, at which the time is stopped. In that case, a measuring cup is also needed. Alternatively, a time can be set in which no more water is allowed to drip out (e.g. one minute).

Properties of the water: quality and transparency

1. First observe: What do you see in the water? Mark with a cross on the line.

many leaves or parts of leaves	◄────────────►	no leaves or parts of leaves
many small animals	◄────────────►	no small animals
a lot of particulate matter	◄────────────►	no particulate matter

2. The transparency of water can be measured by sinking a disk with a pattern printed on it (Secchi-disk) into the water. The depth where the pattern can no longer be seen is called the visible depth of the water. To measure the visible depth, sink the Secchi-disc into the water until you can no longer see the pattern. Note the visible depth below:

Date and time of the measurement: ___________________________________

Visible depth: _______________________

Properties of the water: pH and temperature

1. Use a pH strip to measure the pH of the water. Enter it into the table.
2. Use a thermometer to measure the temperature of the water. Enter it into the table.

Date and time:	
pH:	
temperature:	

University of Cologne
PULCHRA

Teacher information: Seasonal cycle of plants

This material may need to be adjusted to the vegetation on the school ground or its surrounding. Additional images of other plants (mainly trees) can be found on the website of the GLOBE program (http://globe.gov). Search for the term “green-up cards”. Make sure to include the hyphen.

Results ordering of plant growth stages

Grasses: C = 1; A = 2; B = 3

Landscape: A = 1; D = 2; C = 3; B =4

Birch: B = 1; C = 2; A = 3

Seasonal cycles of plants

1. On the worksheets P15b to P15d, number the images in the order in which the stages occur in the seasonal cycle. Start with the phase that appears first in the calendar year.
2. What is the current state of the plants? Compare the images with your surroundings.
3. Write down your observations in the table below.

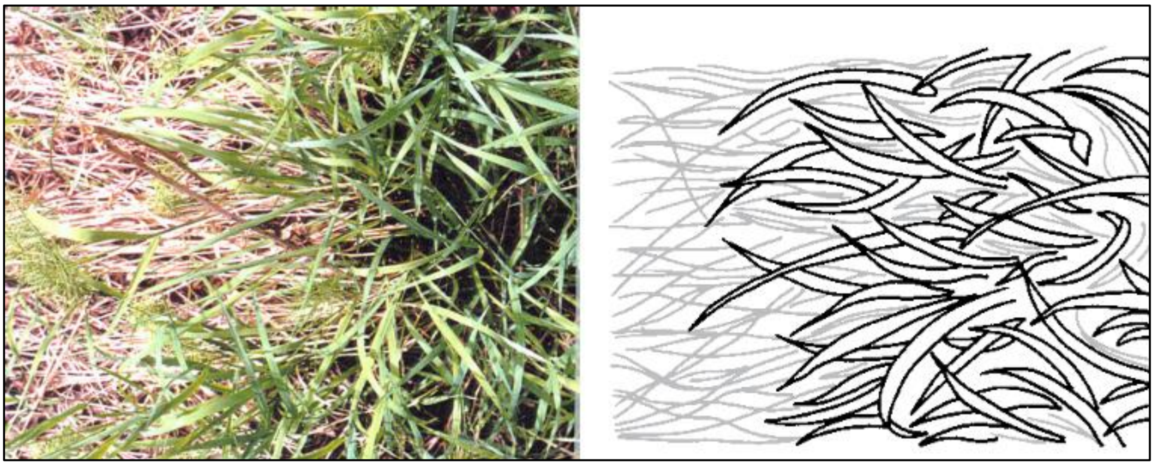
	Current state is similar to image No.	Description of the plant (color, size, buds/leaves/flowers, branches, bark)
Grasses		
Birch		
Landscape		

Source of images: Globe © 2014: Green Up Cards Learning Activity – Biosphere.
https://www.globe.gov/documents/355050/71351540-65d6-46a2-b6dd-1504b4035170

Seasonal cycle - grasses

A

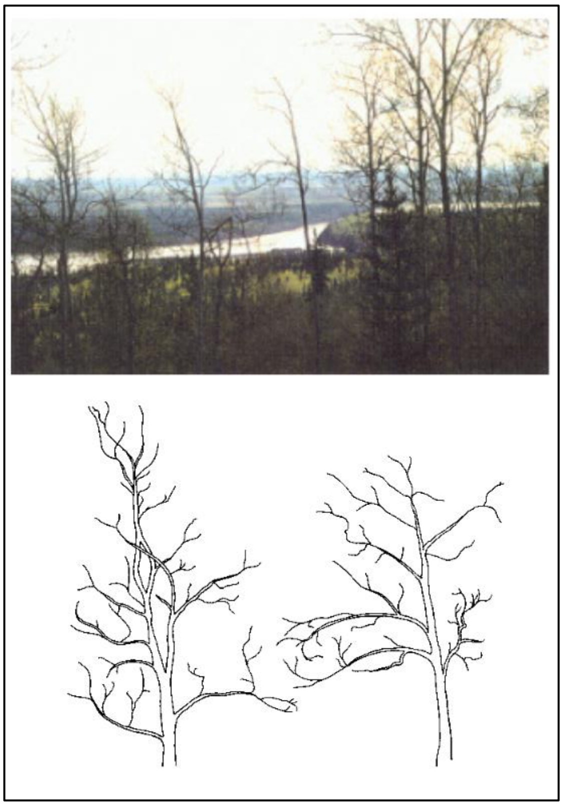
B



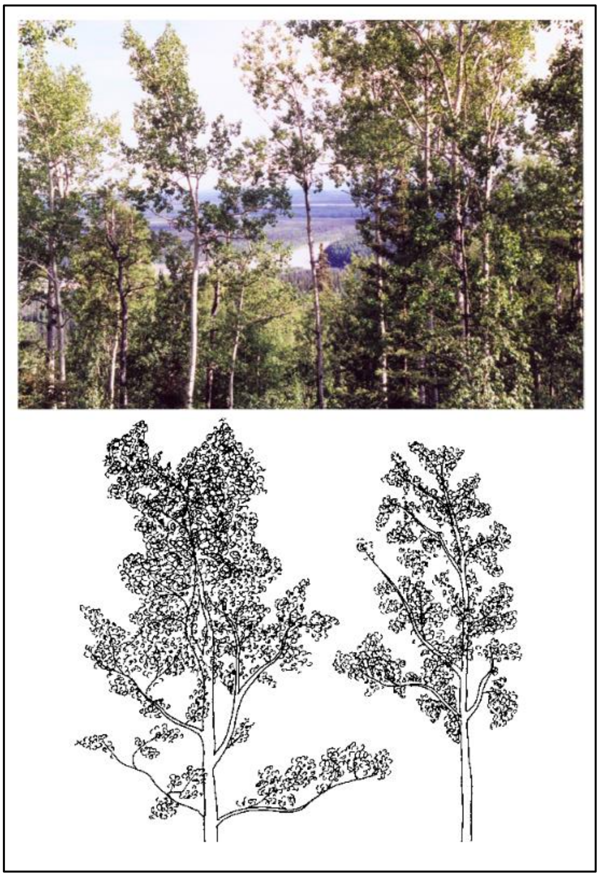
C

Seasonal cycle - landscape

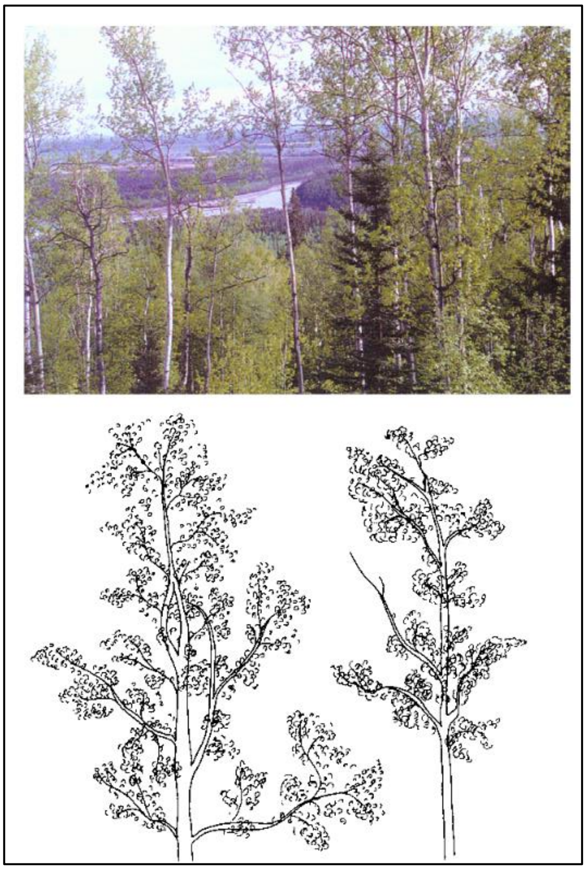
A



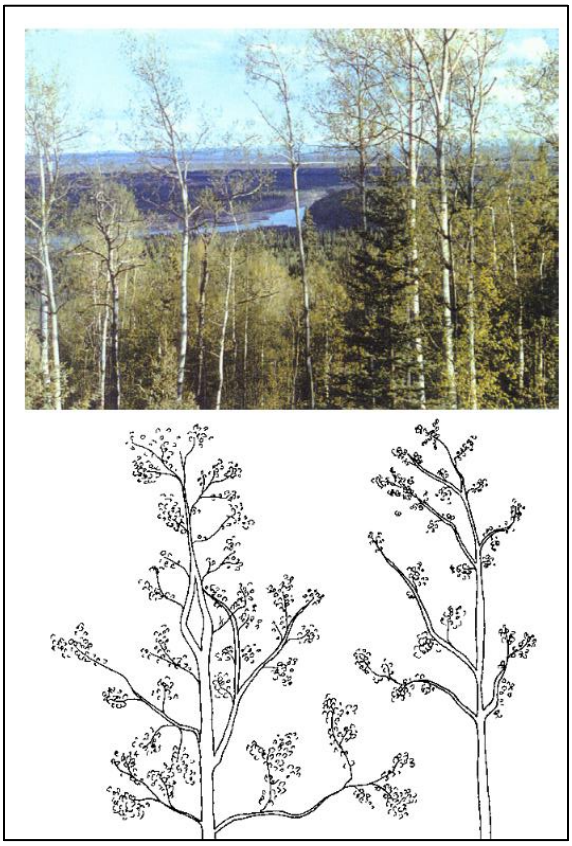
B



C

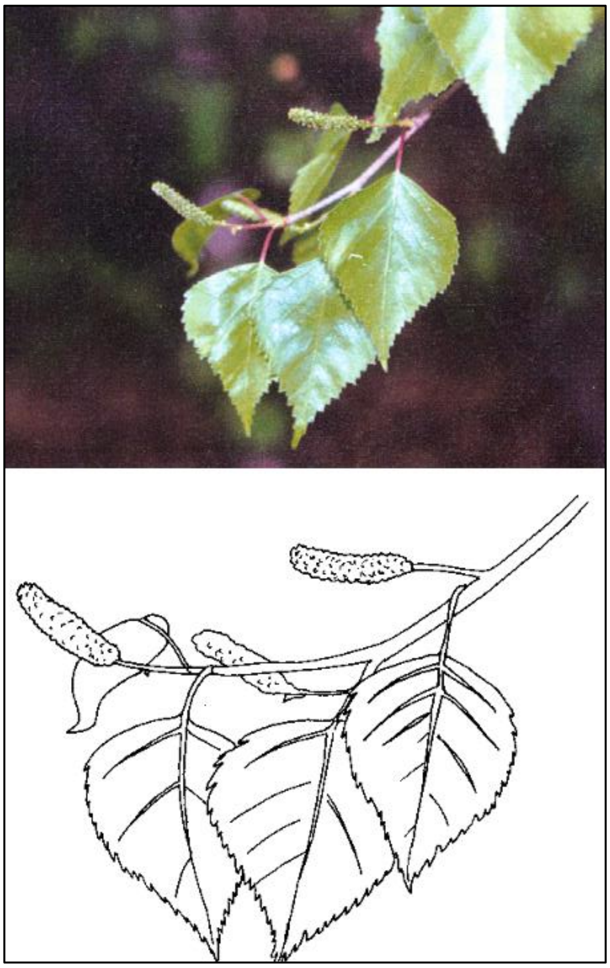


D

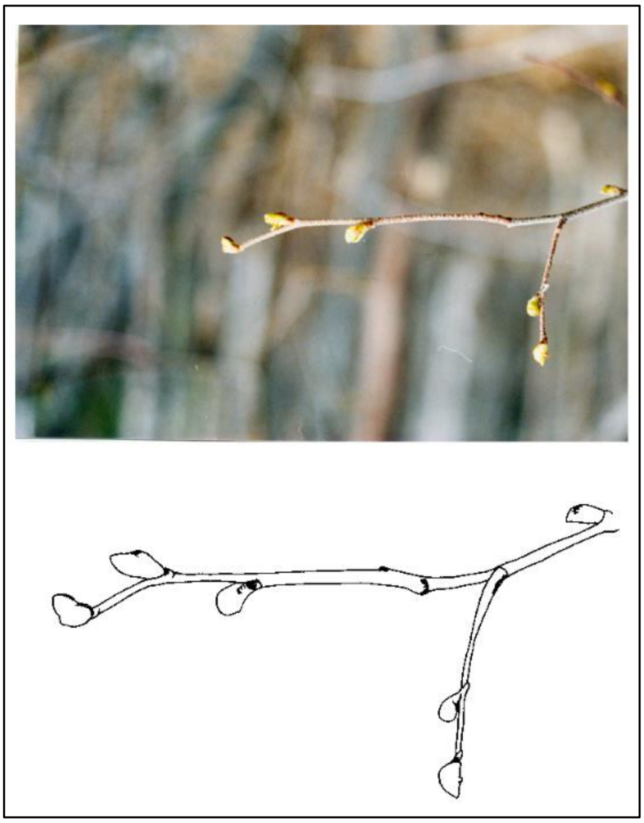


Seasonal cycle – Birch

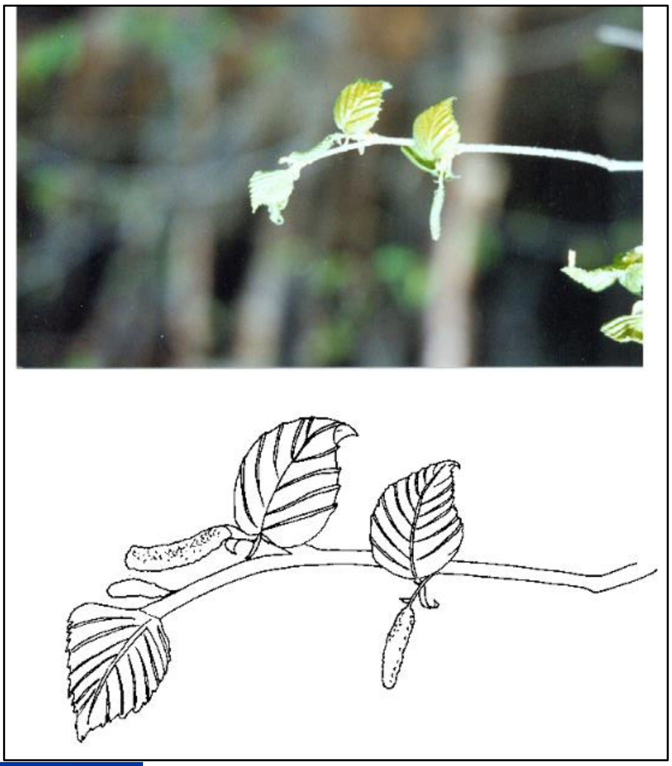
A



B



C



Teacher information: Wind and temperature

This material is about the influence of surface sealing and building on the local (micro-)climate. The data may be compared to other measurements on nearby grassland or under trees/inside forests to show the differences. Measurements of that kind can easily be made using low-priced temperature sensors like iButtons or DIY low-cost system based on Arduino microcontrollers. A building instruction for a radiation shield, which is required for the sensors to measure air temperature, can be found in material P35 of the PULCHRA Collection of Educational Materials.

The Wind measurements on material P16 suggest two methods, which can be applied in parallel. The first is a technical measurement using an anemometer. The second is the pure observational assessment of the wind. The method uses a scale defined by Frances Beaufort (1774-1857). With this method, the wind speed can be described based on phenomena caused by the wind. An explanation for students can for example be found at

https://www.3dgeography.co.uk/beaufort-scale.

Wind and temperature

1. Measure the wind near the school building (max. two meters away) and in the schoolyard (ca. 20 meters away, about 20 great strides). Enter your measurements in the table below.

	Wind speed measured with	
	Anemometer	Observation (Beaufort method)
close to the school building		
on the schoolyard		
Date and time		

2. Measure the temperature of the ground and the air near the school building (max. two meters away) and in the schoolyard (ca. 20 meters away, about 20 great strides). Enter your measurements in the table below.

	ground temperature	air temperature
close to the school building		
on the schoolyard		
Date and time		

What did you observe?

Where is the ground warmer than the air? ________________________________

Where is the air warmer than the ground? ________________________________

Where is the wind blowing more? ________________________________

Imagine standing in the middle of the city. There are a lot of buildings around you. How do you think does that affect the temperature?

Imagine you are in the forest. There are a lot of trees around you. How do you think does that affect the temperature?

➔ Write a story to explain to your little sibling how buildings influence the temperature outside.

Clouds and temperature

1. Use the "data sheet clouds" (P17b) and the fact sheets "Types of clouds" (P17c) to find out which clouds are in the sky. Write your observations into the table.
2. Use the thermometer to measure the warmth of the air and the warmth of the ground (tar or paving) on the schoolyard. Enter your measurements into the table below.

Date and time: ____

		observation / measurement
clouds	cloud cover	
	sky color	
	cloud type	
	conditions at ground level	
temperature	ground temperature	
	air temperature	

Data sheet clouds

Check your observations. In some boxes, you will see a white arrow. Only when you have placed a cross there, you go to the box the arrow points to. If you have not placed a cross there, you can skip this box.

1. What do you see in the sky?

Degree of coverage (clouds, vapor trails)
- O darkened
- O nothing
- O clear (<10%)
- O isolated (10-25 %)
- O scattered clouds (25-50 %)
- O broken cloud cover (50-90 %)
- O overcast sky (90-100 %)

- O fog
- O heavy rain
- O drifting snow
- O heavy snowfall
- O sand

- O spray
- O smoke
- O dust
- O mist
- O volcanic ashes

Move on to box 6.

2. Color and visibility of the sky

Color	O sky invisible	O deep blue	O blue	O light blue	O pale blue	O milky
Visibility	O sky invisible	O very clear	O clear	O slightly hazy	O very hazy	O extremely hazy

3. High clouds and condensation trails

O No high clouds to be seen
Go to box 4.

Type of clouds:
- O condensation trails (number)
- O cirrus
- O cirrocumulus
- O cirrostratus

Number of condensation trails that are ...
- ☐ short-lived
- ☐ lasting, not scattered
- ☐ lasting scattered

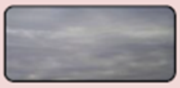
Degree of coverage
- O clear (<10%)
- O isolated (10-25 %)
- O scattered clouds (25-50 %)
- O broken cloud cover (50-90 %)
- O overcast sky (90-100 %)

Opacity of the clouds
- O opaque
- O slightly translucent
- O highly translucent

4. Middle clouds

O No middle clouds to be seen
Go to box 5.

Type of clouds:

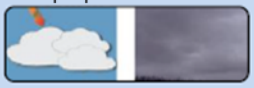
O altostratus 

O altocumulus 

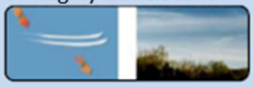
Degree of coverage

O clear (<10%)
O isolated (10-25 %)
O scattered clouds (25-50 %)
O broken cloud cover (50-90 %)
O overcast sky (90-100 %)

Opacity of the clouds

O opaque


O slightly translucent


O highly translucent


5. Low clouds

O No low to be seen
Go to box 6.

Type of clouds:

O fog 

O nimbostratus 

O cumulonimbus 

O stratus 

O cumulus 

O stratocumulus 

Degree of coverage

O clear (<10%)
O isolated (10-25 %)
O scattered clouds (25-50 %)
O broken cloud cover (50-90 %)
O overcast sky (90-100 %)

Opacity of the clouds

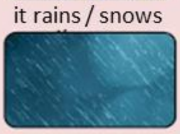
O opaque


O slightly translucent


O highly translucent


6. Conditions close to the ground

Mandatory

	yes	no
snow / ice 	O	O
stagnant water 	O	O
boggy 	O	O
dry 	O	O
trees with leaves 	O	O
it rains / snows 	O	O

Voluntary

temperature: ___________ °C

air pressure: ___________ mb

relative humidity: _______ %

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Types of clouds

Cloud types

Five word elements are used to designate the different cloud types:
CIRRO for clouds at a very high altitude (high clouds), **ALTO** for clouds in medium altitude (middle clouds), **CUMULUS** for fleecy or heap clouds, **STRATUS** for sheet clouds, **NIMBUS** for rain clouds

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High clouds 5-13 km

Cirrus
Feather clouds

Shape: fibrous or thread-like, formed by wind currents; stripes, bands, spots, sometimes bizarre structures
Thickness: very thin, sun shines through
Color: white, with a silky glimmer
Info: always consists of ice crystals

Cirrocumulus
Fleecy clouds

Shape: fine white balls or flakes, thin, sometimes patchy, sheet-like
Thickness: very thin, sun shines through
Color: white
Info: consists of ice crystals, rarely also of supercooled water drops; diameter always < 0.5° (pinky on the outstretched hand)

Cirrostratus
High sheet clouds

Shape: Thin, milky, translucent cloud veil of hairy or fibrous appearance; covers large parts of the sky
Thickness: very thin, sun always shines through and is sharply defined
Color: light grey or whitish
Info: can cause halo appearances around moon and sun

Middle clouds 2-7 km

Altocumulus
Rough fleecy clouds

Shape: stripes, spots, patchy layers; often arranged in banks
Thickness: moderately thick
Color: white or grey shades, partly pearlized
Info: consists of water drops, sometimes supercooled; diameter of cloud elements 1-5° (1-3 fingers on the outstretched hand)

Altostratus Middle sheet clouds

Shape: Dense layer cloud, often even and opaque, usually covering the entire sky
Thickness: moderately thick to thick
Color: grey or blue-gray
Info: no halos; if thick enough continuous rain / snow; consists of supercooled water; if sun visible then as through a frosted glass

Nimbostratus Rain clouds

Shape: Grey veil covering the entire sky, indistinct lower edge
Thickness: thick
Color: medium till dark grey
Info: consists of supercooled water, larger rain drops and snow crystals or snowflakes; causes continuous rain

Cloud types

Five word elements are used to designate the different cloud types:
CIRRO for clouds at a very high altitude (high clouds), **ALTO** for clouds in medium altitude (middle clouds), **CUMULUS** for fleecy or heap clouds, **STRATUS** for sheet clouds, **NIMBUS** for rain clouds

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Low clouds 0-2 km

Stratocumulus
Fleecy sheet clouds

Shape: mosaic-like plaices, rollers, or banks, sharply bounded or frazzled
Thickness: moderately thick
Color: grey or whitish
Info: consists of water or ice crystals; mostly no rain or snow; partly remainders of Stratus or Cumulus clouds

Stratus
Low sheet clouds / high fog

Shape: grey even layer cloud (often high fog); lower edge usually low and rather difficult to detect
Thickness: thin to moderately thick
Color: light grey to dark grey
Info: seldom rain or snow; if sun visible then sharply outlined

Cumulus
Heap clouds

Shape: separate, sharply bounded clouds shaped like hills, knolls, or towers; lower edge flat
Thickness: moderately thick to thick
Color: shining white in sunlight
Info: seldom rain or snow, can be precursor of Cumulonimbus

Low clouds 0-2 km

Cumulonimbus
Shower- or thundercloud

Shape: bulky and dense clouds shaped like a high mountain or tower, often with an anvil
Thickness: thick, looming
Color: lower side dark grey
Info: often brings thunderstorms (lightning, thunder, hail)

Fog
Stratus

Info: Fog is a cloud that touches the ground. You don't usually see what kind of cloud that is.

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Soil identification

Use the data sheet “Soil identification” (P18b) to determine the properties of the soil. Enter your results in the table below.

	Description of properties
Color	
Structure	
Consistency	
Texture	
Gravel	
Roots	

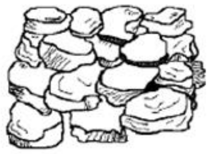
Data sheet "Soil identification"

Structure

Is the soil…

Coarse (grainy): resembles crumbs of cookies and is usually less than 5 mm in diameter. Is often found in horizons near the surface where roots grow

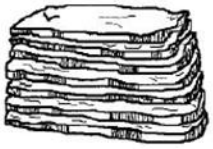

Blocky (lumpy): Irregular blocks, usually 15-50 mm in diameter.

Prismatic: Vertical soil columns (clearly visible in the horizon), which can be a several centimeters long. Usually found in lower horizons.


Column-shaped: Vertical columns with a white rounded "cap" at the top. To be found in soils in arid climate.

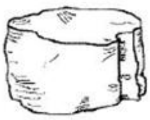

Plate-like: Thin, flat, horizontal soil sheets. Found in compacted soils.

Sometimes, soil samples do not have a visible structure. These are divided into the following two types:

Single-grained: The soil is broken up into individual particles that do not adhere to each other. The sample therefore always has a loose consistency. Is usually found in sandy soils.

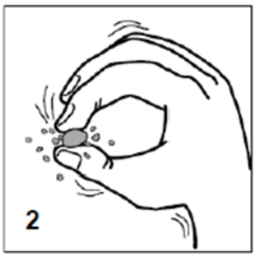
Solid (compact): The soil has no visible structure, is almost impossible to break up and shows itself in large chunks.

Is the soil...

Consistency

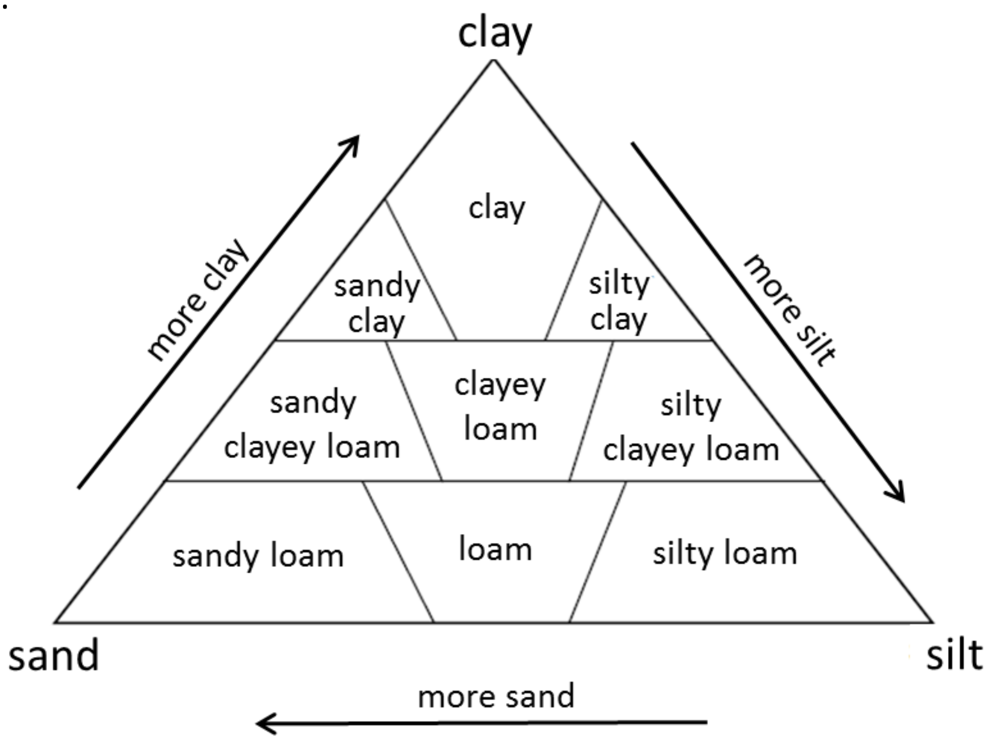
Is the soil...



1. **Loose:** It is difficult to take out a crumb and the structure falls apart before you start to work. Note: Single grain soils always have a loose consistency.
2. **Crumbly:** The soil crumb disintegrates even at low pressure.
3. **Firm:** The crumb only disintegrates under pressure, so the crumb leaves an imprint in your fingers.
4. **Very firm:** the crumb cannot be crushed with the fingers, you need a hammer for this.

Texture

Is the soil...



Mark with a cross	Gravel	
none	← →	many
Mark with a cross	Roots	
none	← →	many

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Teacher information: The way of the water

The question: Where does the water go starting at the ground surface?

Reflection: Why is it important to know where the water goes when it rains?

	Direction of motion		
	downwards	along the surface	upwards
Where does the water go when it moves in this direction?	Into the soil	Downhill following the slope of the terrain	Into the atmosphere, it evaporates
How long do you think does the water stay there?	Days up to weeks or even longer	Some hours	It is quickly moving into the atmosphere, but remains in the atmosphere for a few days on average
Where does it go thereafter?	Into the groundwater, into streams and rivers, or it is taken up by plants	To a stream, a river, or into the ocean	It returns as precipitation (rain)
Why is it important that the water can seep into the soil?	- So that less flooding can occur - So that the plants have water to evaporate (transpire) and can grow - So that the animals living in the soil have water - So it doesn't get too warm, because when the plants transpire, it stays cooler - …		
Does the water seep away at the same rate in all places on your LEAP? If not, where is it the slowest and where the fastest?	Park > sports ground > schoolyard		

The way of the water

Where does the water go starting at the ground surface?

Think and fill in the table below.

	Direction of motion		
	downwards	along the surface	upwards
Where does the water go when it moves in this direction?			
How long do you think does the water stay there?			
Where does it go thereafter?			
Why is it important that the water can seep into the soil?			
Does the water seep away at the same rate in all places on your LEAP? If not, where is it the slowest and where the fastest?			

Teacher information: Example Route card

This route card is an example for an experiments day in a project week at a school. The example refers to the example course and overview plan shown in section 2.4.1 of the PULCHRA Handbook of Educational Materials. In the table, the experiments are given as questions. These are not the research questions from P16 but are more closely related to the experiment or observation. Answers to these experimental or observational questions can then be used to answer the research questions from P16.

Example Route card

place	experiment / measurement / observation	materials
Park	- What color are the leaves? - In which growth stage are the plants?	- P8: Leaf colors - P15: plant growth stages
school building	- How strong is the wind blowing? - How warm are air and ground close to the building and in the school yard?	- P16: Wind and temperature
schoolyard	- Which type of clouds can we see? - How warm are the ground and the air?	- P17a: Clouds and warmth - P17b: Data sheet clouds - P17c: Types of clouds
stream	- How fast does the water flow? - How transparent is the water?	- P14a: transparency - P14b: pH and temperature
sports ground	- Which kinds of soil do we find? - How fast does water seep into different soils?	- P18: Soil identification - P36: Infiltration

Group 1: Home group "park"

	Time
park	09:00 – 10:00
school building	10:30 – 11:45
schoolyard	11:45 – 12:50
stream	13:40 – 14:25
sports ground	14:25 – 15:15

Group 2: Home group "school building"

	Time
school building	09:00 – 10:00
schoolyard	10:30 – 11:45
stream	11:45 – 12:50
sports ground	13:40 – 14:25
park	14:25 – 15:15

Group 3: Home group "schoolyard"

	Time
schoolyard	09:00 – 10:00
stream	10:30 – 11:45
sports ground	11:45 – 12:50
park	13:40 – 14:25
school building	14:25 – 15:15

Group 4: Home group "stream"

	Time
stream	09:00 – 10:00
sports ground	10:30 – 11:45
park	11:45 – 12:50
school building	13:40 – 14:25
schoolyard	14:25 – 15:15

Group 5: Home group "sports ground"

	Time
sports ground	09:00 – 10:00
park	10:30 – 11:45
school building	11:45 – 12:50
schoolyard	13:40 – 14:25
stream	14:25 – 15:15

Teacher information: Analysis of results

These work sheets are intended to make the students gather data from other groups and thus prepare the data basis for the analysis.

Material P21f refers to measurements and observations, which are interesting in the context of water quality studies but are not described in the PULCHRA Collection of Educational materials (electric conductivity, pH). Please refer to other sources or ask the PULCHRA team.

Analysis of results: Plants

Leaf colors

Gather the data on leaf colors (sheet P8) of all groups. Mark with a cross which color each group assigned the leaf, respectively. Compare the results of the groups.

	rather blue/green	rather yellow/green	rather brown/green	rather brown/red
Group 1,	Date, time:			
Plant 1				
Plant 2				
Plant 3				
Group 2,	Date, time:			
Plant 1				
Plant 2				
Plant 3				
Group 3,	Date, time:			
Plant 1				
Plant 2				
Plant 3				
Group 4,	Date, time:			
Plant 1				
Plant 2				
Plant 3				
Group 5,	Date, time:			
Plant 1				
Plant 2				
Plant 3				

Analysis of results: Plants

Growth stages

Gather the data on growth stages (sheet P15a) of all groups. Note two or three keywords per plant with which all groups have used to describe these plants.

	All groups wrote:
Grasses	
Birch	
Landscape	

Analysis of results: Weather

Wind speed

Gather the data on wind speed (sheet P16) of all groups. Compare the results of the groups. Enter them into the table below.

	Group 1	Group 2	Group 3	Group 4	Group 5
Time					
Wind speed close to the school building					
Wind speed at the schoolyard					

Temperature

Gather the data on air temperature (sheet P16) of all groups. Compare the results of the groups. Enter them into the table below.

	Group 1	Group 2	Group 3	Group 4	Group 5
Time					
Temperature close to the school building					
Temperature at the schoolyard					

Analysis of results: Weather

Clouds and temperature

Gather the data on clouds and temperature of ground and air (sheet P17a) of all groups. Compare the results of the groups. Enter them into the table below.

	Group 1	Group 2	Group 3	Group 4	Group 5
cloud cover					
cloud type					
ground temperature					
air temperature					

Analysis of results: Soil and water

Infiltration

Gather the data on infiltration (sheet P36) of all groups. Compare the results of the groups. Enter them into the table below.

	distance in cm	time in minutes	= cm per hour***
EXAMPLE	*7 cm*	*36 minutes*	*11.64 cm per hour*
Group 1			
Group 2			
Group 3			
Group 4			
Group 5			

*** You have to calculate that with rule of three. You can use the calculator.

This is the solution for the ***EXAMPLE*** using the rule of three:

	7 cm	→	36 minutes	
: 36				: 36
	0.194 cm	→	1 minute	
• 60				• 60
	11.64 cm	→	60 minutes	

Analysis of results: Soil

Soil identification

Gather the data on soil properties (sheet P18a) of all groups. Find out, what the majority of groups wrote about each soil property. If you disagree with the majority's opinion for a reason, discuss this with your teacher. Enter the results into the table below.

For gravel and roots, make up your mind how to depict the result as a number.

property	result
Color	
Structure	
Consistency	
Texture	
Gravel	
Roots	

Analysis of results: Water

Visible depth

Gather the data on visible depth (sheet P14a) of all groups. Compare the results of the groups. Enter them into the table below. For leaves, small animals, and particulate matter, make up your mind how to depict the result as a number.

	Group 1	Group 2	Group 3	Group 4	Group 5
Date, time					
leaves or parts of leaves					
small animals					
particulate matter					
visible depth					

Other measurements

Gather the data on pH, temperature, and electric conductivity (sheet P14b and P14c) of all groups. Compare the results of the groups. Enter them into the table below.

	Group 1	Group 2	Group 3	Group 4	Group 5
Date, time					
pH					
temperature					
electric conductivity					

Analysis of results: Water

Flow velocity

Gather the data on flow velocity (sheet P14d) of all groups. Compare the results of the groups. Enter them into the table below.

	Group 1	Group 2	Group 3	Group 4	Group 5
Date, time					
In the middle					
near the bank, left side (in flow direction)					
near the bank, right side (in flow direction)					

Analysis of results: Comparison

1. **Which results are equal or similar?**

2. **Which results are clearly different?**

3. **What may be the reason for these differences? (reasons, ideas, suppositions)**

Teacher information:
Temperature diurnal course and clouds

Material P23 deals with the influence of clouds on temperatures. The temperature curves shown here were measured with the Cool City Lab. The DIY experiment “Cool City Lab” is introduced in materials P30 (building instructions), P31 (experimentation guide for beginners), and P32 (experimentation guide for advanced learners).

To simplify the work with P23 only one temperature curve can be shown. At the same time, questions 7 and 8 can be skipped.

Temperature diurnal course and clouds

In the figure, you can see the temperatures in the boxes of the Cool City Lab (P30, P31) for the period 2019/03/25 until 2019/03/28.

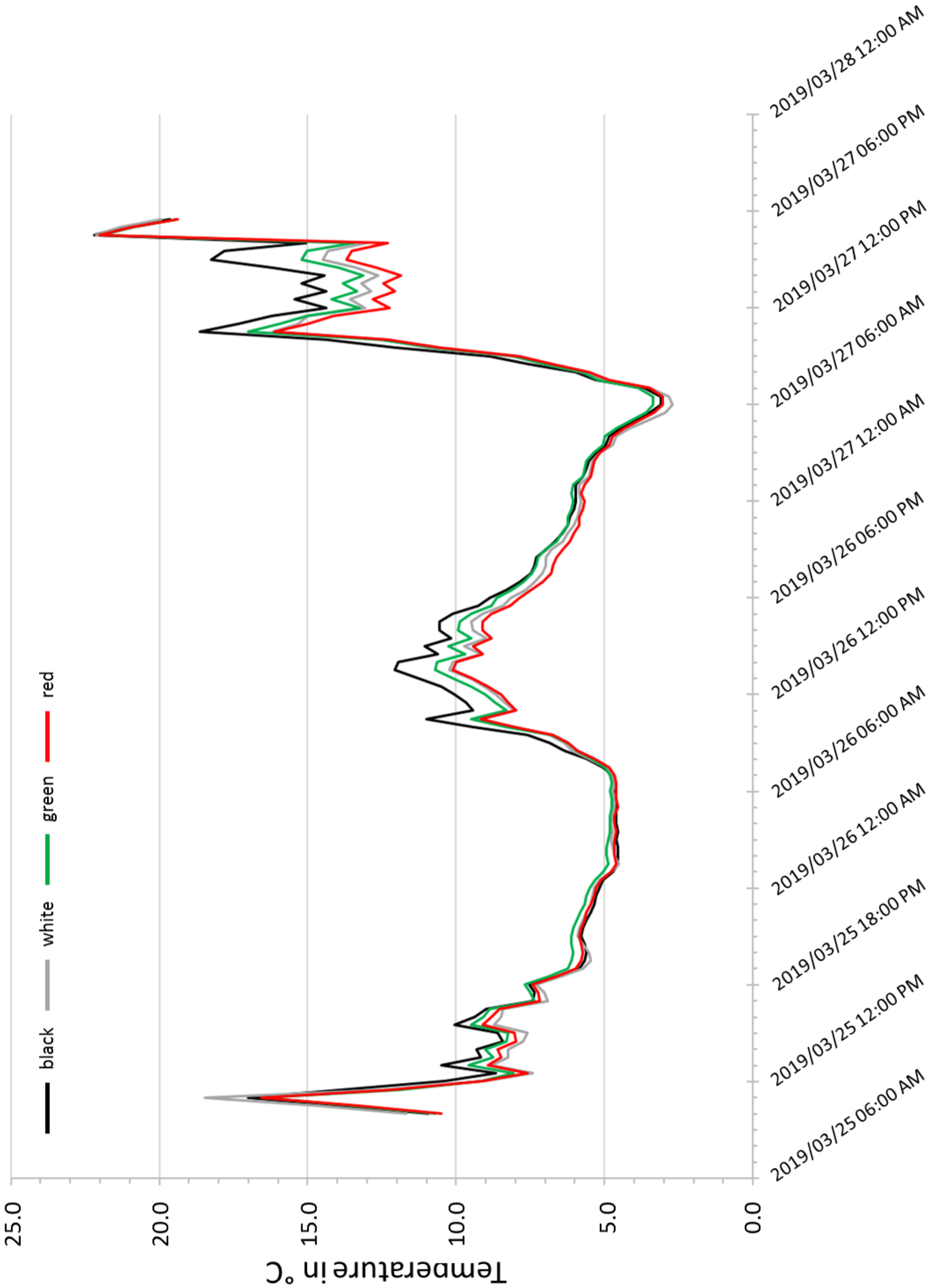
1. **On the x-axis, circle the measurements that belong to the same day (2019/03/25; 2019/03/26; 2019/03/27; 2019/03/28).**
2. The sun's peak was at about 1:34 PM. This was not at 12:34 PM because it is daylight savings time. During daylight savings time, the clocks are set forward for one hour). **Mark the measurement for each day at 12 noon with yellow.**
3. **At what time is it coldest?**
   a. on 2019/03/25:___________
   b. on 2019/03/26:___________
   c. on 2019/03/27:___________
   d. on 2019/03/28:___________
4. **At what time is it warmest?**
   a. on 2019/03/25:___________
   b. on 2019/03/26:___________
   c. on 2019/03/27:___________
   d. on 2019/03/28:___________
5. ☆☆ Why is it coldest early in the morning and not at midnight?

6. ☆☆ Why is it not warmest at noon?

7. **Which box is warmest during the day?** The ________________________ box
8. **Which box is coldest during the day?** The ________________________ box
9. **Mark the location of Germany on the satellite images (approximately).**
10. **Look at the satellite images. What was the weather like on these days? Mark with a cross.**

			
on 2019/03/25			
on 2019/03/26			
on 2019/03/27			
on 2019/03/28			

11. **Compare the cloudiness found in the satellite images with the temperatures found in the boxes. Is there a relation? What could be the reason?**


black
white
green
red
Temperature in °C
0.0
5.0
10.0
15.0
20.0
25.0
2019/03/25 06:00 AM
2019/03/25 12:00 PM
2019/03/25 18:00 PM
2019/03/26 12:00 AM
2019/03/26 06:00 AM
2019/03/26 12:00 PM
2019/03/26 06:00 PM
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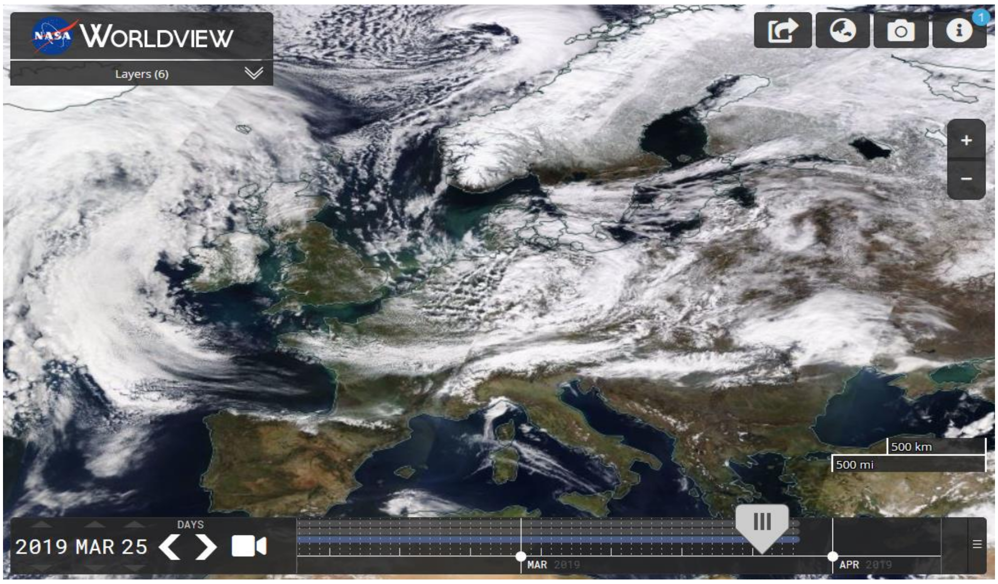
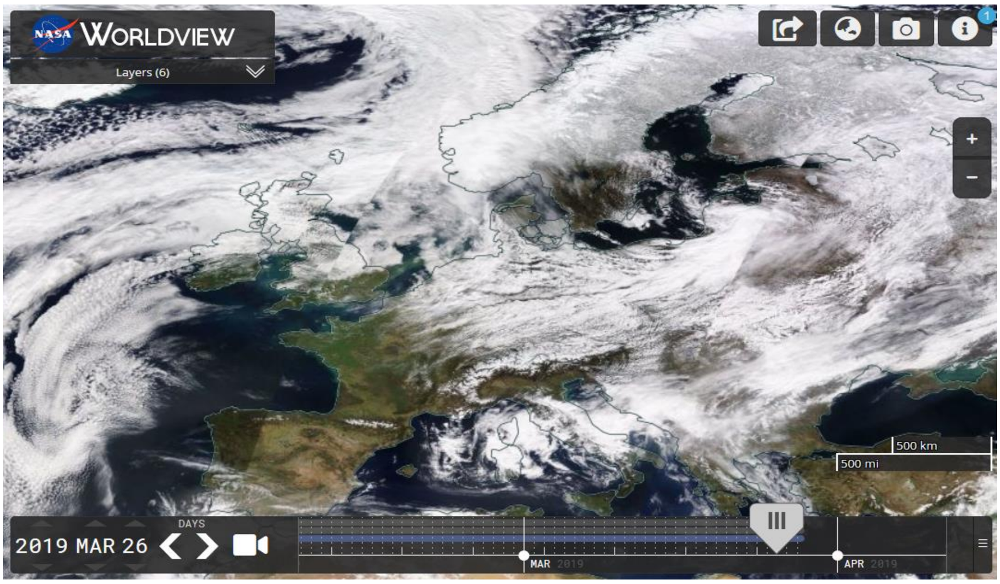
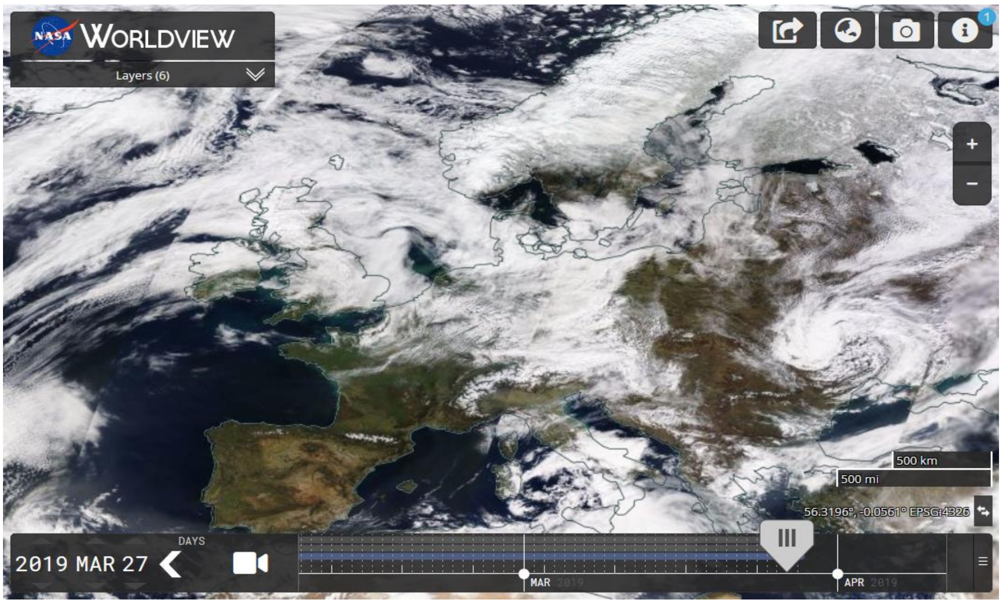
2019/03/27 06:00 AM
2019/03/27 12:00 PM
2019/03/27 06:00 PM
2019/03/28 12:00 AM


NASA
WORLDVIEW
Layers (6)
500 km
500 mi
DAYS
2019 MAR 25
MAR 2019
APR 2019


NASA
WORLDVIEW
Layers (6)
500 km
500 mi
DAYS
2019 MAR 26
MAR 2019
APR 2019


NASA
WORLDVIEW
Layers (6)
500 km
500 mi
56.3196°, -0.0561° EPSG:4326
DAYS
2019 MAR 27
MAR 2019
APR 2019

Teacher information: Description sheets for the LEAP

Material P24 is on the preparation of the descriptions sheets, which will finally presented at the LEAP. It includes the sheets (P24a-e) and supporting material for the analysis and evaluation of the results (P24g-i). It is accompanied by the presentation P24f, which introduces to the gathering, analysis, and evaluation of the results from the experiments and observations. **This presentation serves as the introduction to this part of the course.**

Since P24f is a presentation, it is not included in this file but is available as a separate file (MS Powerpoint) accompanying the PULCHRA Collection of Educational Materials. It can be downloaded from the PULCHRA homepage.

Along the template P24b – P24e, the students create a description sheet for each station of the Learning, Exploring and Activity Path (LEAP). The students can fill in the description sheets by hand or using a computer.

Since the profiles are addressed to the "public", the teacher should advise the students to write their texts in such a way that they can be understood by everyone and that they are of good text quality. The students can check and correct their texts mutually, or they can give them to the teacher for checking.

With regard to language-sensitive teaching, this material contains a sheet on phrasing assistance (P24h), which can help when filling out the description sheet, especially for students who have to work in a foreign language or students with language support needs in general.

Our school – a Learning, Exploring and Activity Path

Station 1: The stream

Description:

Our research question:

Our hypothesis:

This is how we investigated it:

Materials:	Experimental set-up:
Procedure:	

Here is what we found out:

Our hypothesis was ☐ confirmed ☐ refuted

Our school – a Learning, Exploring and Activity Path

Station 2: The park

Description:

Our research question:

Our hypothesis:

This is how we investigated it:

Materials:	Experimental set-up:
Procedure:	

Here is what we found out:

Our hypothesis was ☐ confirmed ☐ refuted

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Our school – a Learning, Exploring and Activity Path

Station 3: The school building

Description:

Our research question:

Our hypothesis:

This is how we investigated it:

Materials:	Experimental set-up:
Procedure:	

Here is what we found out:

Our hypothesis was ☐ confirmed ☐ refuted

Our school – a Learning, Exploring and Activity Path

Station 4: The schoolyard

Description:

Our research question: ***Our hypothesis:***

This is how we investigated it:

Materials:	Experimental set-up:
Procedure:	

Here is what we found out:

Our hypothesis was ☐ confirmed ☐ refuted

Our school – a Learning, Exploring and Activity Path

Station 5: The sports ground

Description:

Our research question:

Our hypothesis:

This is how we investigated it:

Materials:	Experimental set-up:
Procedure:	

Here is what we found out:

Our hypothesis was ☐ confirmed ☐ refuted

Presentation of results

Task: Create a first draft of your description sheet. You can use the phrasing assistance on sheet P24h.

	done! ✓
1. Create a **description of the place**. Regard the following a. Your original description of the place b. Further information on the site collected during the experiment.	
2. Write down your **research question** and **hypothesis** on the description sheet.	
3. Create a **list of materials** containing the things you used for the experiment, the measurement, or the observation that belongs to your place.	
4. Describe the **experimental set-up** you used for your experiment. You can either a. describe the experiment in writing OR b. illustrate the experimental set-up with a drawing.	
5. Describe the **procedure** during the experiment.	
6. Describe the results of your experiment. a. Write a short summary (two to three sentences) about what you found out. b. Present you results in a clear and vivid way using <u>at least two</u> display formats. The following list shows some suggestions but you can develop your own form as well. 1. Diagram 2. Comic 3. Story 4. Drawing	

When you are done with everything:

1. **Show your description sheet to your teacher and have it checked.**
2. **Make a final version of your description sheet by copying it down nicely. This profile will be laminated and will be presented at your station of our LEAP.**

Phrasing assistance

Phrasing assistance "description":

Write in this field the special characteristics of the place. This could be, for example what the place looks like. You can describe the soil, important plants, the appearance of the water, or whether the sky is visible. Doing this, you should also pay attention to your research question.

Phrasing assistance "hypothesis":

A hypothesis always refers to question. In addition, there must be a way to test what is stated in the hypothesis. Thus, a hypothesis can often be formed by repeating parts of the question. For example, a hypothesis for the question "when will it be light?" may be "It will be light when the sun rises". This can easily be tested by observing the light in the early morning.

Phrasing assistance "materials and experimental set-up":

This part becomes most clearly arranged if you write down the material in a list. You can list the material in the order in which it was used. You can also draw the experimental set-up.

Phrasing assistance "procedure":

Write short sentences on what your group did like "At first we… Then we… Finally we…".

Phrasing assistance "results":

In the results, you can describe what you observed: "We observed that..."

You can describe what you have measured: "We have measured … It was …. °C warm; … meters long; … km/h fast."

Checklists

Description

	++	0	--
Things that can be seen are described.			
The **colors** of the things/plants are described.			
The **sizes** of things/plants are described.			

Materials

	++	0	--
All the things needed for the experiment are named.			
The materials are clearly presented in an orderly list.			

Experimental set-up

	++	0	--
drawn:			
The picture is clearly visible and neatly drawn.			
The image is labeled (e.g. with arrows and names of the things).			
written:			
Someone who did not do the experiment can understand…			
…where the experiment was conducted.			
…what was measured.			
…what was used to measure.			

Procedure

	++	0	--
The words or terms "at first", "then", "thereafter" are used to show what was done **in which order**.			
All steps of the experiment are described.			

Symbols: ++ completely fulfilled
0 partly fulfilled
-- not fulfilled

Evaluation sheet for presentations

Rate the presentation for each aspect with ++, +, o, or -

	Schoolyard	School building	Sports ground	Stream	Park
All members of the group took part in the presentation.					
All members of the group spoke loud and clear.					
The group's research question was clearly explained.					
The group's hypothesis was clearly explained.					
It was explained, which experiments / observations were made.					
The results were explained.					
It was told whether or not the hypothesis was confirmed.					

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Participatory Urban Learning Community Hubs through Research and Activation

The PULCHRA Collection of Educational Materials

University of Cologne

Our two votes go to the groups:

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Participatory Urban Learning Community Hubs through Research and Activation

The PULCHRA Collection of Educational Materials

University of Cologne

Our two votes go to the groups:

PULCHRA

Participatory Urban Learning Community Hubs through Research and Activation

My Research Diary

Name: ....

School: ....

University of Cologne
PULCHRA

Date: ________________________________

What did I do today?

Which methods and materials did I use?

This is what I learned today:

I enjoyed / did not like this today:

Date: ________________________________

What did I do today?

Which methods and materials did I use?

This is what I learned today:

I enjoyed / did not like this today:

The PULCHRA Collection of Educational Materials

Evaluation of the research day

The research day was …	interesting						boring
Working with the other kids was…	great						bad
I learned …	a lot						nothing
I could explore my own questions:	yes						no
I would now like to learn more about research:	yes						no

Please complete the sentences:

Before the research day today, I had no idea that ____

____

____

The thing that surprised me most today was ____

____

____

Evaluation of the research week

The research week was …	interesting						boring
Working with the other kids was…	great						bad
I learned …	a lot						nothing
I could explore my own questions:	yes						no
I would now like to learn more about research:	yes						no

Please complete the sentences:

Before the research week, I had no idea that ____

____

____

The thing that surprised me most today was ____

____

____

Smartphone apps for environmental observations

Several Smartphone-Apps are available to accompany the materials in the PULCHRA Collection of Educational Materials. These Apps do not require installation from a repository but run in the browser. The central Website for these apps is:

https://geographie.uni-koeln.de/en/outreach/citizen-science-with-smartphones/list-of-apps

Not all apps listed on that site are available in English, yet.

Apps for the following topics are provided and introduced in the given materials:

Weather observer (P28a)
https://enketo.ona.io/x/2RTmeT7N

Cloud types (P28b)
https://enketo.ona.io/x/#pULJ

Leaf damages (P28c)
https://enketo.ona.io/x/#dFA26bHV

Soil texture (P28d)
https://enketo.ona.io/x/#pUL9

Soil type (P28e)
https://enketo.ona.io/x/#pUAo

Animal tracks (P28f)
https://enketo.ona.io/x/#pUAH

Land cover / land use (P28g)
https://enketo.ona.io/x/#pUxR

Plant phenology / seasonal cycle of plants (P28h)
https://enketo.ona.io/x/#pUx1

River structural quality, short version (P28i)
https://enketo.ona.io/x/#p0ku

River structural quality, expert version (P28j)
https://enketo.ona.io/x/#p05z

Flow velocity and runoff (P28k)
https://enketo.ona.io/x/#p0xf

Rocks (P28l)
https://enketo.ona.io/x/ #f9br6yCH

Information on the use of the Apps can be found here:

https://geographie.uni-koeln.de/en/outreach/citizen-science-with-smartphones/app-use

There, you also find a FAQ and a list of known problems.

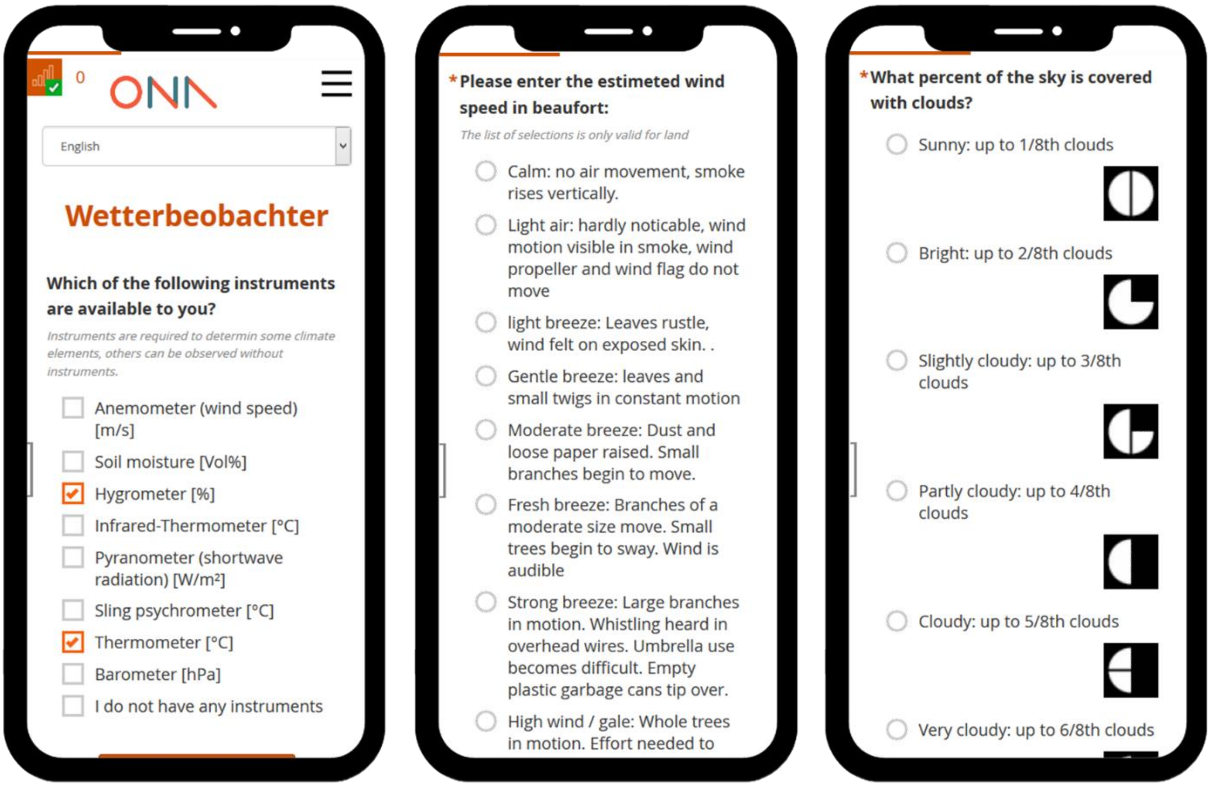
The linguistic style of the apps addresses more advanced students, who are familiar with the terminology and technical language.

App: Weather observer

With this app, weather phenomena can be documented. It is part of the app collection for the documentation of geographic excursions. Through systematic documentation, processes in the atmosphere can be recognized and analyzed in their regional characteristics. The collected data are available for subsequent evaluation. We hope you enjoy your excursion and explore the environment.

This app is available at https://enketo.ona.io/x/2RTmeT7N

Languages (other language versions will be added in the course of the project):



Smartphone image cut out from http://www.pngall.com/?p=35820, license CC 4.0 BY-NC

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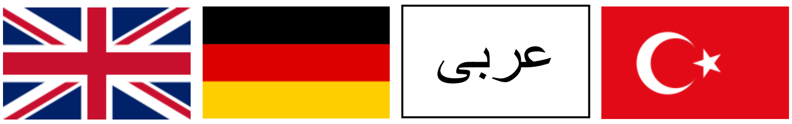
App: Cloud types

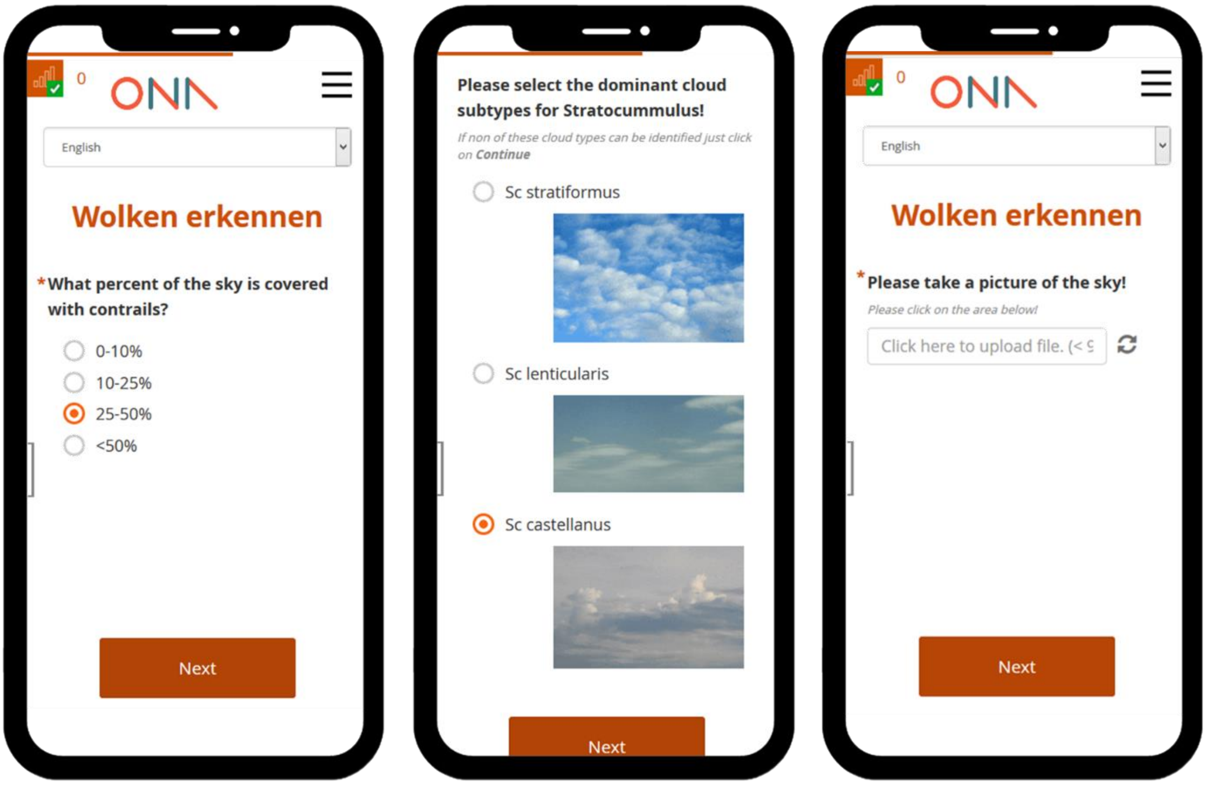
With this app, you can identify different cloud types. By observing clouds you will learn much about the actual weather situation, the state of the atmosphere and you may even make weather predictions. If you monitor clouds over a period of hours or days, you will see regularities in the atmospheric processes (e.g. warm fronts, cold fronts, thunderstorm, or fog formation).

Whether used for education, science or just for fun, monitoring clouds and their change is scientifically rather important and also very interesting. You will be surprised how many thrilling things you can learn about the atmosphere by observing clouds. Have fun exploring.

This app is available at https://enketo.ona.io/x/#pULJ

Languages (other language versions will be added in the course of the project):





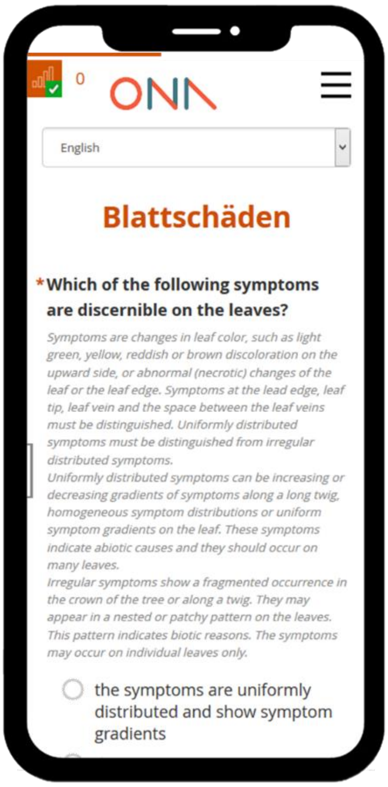
Smartphone image cut out from http://www.pngall.com/?p=35820, license CC 4.0 BY-NC

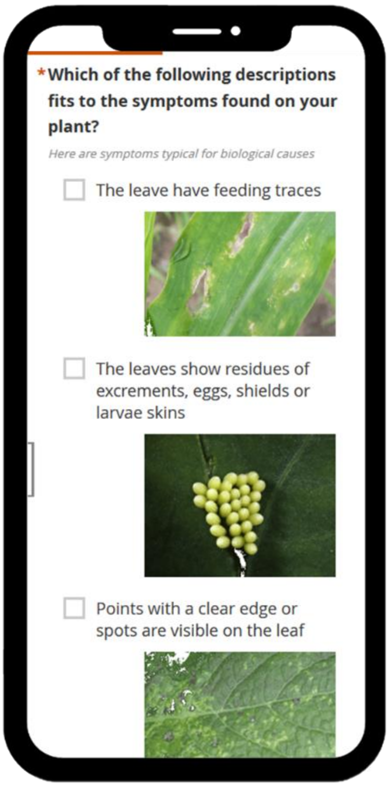
App: Leaf damages

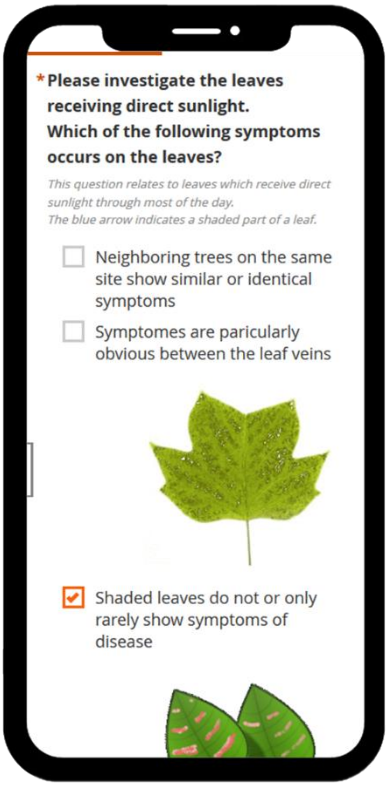
Plants and particularly leaves can indicate environmental pollution. This app helps you to identify symptoms of diseases on deciduous trees. This app considers particularly also symptoms related to ozone damage. However, there are also other stress factors such as drought stress, nutrition stress, insects of diseases, which result in visible damages to the leaves. This app helps to identify leave damage and provide a first diagnosis. A certain diagnosis typically requires additional independent evidence and measurements. Have fun while exploring and discovering nature.

This app is available at https://enketo.ona.io/x/#dFA26bHV

Languages (other language versions will be added in the course of the project):







Smartphone image cut out from http://www.pngall.com/?p=35820, license CC 4.0 BY-NC

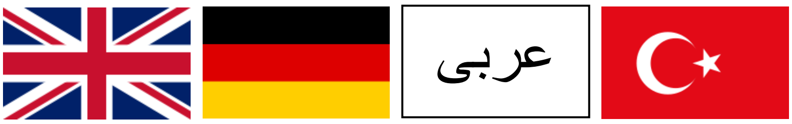
App: Soil texture

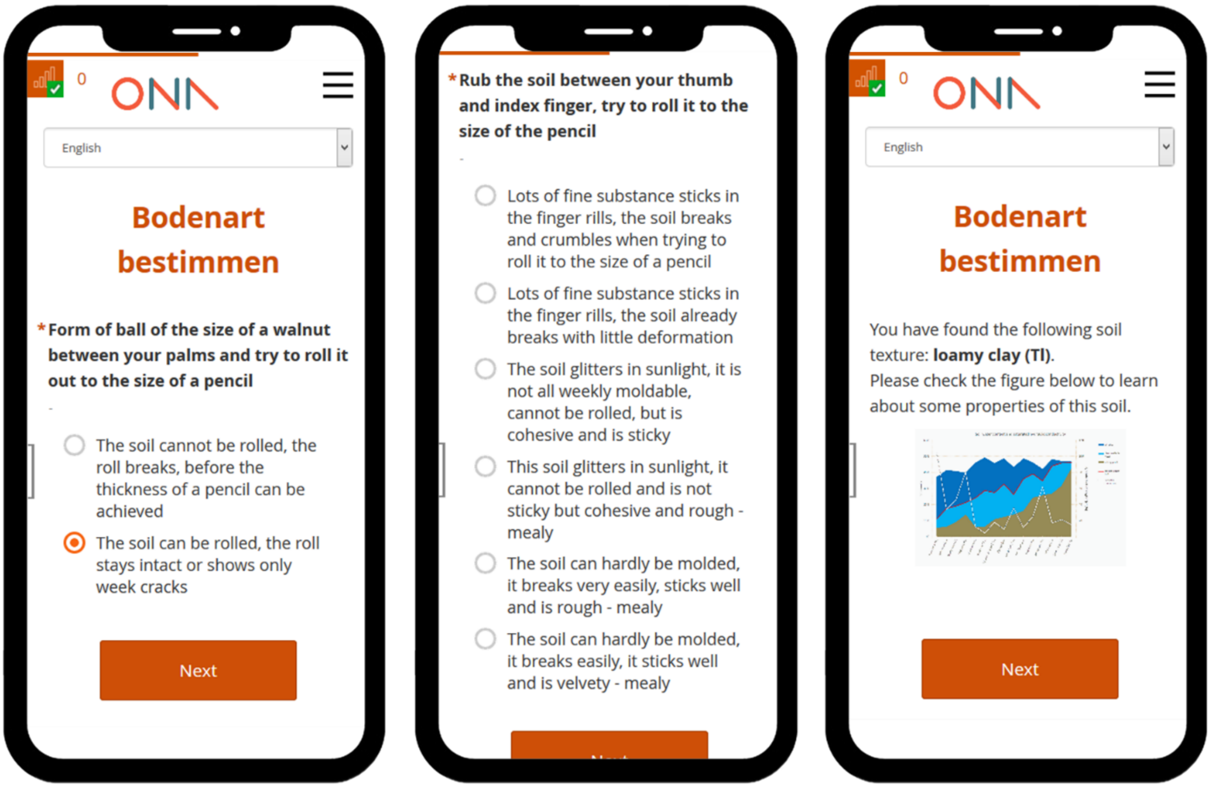
With this app, you can determine the soil texture. The soil texture is another word for the grain size distribution. With this app, you can estimate the fractions of clay, silt and sand. Soil texture is important for plant growth but also for water conductivity and nutrient availability of the soil. If you know the soil texture, you already know a lot about the development of the soil and its properties.

You will be surprised about the variety of soils and how soils determine the plant communities. Explore your environment and experience how soils, plants and climate interact.

This app is available at https://enketo.ona.io/x/#pUL9

Languages (other language versions will be added in the course of the project):





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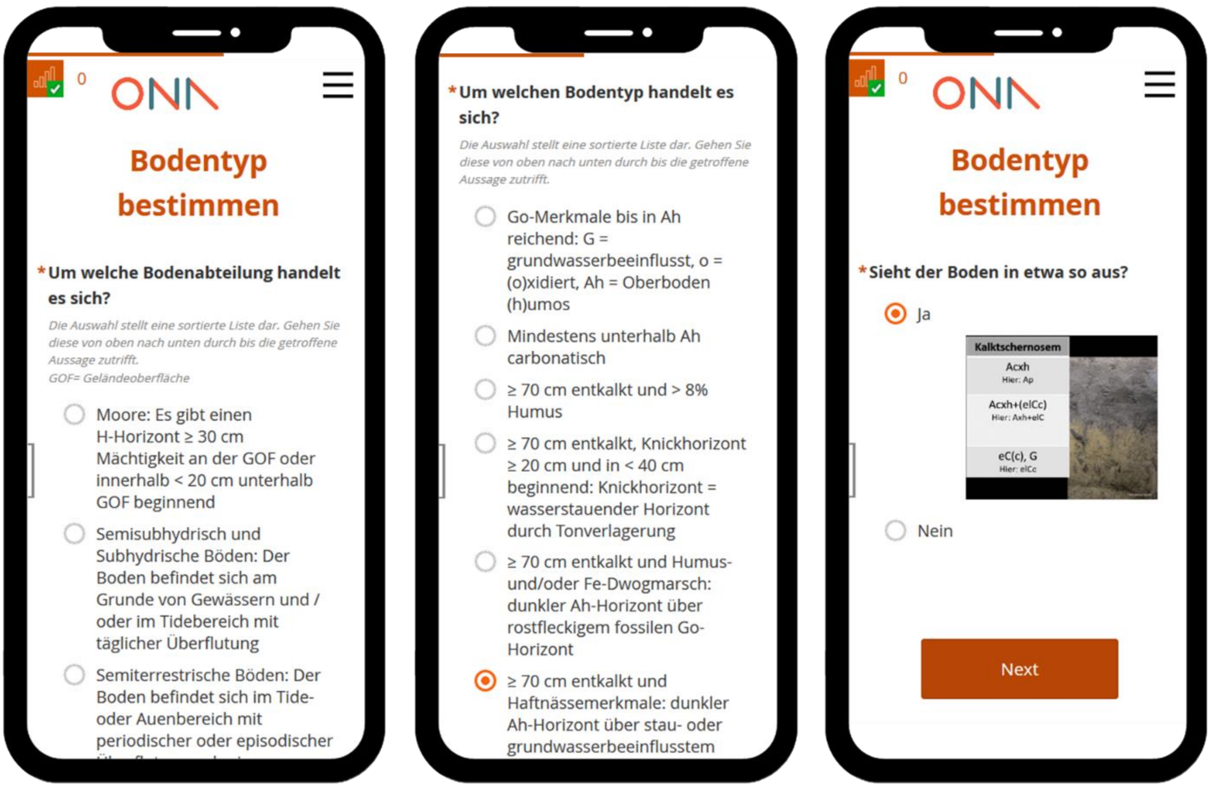
App: Soil type

With this app, you can determine the soil type. The soil type results from the layer sequence of the soil. With this, you can say a lot about the conditions of the soil. The soil type is not only important for plant growth, but also for the chemistry and the availability of nutrients. You will be surprised how different soils can be and how the soils determine the occurrence of plants. Discover your environment and experience how soil, plants and climate influence each other.

This app is available at https://enketo.ona.io/x/#pUAo

Languages (other language versions will be added in the course of the project):



Smartphone image cut out from http://www.pngall.com/?p=35820, license CC 4.0 BY-NC

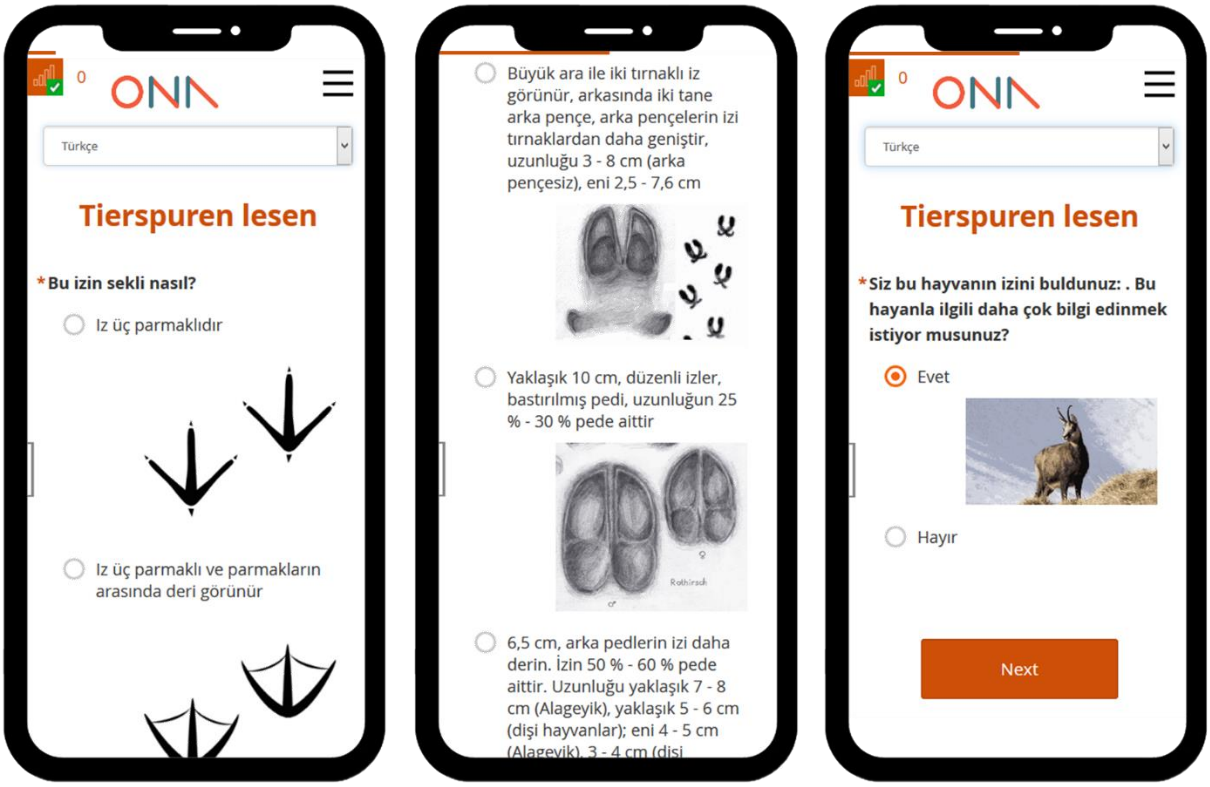
App: Animal tracks

This app helps you to identify animals by means of traces. Several traces in a row form a track. We share our habitat with a variety of other creatures. Even if we do not see many wild animals, we should adjust our behavior so that the animals are not unnecessarily disturbed or we do not destroy their habitat. For this purpose, it is important to know which animals are present here. Animal tracks help to do this. Use this app to discover which animals live here. Learn something about their habits and needs. Help to keep this habitat attractive for humans and animals. Mutual consideration is necessary for this. Have fun getting to know the animal world in your area.

This app is available at https://enketo.ona.io/x/#pUAH

Languages (other language versions will be added in the course of the project):

عربى



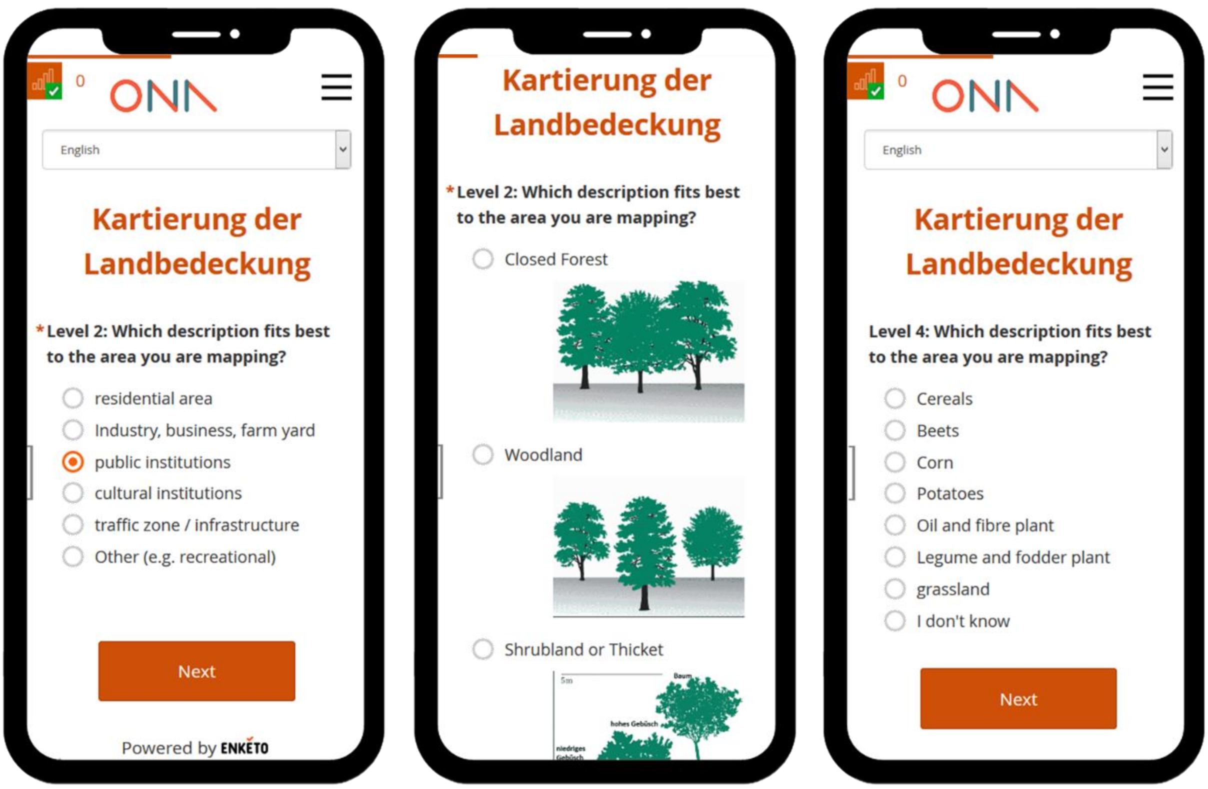
Smartphone image cut out from http://www.pngall.com/?p=35820, license CC 4.0 BY-NC

App: Land use /land cover

With this app you can map vegetation types, land use and land cover. Whether used for education, science or just for fun, monitoring land use / land cover and its change is scientifically rather important and also very interesting. You will be surprised how rapidly some landscape change over time. Explore your environment and experience the dynamics of land use change.

This app is available at https://enketo.ona.io/x/#pUxR

Languages (other language versions will be added in the course of the project):



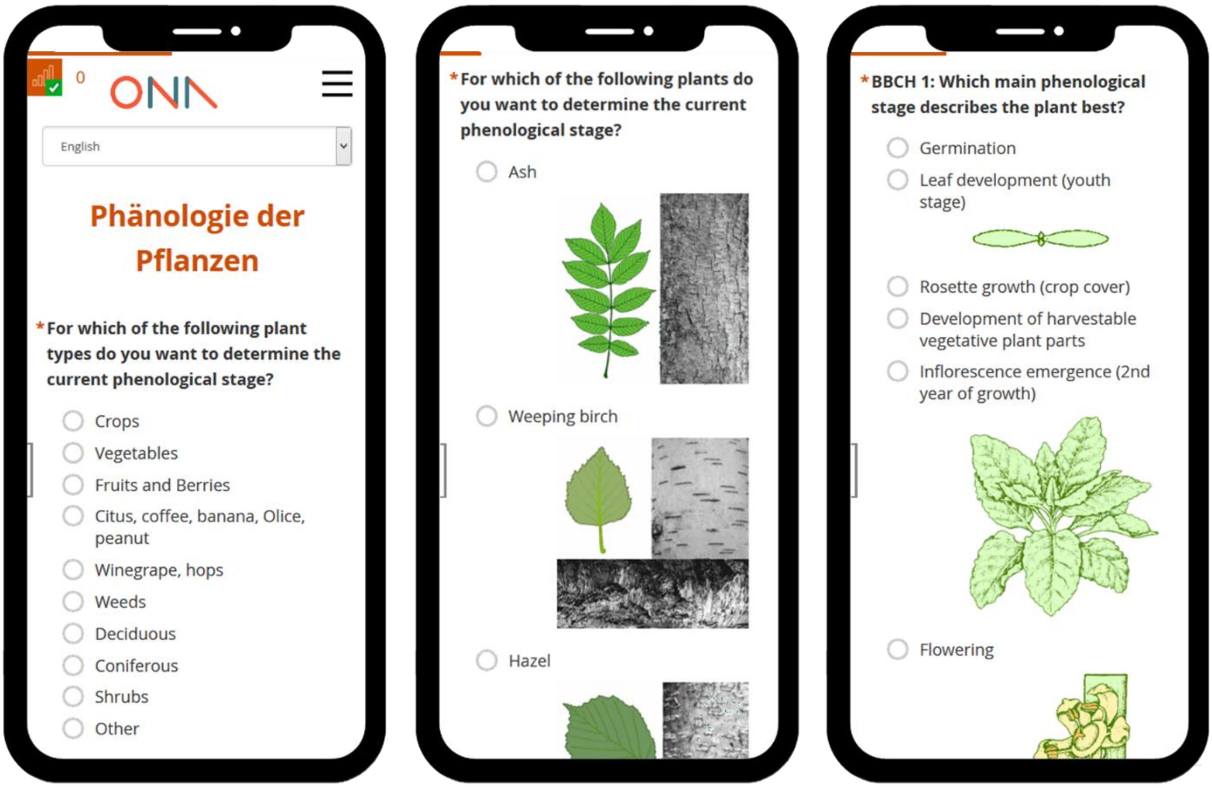
Smartphone image cut out from http://www.pngall.com/?p=35820, license CC 4.0 BY-NC

App: Plant phenology

With this app, you can determine the phenology of different plants using the scientifically recognized BBCH method. Explore your environment and learn about the relationship of climate and plant development.

This app is available at https://enketo.ona.io/x/#pUx1

Languages (other language versions will be added in the course of the project):



Smartphone image cut out from http://www.pngall.com/?p=35820, license CC 4.0 BY-NC

App: Quality of rivers, short version

With this app, you can determine the structural quality of a water body. This app is a simplified and shorted version for beginners. You can find the full version of this app, which requires more time, in material P28j.

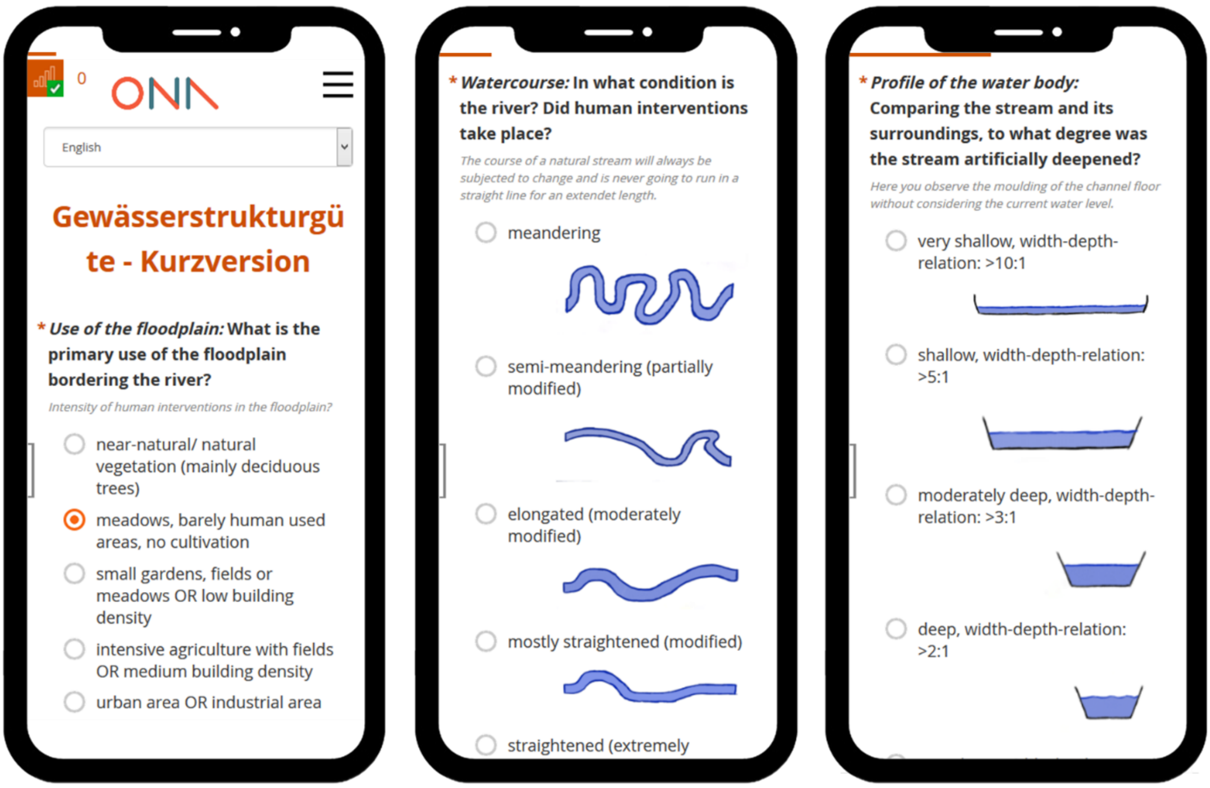
Learn more about the state of the water bodies in your neighborhood and help to preserve and improve this precious environment.

The structural quality of a waterbody describes the diversity of forms of any given waterbody. The structural quality of a water body has strong impacts upon the physical, chemical and biological properties. Thus, monitoring the structural quality tells a lot about the state of the water body, its suitability for aquatic communities, its function and the overall health of the ecosystem.

To evaluate the structural water quality, it is recommended that you investigate an approximately 100 meters long section of the water body.

This app is available at https://enketo.ona.io/x/#p0ku

Languages (other language versions will be added in the course of the project):



Smartphone image cut out from http://www.pngall.com/?p=35820, license CC 4.0 BY-NC

App: Quality of rivers, expert version

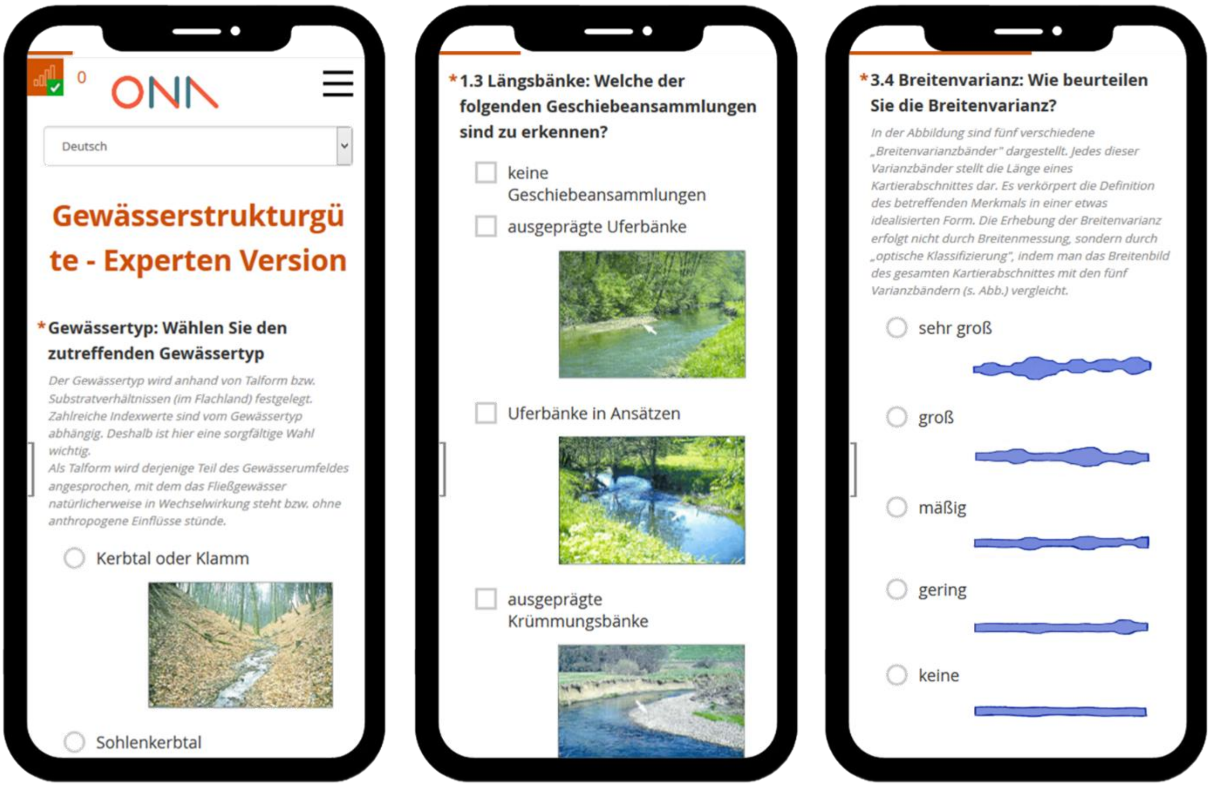
With this app, you can determine the water body structural quality.

Our water bodies are an essential part of a good environment. Their great importance has long been disregarded. Increasing flood risks, decreasing environmental quality and many other disadvantages were the result. For this reason, the EU Member States have set themselves the ambitious goal of achieving a good ecological status of water bodies by 2015. The benchmark for the assessment is the current potential natural status. In order to achieve or maintain a good status, your participation is also necessary.

How far have the measures been implemented so far? With this app, you can check this. The app is quite comprehensive and corresponds to the procedure used by experts. The water body structural quality is assessed in six categories. However, you do not have to work on all six categories. You can also select only one or two categories. Alternatively, you can also use the highly simplified version, which is included as material P28i in the PUJLCHRA Collection of Educational Materials.

This app is available at https://enketo.ona.io/x/#p05z

Languages (other language versions will be added in the course of the project):



Smartphone image cut out from http://www.pngall.com/?p=35820, license CC 4.0 BY-NC

App: Flow velocity and runoff

With this app, you can estimate the flow velocity and discharge of a river or stream. The discharge is the volume of water that flows through a given cross-section in a given time and is therefore expressed in m³/sec.

You can determine the flow velocity as:

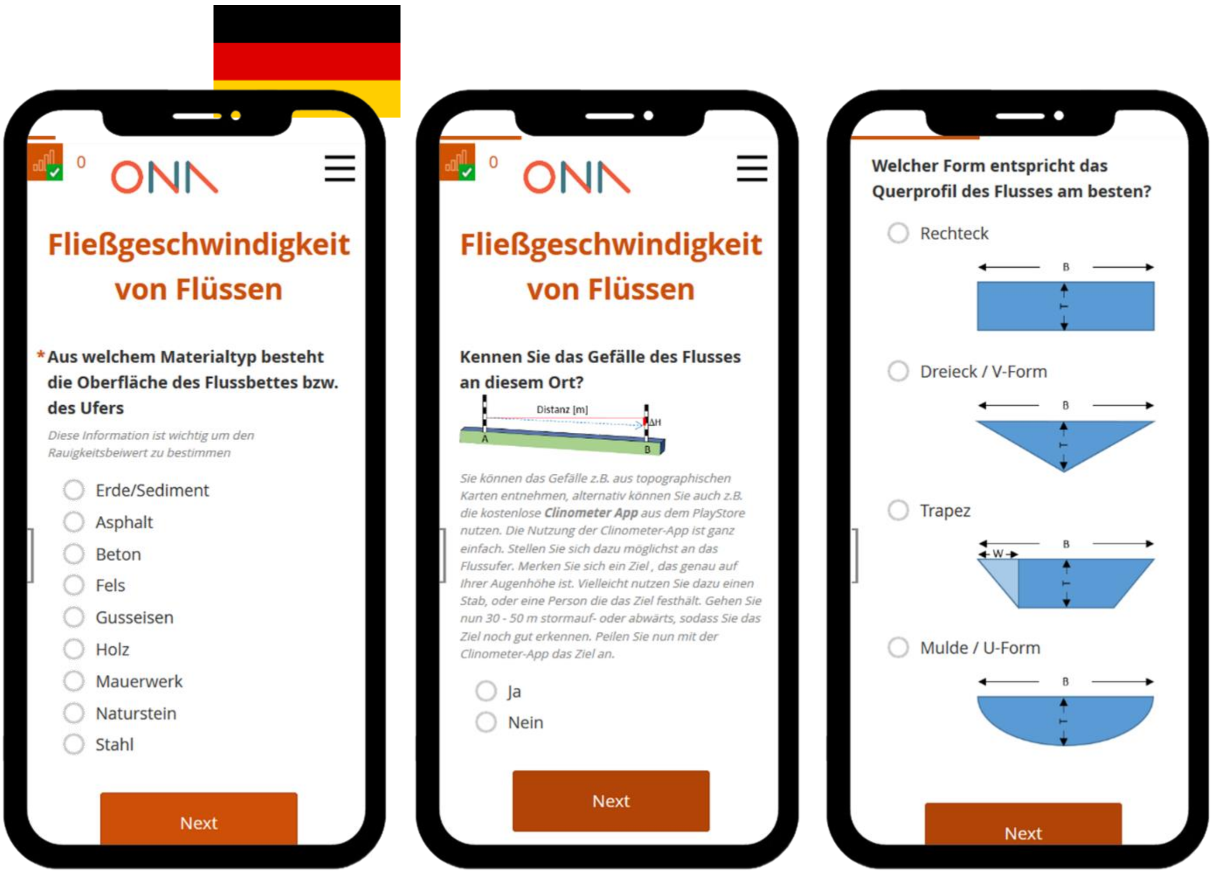
flow velocity = potential difference / flow resistance.

The driving potential is gravity.

The potential difference is therefore the slope (S) of the river or stream. The flow resistance results from the roughness of the surface (n) and the ratio of the cross-section (A) through which the river or stream passes to the length of the waterway (P). A/P is also called hydraulic radius (R). The mean flow velocity (v) is calculated here according to the Manning-Strickler method as: $v = 1 / n * R^{2/3} * S^{1/2}$. There is an illustrative drawing for this in the app.

This app is available at https://enketo.ona.io/x/#p0xf

Languages (other language versions will be added in the course of the project):



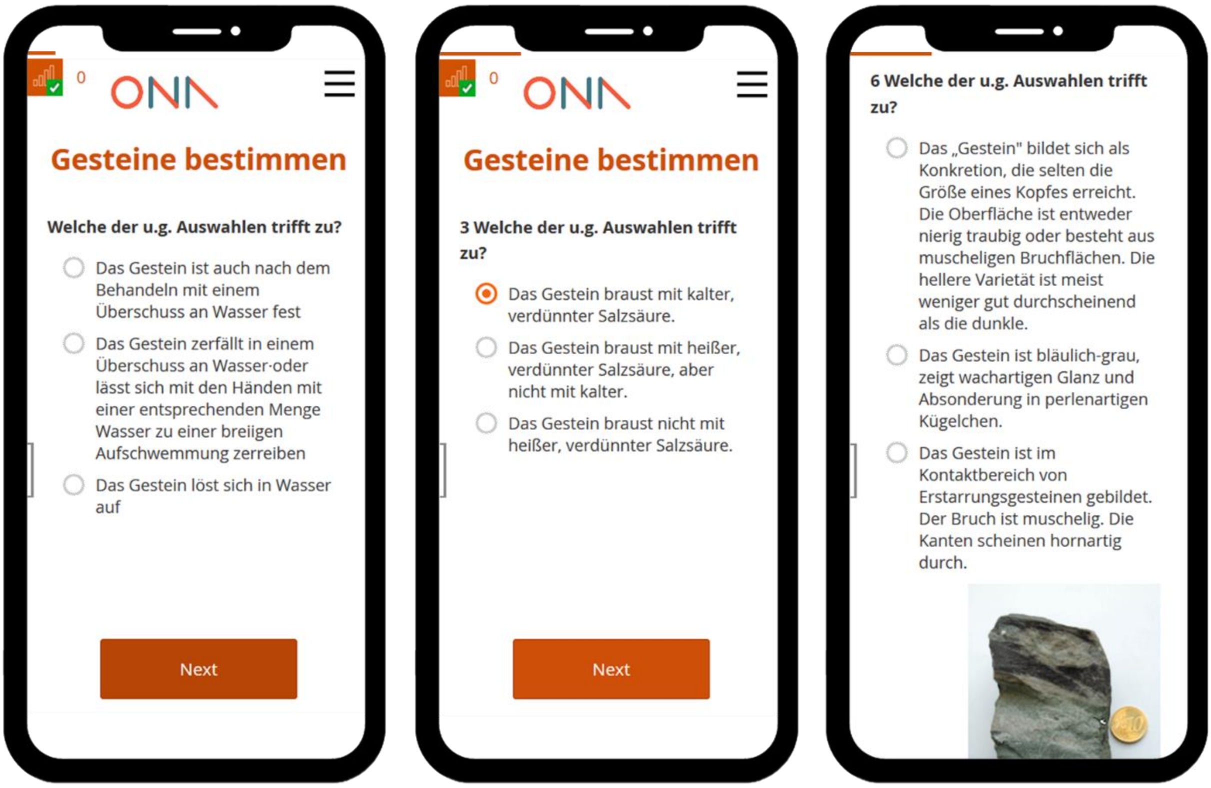
Smartphone image cut out from http://www.pngall.com/?p=35820, license CC 4.0 BY-NC

App: Rocks

With this app, you can identify rocks. This app is part of the app collection for the documentation of geographic excursions. The systematic documentation allows you to recognize and analyze interactions and dependencies in the human-environment system in their regional characteristics. The collected data are available for subsequent evaluation. We hope you enjoy exploring the environment.

This app is available at https://enketo.ona.io/x/#f9br6yCH

Languages (other language versions will be added in the course of the project):



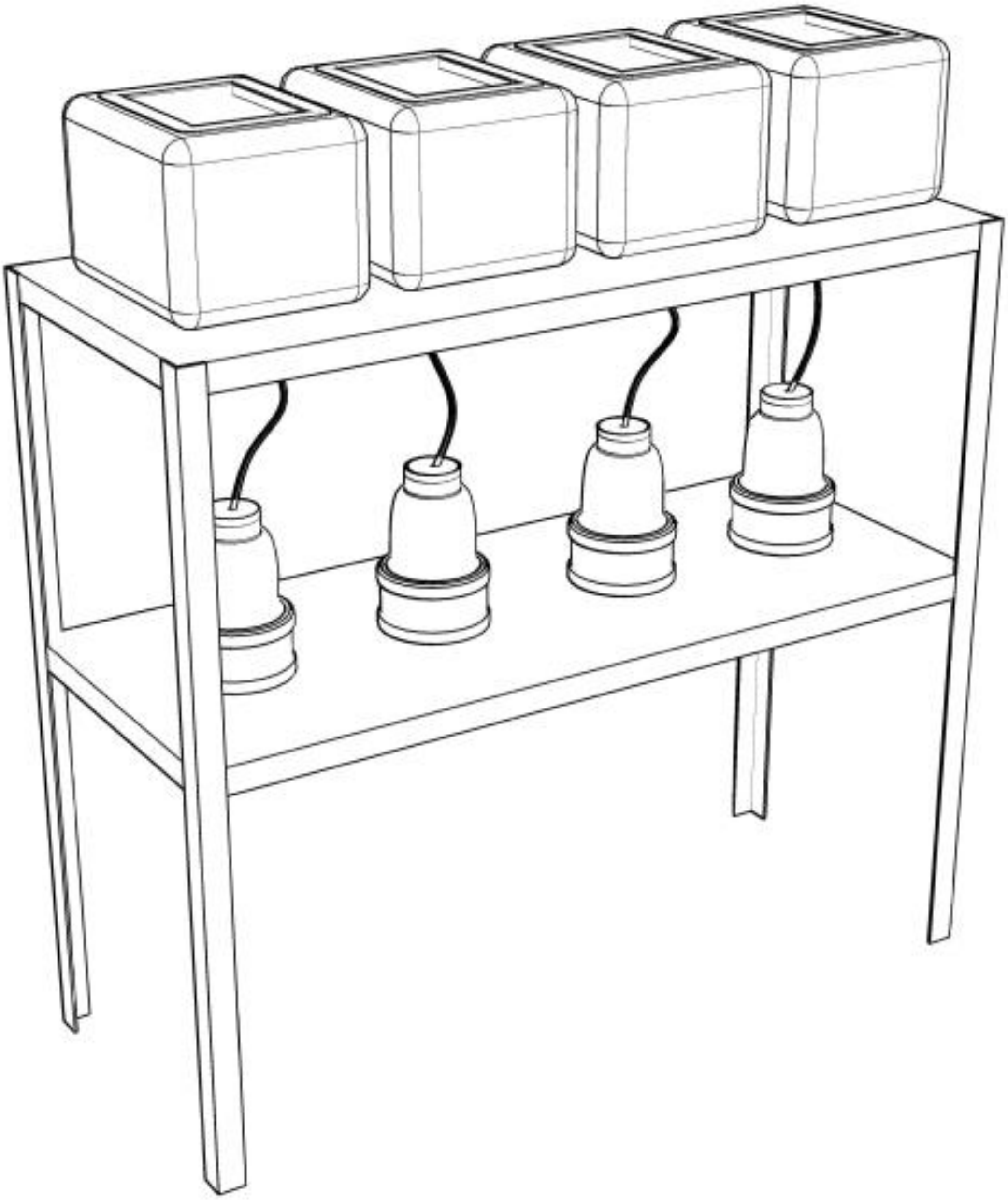
Suitable research questions

The research question is the starting point of the research cycle. It specifies what we want to find out in our research.

- Prior to setting up a research question, the topic needs to be specified.
- The question has to include a question word like what, which, how, why, or where.
- The question must be complex enough but not too complex
- You have to be able to answer the question using the means available in the time available.

Now think of an example of a good research question and write it down in the box below. In your group, discuss why you think this question can be a research question.

Building the Cool City Lab



Authors: Karl Kemper, Tim G. Reichenau, Karl Schneider

Institute of Geography, University of Cologne, Germany, 2020

1. The Cool City Lab

Even during short walks in the city, you can experience that it feels differently warm at different places. With the Cool City Lab, we want to explore this. It is about the question "Why does it feel warmer or colder in some places in the city than in others?”. If you look at different places in the city, you notice that the ground also looks different. Sometimes the surface it is almost white, as for example light-colored stones, sometimes it is black, as for example a tarred surface. With the Cool City Lab, we can investigate whether and how the temperatures are related to the surfaces sand, stones, tar and grass. This manual explains how to build the Cool City Lab.

2. List of materials

1. 4 Polystyrene **boxes**, external dimensions: length 26 cm, width 21 cm height 18 cm.

2. Metal **shelf**, roughly in the proportions: width 100 cm, depth 40 cm, height 90 cm. In this manual, it is a boltless shelf from the hardware store.

3. 4 simple plastic **funnels**: diameter at the top about 7.5 cm.
   The outlet at the bottom must have a suitable dimension to either fit into the hose from point 9. or onto it.

4. **Bolts**: 4x M4x20 with 4 nuts, 8x M8x40 with 8 nuts and 8 suitable washers.

5. 4 plastic **tubes** (e.g. cable conduit), dimension: length 7 cm, outer diameter 2 cm.

6. 4 gripper **clamps**, fitting the outside of the plastic tube in point 5.

7. 4 **wood strips**, measures depending on the polystyrene box: length 30 cm, width 2 cm, thickness 0.5 cm.

8. **Wire**: 4 pieces of simple florist wire: length ca. 10 cm.

9. 4 **hoses**, dimensions: length 40 cm (depending on the shelf), outer diameter about 1 cm (suitable to fit into or onto the outlet of the funnel from point 3).

10. 4 wide-mouth **bottles** with a capacity of 1 liter.

11. 4 sewer pipe **collars**

12. 4 sewer pipe **socket plugs**, for the sewer pipe collars in point 11.

13. 12 aluminum take-away **containers**, dimensions of about: length 22 cm, width 17 cm, height 3 cm. The base area must be smaller than the lid of the polystyrene boxes from no. 1.

14. Acrylic **paint** in black, red, and green.

15. 4 **temperature probes.**

16. Light **stones** (often named decorative or ornamental gravel in a hardware store), they can be relatively large.

17. Potting **soil** and grass **seeds**

18. **Asphalt** (often you can get it from a road construction site if you ask nicely; asphalt may also be bought at a hardware store but make sure, it is really asphalt and not bitumen)

19. **Sand** (e.g. playground sand from the hardware store)

3. The Boxes

In the end, the four boxes will be placed on the top shelf. They will be covered with different materials (grass, asphalt, stones, sand). Inside the boxes, effects of the different coverings will be measured.

You need:

Material: The 4 polystyrene boxes, the aluminum take-away containers and the acrylic paint.

Tools: A sharp knife, a pen, a tape measure or folding rule, a brush, and a cordless screwdriver with an 8 mm drill bit.

You do:

At first, you paint the boxes.

1. You take the brush and paint the first box black, the second one green, and the third one red. In between, you have to wash the brush. The last box stays white.

After the paint has dried, the aluminum containers will be placed in the lid of the polystyrene boxes.

2. Measure an aluminum container. Since it will be placed in the lid of the polystyrene box, you only measure the container itself, without the folded edge.
3. Draw a rectangle in the measured dimensions on the lid of a polystyrene box. You can also use the bottom of the aluminum container as a template and draw its outline (note that the containers usually get bigger towards the top). Then cut out the opening for the container with a knife.
4. Stack three aluminum containers to give them more stability. Drill a hole through the bottom in the middle of the containers with the 8 mm drill bit or use the knife.
5. Place the stack of three aluminum containers in the hole in the lid of the polystyrene box.

Repeat steps 3 through 5 with all four boxes. The lids will look like in the picture.

4. The inside of the boxes

The next step is to prepare the inside of the boxes. The water that comes through the hole in the aluminum container will be collected with a funnel and stored in a bottle.

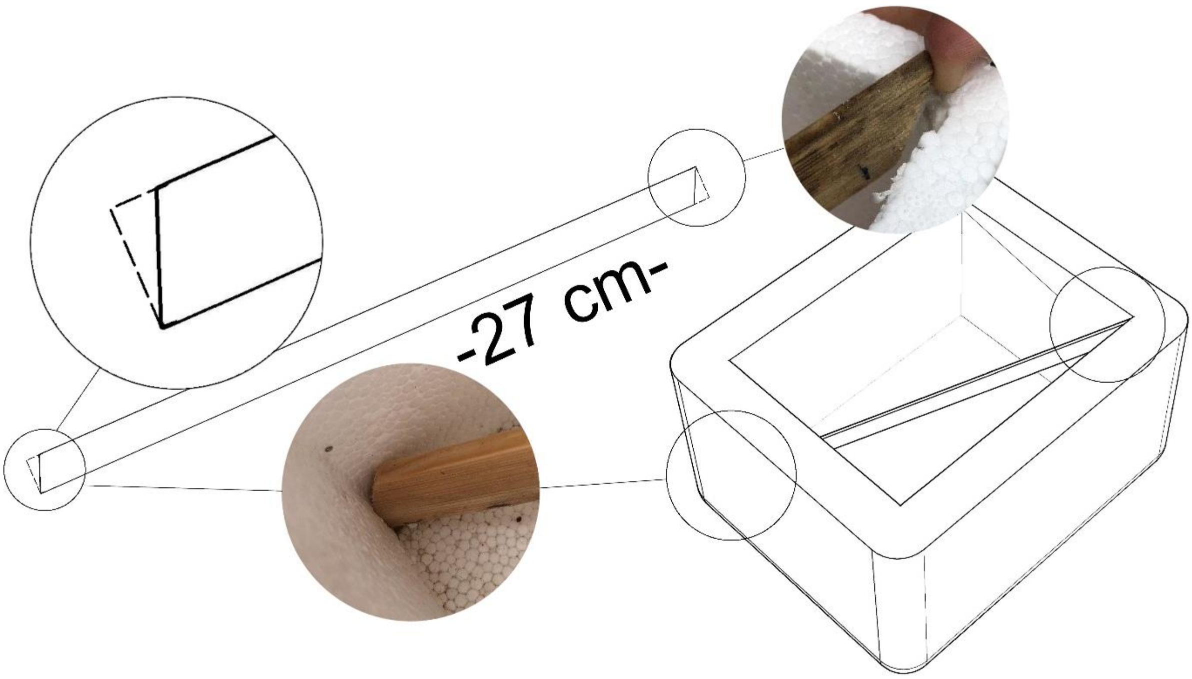
You need:

> Material: The funnels, the fitting plastic hoses, the wood strips, the bolts M4x20 with nuts, the 2 cm plastic tubes, the fitting gripper clamps, and the wire.
>
> Tools: A saw, a pen, a tape measure or folding rule, a cordless screwdriver with 4 mm and 10 mm drill bits (or with the same diameter as your hose), and a fine saw.

You do:

1. Measure the diagonal of your polystyrene box, i.e. from the bottom front corner to the top back corner, diagonally through the whole box. This is the longest distance you can measure in the box.
2. Saw the wooden strip on this length.
3. Saw off a corner on both sides of the wooden strip, as shown in the picture below, so that it has the shape of a parallelogram and fits into your polystyrene box.

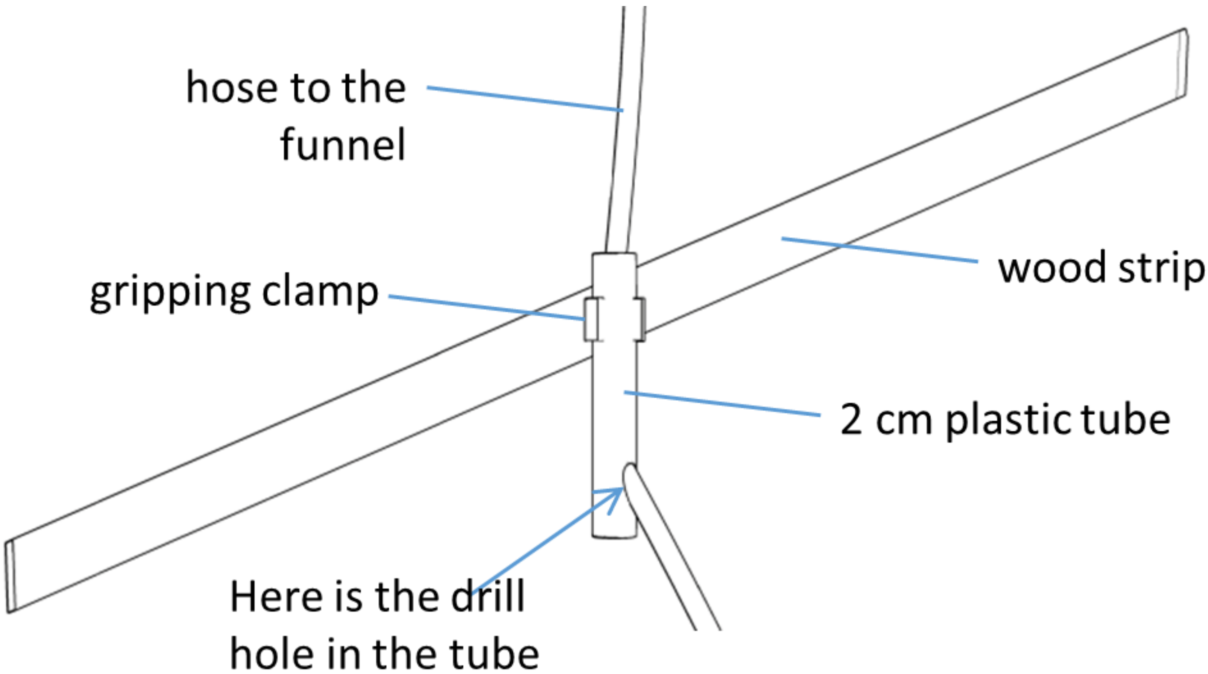
Repeat steps 2 and 3 until you have strips for all four boxes.



The tube that will hold the funnel, will be attached to the wooden strip

4. Drill a hole in the middle of the wooden strip with a 4 mm drill bit and attach the gripper clamp with the M4x20 bolt and the appropriate nut at this point.
5. Cut the 2 cm plastic tube to a length of about 7 cm with the fine saw. You might have to adjust the length a bit later.
6. Drill a hole in the bottom part of the tube with the 10 mm drill bit (or with a drill bit that suits the diameter of you hose) and thread the hose through this hole. Look at the illustration and the photo below to understand better, what is meant.
7. Put everything together, i.e. put the hose into the plastic tube and through the hole, the tube into the gripping clamp and then the wooden strip with the plastic tube into the polystyrene box.
8. On the bottom of the polystyrene box mark where the hose that comes out of the tube will go through the bottom of the box.
9. Drill a hole with the 10 mm drill bit (or with a drill bit that suits the diameter of you hose) through the bottom of the box. Thread the hose through the hole so that it sticks out of the box at the bottom.

Repeat these steps with all four boxes.



Then, the funnel will be attached to your construction.

10. Insert the outlet of the funnel into or onto the hose that sticks out of the top of the plastic tube. If the diameters are fitting correctly, the connection will be tight and firm.

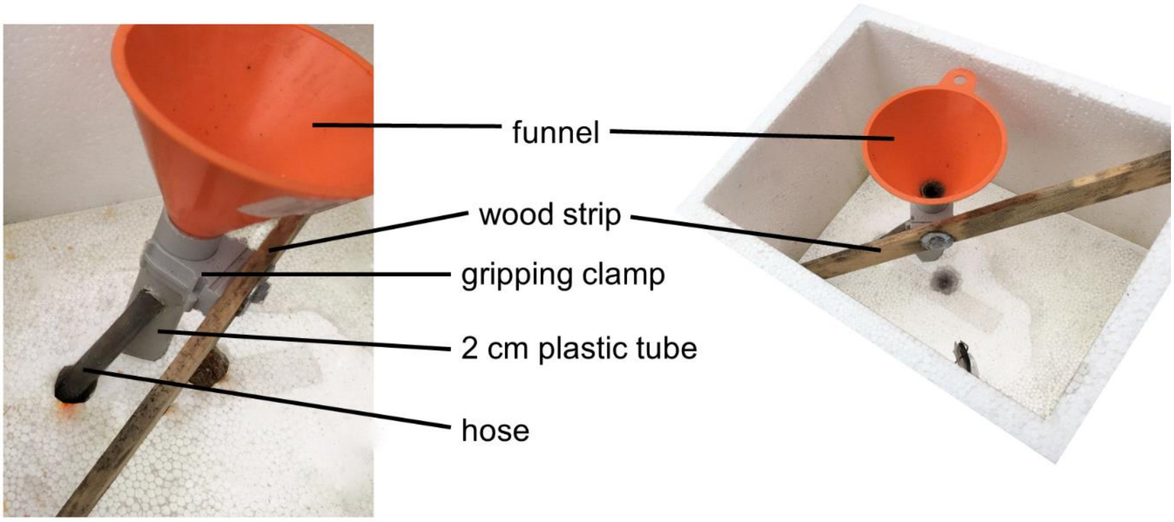
Again, repeat this step for all four boxes.

Finally, you have to build the hanger for the temperature probe.

11. Bend a piece of wire so that you can insert one end into the wall of the polystyrene box from the inside. In the other end of the wire, you bend a small hook so that you can hang the temperature probe on it.
    The important thing is that the temperature probe itself hangs in the air and does not touch anything so that it measures the air temperature and not the temperature of a surface.

Repeat this step for all four boxes.

Now you can assemble everything, it should look somehow like in the picture below.



5. Mounting the boxes to the shelf

The completed boxes can now be mounted to your metal shelf. The boxes will be attached to the shelf with a bolt going right through the bottom of the box and the shelf.

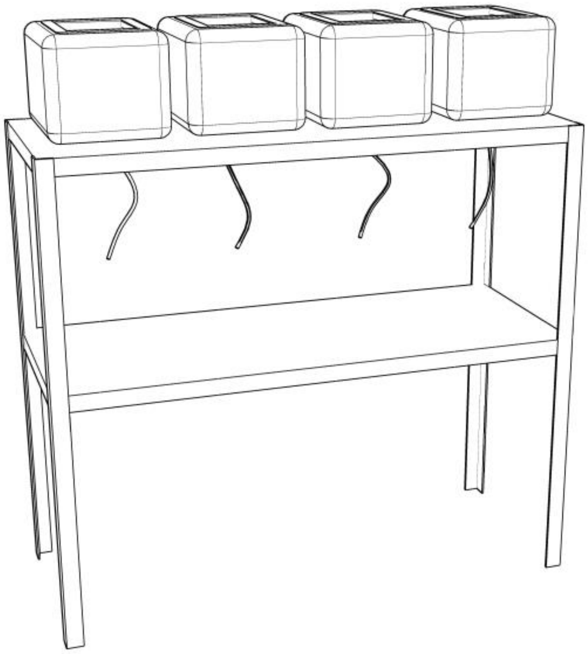
You need:

> Material: The metal shelf and the M8x40 bolts with nuts and washers.
>
> Tools: An 8 mm wrench for the M8x40 bolts and a cordless screwdriver with 8 mm and 10 mm (or with the same diameter as your hose) drill bits. Use metal drill bits to drill through the shelf.

You do:

1. Assemble the shelf according to the manufacturer's instructions. It should look similar to the picture below.
2. Place the boxes at equal distances on top of the shelf. To do this, you have to pull the tubes out of the hole in the bottom of the boxes again.
3. Drill a hole through the bottom of the polystyrene box and the metal shelf with the 8 mm drill bit, but not too close to the position where the plastic tube rests.
4. Thread the washer onto the M8x40 bolt and insert it from above into the hole you have just drilled.
5. Fix the box to the shelf with the bolt and the matching nut from below.
6. Use the 10 mm drill bit (or with the same diameter as your hose) to extent the hole for the hose in the bottom of the box through the shelf.
7. Put the hose back through the hole so that it now sticks out of the bottom of the shelf.

Repeat steps 2 to 7 for all four boxes.



6. The seepage water collection bottles

The water that seeps through the content of the aluminum container into the funnel will be collected in bottles on the bottom shelf.

You need:

Material: The wide-mouth bottles, the sewer pipe collars and socket plugs, and the M8x40 bolts with nuts and washers.

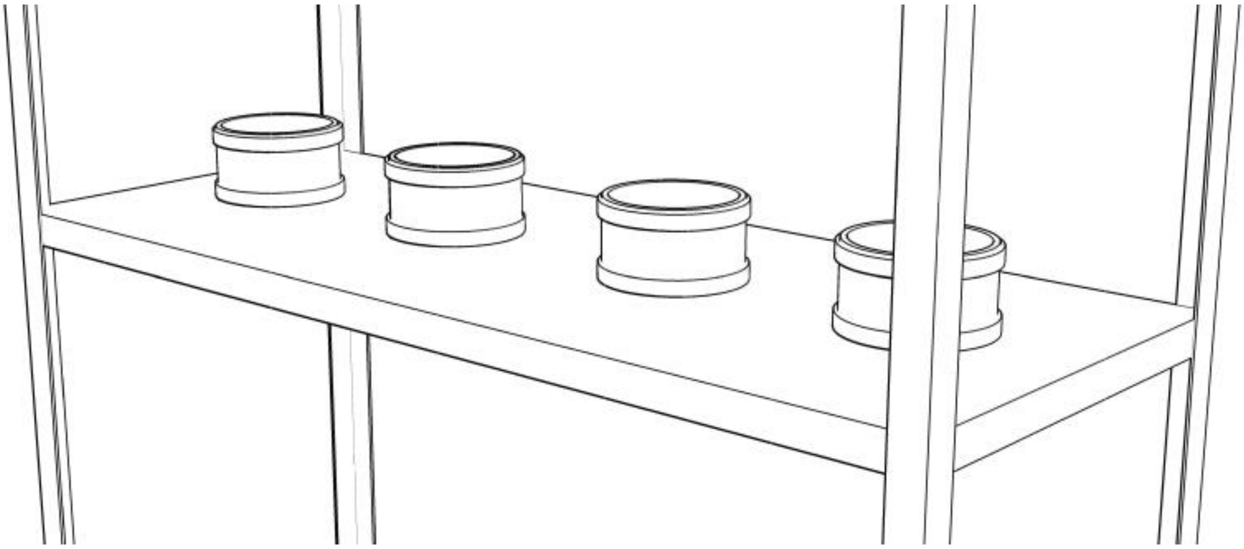
Tools: A wrench for the M8x40 bolts and a cordless screwdriver with 8 mm and 10 mm (or with the same diameter as your hose) drill bits. Use metal drill bits to drill through the shelf. You will need a measuring cup and a waterproof foil pen if the wide-mouth bottles do not have scales for reading the amount of water.

You do:

The sewer pipe collars and socket plugs become bottle holders for the seepage water collection bottles as shown on the illustration below.

1. First, check whether the wide-mouth bottles have scales for reading the amount of water. If not, fill in water from the measuring cup in steps of 50 ml and mark the water level with a line on the bottle using the waterproof foil pen. Note the amount of water next to the line. You might have to use a different amount of water per filling step. This depends on the size and shape of the bottle.
2. Drill a hole in the middle of the sewer pipe socket plug with the 8 mm drill bit.
3. On the lower shelf, mark the position in middle under one of the boxes.
4. Drill through the shelf at the mark using the 8 mm drill bit.
5. Put the sewer pipe collar onto the lower shelf so that the holes align. Thread a washer onto the M8x40 bolt and insert it through the socket plug from above into the hole you have just drilled. Tighten the bolt with a nut from below.
6. Put the sewer pipe collar on the socket plug. The rubber seal should keep them quite tight together.

Repeat these steps for all four boxes.



After finishing the preparation of the bottle holders, the bottles have to be prepared.

7. Take the lid of a wide-mouth bottle and drill a hole in the middle with the 10 mm drill bit (or with the same diameter as your hose).
8. Thread the end of the hose through the lid.
9. Shorten the hose so that it almost reaches the bottom of the bottle when it is in the bottle holder. The hose must be loose but must not have any loops where the water may accumulate.

Repeat these steps for all four bottles.

The experimental setup is now finished and should look similar to the illustration on the first page.

7. Filling the containers

The aluminum containers are now ready to be filled.

You need:

> Material: The potting soil and grass seeds, the light stones, the asphalt, the sand, and a piece of cloth, filter paper, or something similar that prevents sand from trickling through a hole.

You do:

The **green box** will be covered with grass in the aluminum container to simulate a lawn.

1. Fill the stacked aluminum containers with potting soil.
2. Saw the grass seeds in the potting soil.
3. Now you have to wait and water regularly. You also have to water the grass when the Cool City Lab is finished and it has not rained for some days or when it is indoors, otherwise the grass will dry up. Always note exactly how much water you used to water the grass. Pour the same amount of water on the other boxes so that they can be compared at the end of the experiment. You can also install a self-watering system as shown in section 8.
4. Put the container into the lid of the green box.

The **black box** will be covered with asphalt to simulate a street or a square.

5. Fill asphalt into the stacked aluminum containers. If the asphalt is from a hardware store, follow the given instructions supplied.
6. Put the container into the lid of the black box.

The **white box** will be covered with light stones.

7. Fill the stones into the stacked containers and put them into the lid of the white box.

Now only the **red box** remains. It will be filled with sand.

8. Cover the hole in the stacked aluminum containers with a piece of cloth or something that prevents sand from trickling through.
9. Fill the sand into the containers.
10. After filling the sand into the containers, put them into the lid of the red box.

8. Optional: Capillary watering

If you do not water the grass regularly, it will dry out quickly. To avoid this, you can build a watering system with a watering wick. During the experimental phase, however, watering should be done manually so that you know the exact amount of water for the analysis of the results.

This works like the wick of a candle but it sucks water instead of wax. The water is sucked from a container by capillary force. You can get the required material in the hardware store or on the internet.

<u>You need:</u>

> <u>Material:</u> A capillary wick or simply a cotton cloth or socks and a container, e.g. a wide-mouth bottle with a lid or simply a jam jar.

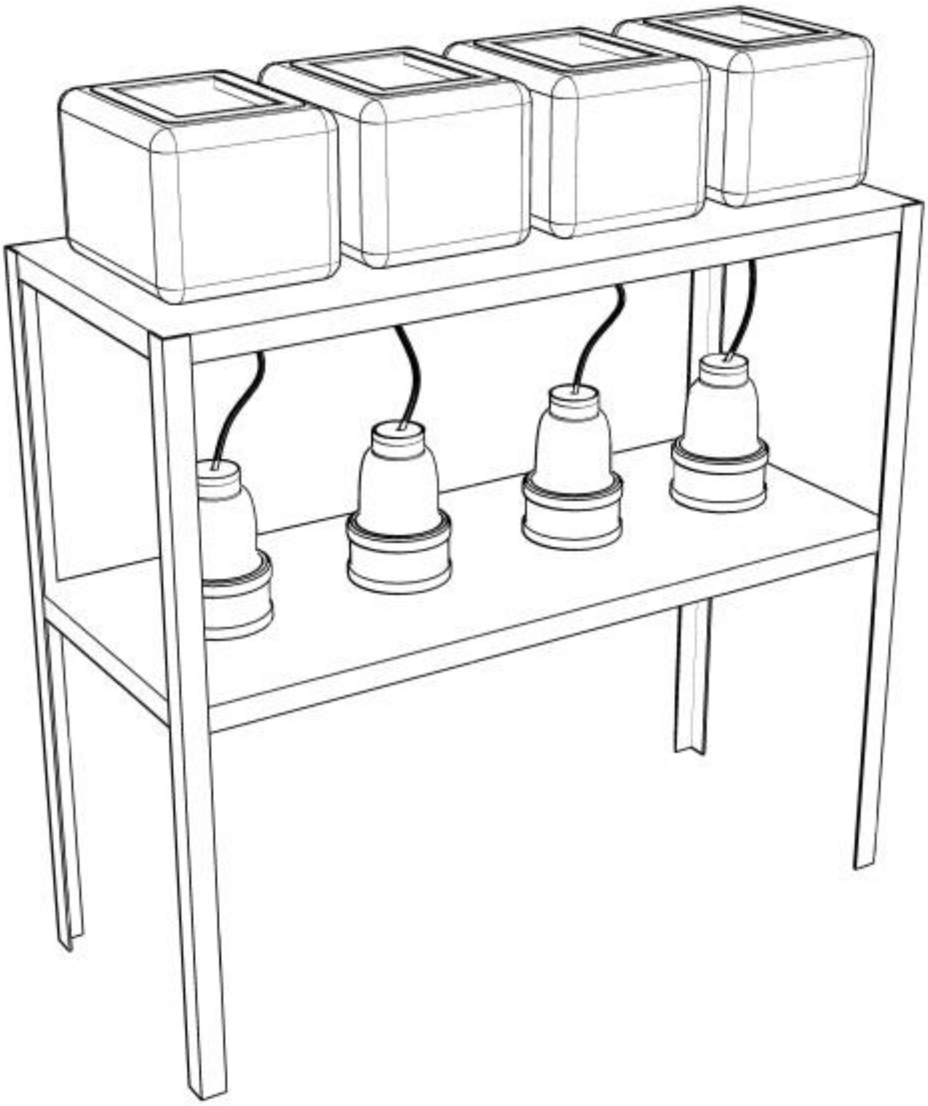
<u>You do:</u>

1. Remove the lid from the container and put a hole in it large enough for the capillary wick to fit through.
2. Thread one end of the capillary wick through the hole in the lid and bury the other end in the soil of the green box. Make sure that a good proportion of the capillary wick is in the soil.
3. Fill the container with water and screw the lid on so that a good proportion of the wick is in the water.
4. Place the water container in a position at the same height or higher than the grass.

Make sure that there is always enough water in the water container. If it gets very hot, your watering system may not be able to supply enough water. Then you have to water the grass manually to keep it from drying out.

Why do surfaces have different temperatures and what does that mean for the city?

An experiment with the Cool City Lab



Authors: Tim G. Reichenau, Karl Kemper, Karl Schneider

Institute of Geography, University of Cologne, Germany, 2020

1. What can be explored with the Cool City Lab

You have certainly walked through the city in summer, through narrow streets, through parks and perhaps past a fountain or pond.

Maybe you can remember it, or, if it is hot outside right now, you can just do it again!

You will see that it is hottest on the street or in a parking lot. When you walk through a park, it feels a lot more pleasant. However, the coolest is, when you stop at a fountain. Here you can often feel a real cool breeze in summer. This raises the research question "Why does it feel warmer or colder in some places in the city than in others?”.

One idea to explain this is that it might be caused by different surfaces of the ground like sand, stones, lawn, or tar. In science, we call the idea to answer a research question a hypothesis. Therefore, our hypothesis is "The different surfaces in the city make it feel warmer or colder in some places than in others". With the Cool City Lab, we want to find out if our hypothesis could be correct. It exposes different surfaces to the weather to imitate the different places.

We can use the Cool City Lab to investigate what causes the temperature differences. We study different surfaces as we find them in the city: Tar, stones, sand and grass (lawn). To find out differences, we put these surfaces on polystyrene boxes and put the experiment outside where it is exposed to the weather. Depending on the air temperature and radiation, the surfaces either get warmer or cool down. The sun, whose radiation can be felt on the skin as warmth, shines on the surfaces. Furthermore, there is the rain, which makes the surfaces wet and then seeps in or runs off at the surface. In the Cool City Lab, we measure how warm it is inside the boxes with the different surfaces. We also measure how much water seeps through the surfaces. In the end, we compare the temperatures and amounts of seepage water of the different surfaces and try to find out why it feels differently warm in different places in the city.

How one can work with the Cool City Lab:

1. If it has not been done yet, build the Cool City Lab (building instructions are in material P30 of the PULCHRA Collection of Educational Materials). If you have an already finished Cool City Lab, have a close look at how it is build and how it works.
2. Carry out the experiment as described in chapter 2. This takes at least one week.
3. While the experiment is running, read the information on what is going on at the surfaces in chapter 3 and work on the tasks. This includes making your own hypotheses.
4. Once the experiment is finished, the analysis of the measurements begins. How this can be done is explained in chapter 4. This includes thinking about what the results mean for the hypotheses.

5. Due to climate change, the temperatures are changing and it is getting warmer and warmer, in summer it is more and more often really hot. Now that you know more about why it is warmer in one place than another, you can end up by thinking about what the results of the experiment could mean for your school, city, or home. To do that, you will find suggestions and questions in chapter 5.

2. Carrying out the experiment

Procedure

To find out how different surfaces act on temperatures, the Cool City Lab must be set up outdoors, where the effects of real weather can be seen. It should be set up in the open air, without a roof above it and with as little shade as possible in order to record the real environmental influences. The experiment should be set up outside for at least a week to have enough data for the analysis. If possible, the experiment should run longer, up to four weeks. It is best to do the experiment on hot summer days, as the effects are strongest then. However, you can do the experiment in all seasons.

Before starting the experiment, the temperature sensors must be set up to do regular measurements. Some types of sensors have to be programmed. Others require programming a control unit, which is connected to the sensors. That depends on the type of sensor used.

During the measuring period, nothing should be changes inside and on the boxes, in order not to confound the measurements. The lids should stay closed and the Cool City Lab has to stay at the same place. Therefore, it makes sense to carry out the experiment in a backyard or fenced area.

It is important that the four boxes are always treated exactly the same. Otherwise, any differences you find in the measurements could be because you handled the boxes differently. In that case, we do not know whether a difference is caused by the surface of the box or by the fact that we did something different with one box than with another.

The only permitted intervention is watering of the surfaces if the grass tends to dry out. In this case, however, the same amount of water (e.g. about 200 ml per day in hot weather) should be poured on all boxes. The water has to be poured in such a way that the whole surface is evenly wetted and the water can seep or evaporate. This is important in order to be able to correctly assess the amount of water in the seepage water collection bottles afterwards.

Measurement data

Usually the temperature measurements will be carried out automatically and the data will be saved. If there is a way to access the measured data while the experiment is running, a copy should be saved in a different location every now and then. If something goes wrong later, you still have the saved data. If the data is saved on the temperature sensors inside the boxes, this unfortunately is not possible, because the boxes should not be opened during the experiment.

The amount of water in the seepage water collection bottles should also be read off regularly, preferably every day. You should enter this data carefully in a table. Do not forget to also note date and time. If the scale on the bottle is imprecise, another way is to weigh the bottles. The weight of the empty bottle must also be known. It is best to write this on the bottle with a waterproof pen.

The experiment can be evaluated particularly well if, in addition to the data measured in the Cool City Lab, you also have measurement data about the weather. If you measure the air temperature outside the boxes, you know whether it is warmer or colder inside the boxes than outside. If you measure the amount of rain, you know how much water has fallen on the surfaces and this can be compared with the amount of water in the seepage water collection bottles. It can be also of interest how much solar radiation has reached the experiment or how cloudy it was.

To measure the air temperature outside the boxes with a small temperature sensor like the ones used in the Cool City Lab, you need a radiation shield, which you can build yourself as shown in material P35 of the PULCHRA Collection of Educational Materials.

3. What happens at the surfaces?

To evaluate and understand your measured data, you need to understand what happens at the surfaces. In science, we call the things happening processes.

<u>Reflection</u>

Reflection takes place, when a part of the radiation that arrives at a surface is radiated back. This is comparable to a mirror. The measure for the fraction of radiation that is reflected by a surface is called albedo. If you shine your flashlight against a bright wall in the dark, the light comes back, it is reflected and the whole room is illuminated. That means the wall has a high albedo. However, if you shine against a black wall, there is much less reflection of the light. It seems like the wall swallows the light. That means the wall has a low albedo.

Light is the visible fraction of the shortwave radiation from the sun that arrives at the surface coming from the sun. However, where does the energy / light go if it is not reflected?

It is converted into heat. That is why it becomes hot in a black car in summer, while it stays much cooler in a white one.

Evaporation

If you leave a glass of water, the water will become less and less over time. It evaporates. What is the force that causes the water to evaporate?

When it is warm, water evaporates faster than when it is cold, as anyone who has ever lain in the sun with wet swimwear knows. It usually feels quite cold! So what do you do instead when you come out of the water after swimming? You towel yourself off first! Because, if you stand outside the water with a wet body, it suddenly gets quite cold, despite the sun.

The sun’s radiation itself is not warm, when it reaches the earth. First of all, it brings energy to the earth. This energy can be used for different processes such as heating up the surface, evaporating water, or simply reflecting it back into the atmosphere. When water evaporates, it changes from liquid to the gaseous state. This change of state requires energy. Energy can never be destroyed it can only change form. Thus, the energy taken up to evaporate water is hidden in the gaseous state of the water. This energy is called latent energy or latent heat. It is released again when the water condenses.

The process of taking up solar energy and converting it to a different form is called absorption. When the sun hits a dry surface, this surface gets warm. On a sunny day, you may feel this on your skin. Thus, this energy flux is call sensible heat flux. The radiation is converted into thermal energy on your skin.

However, if your skin is wet, the sunrays first hit the water on your skin, where energy is used to evaporate this water. The process of evaporation even takes heat out of your skin and you get cold. Thus, both sensible heat and latent heat fluxes typically happen at the same time.

So we now know that evaporation cools because the process converts energy into latent heat that we do not feel as sensible heat.

A process in which water evaporates also occurs in plants. Evaporation cools the surface and therefore a plant from overheating in the sun. As water evaporates from the surface, the plants draw water through its roots from the soil. This is comparable to a straw where evaporation is sucking on the upper end and water is taken up at the lower end. Since it can be controlled by the plant via opening and closing of small openings in the leaves (stomata), evaporation from leaves has a different name. It is called transpiration. Transpiration generates a flow of water from the soil trough the plant into the atmosphere. This flow –or often called flux– also transports nutrients from the soil into the plant. Plants can take up water from considerable depth, as deep as their roots reach. Evaporation can take water only from the surface.

Other ways of the water

After the rain, the water does not simply remain on a surface. It disappears over time even when it does not evaporate. Using material P19 of the PULCHRA Collection of Educational Materials, you can think about where the water goes and what happens to it. If you want to do this, only read on afterwards.

So where does the water go that reaches a surface when it rains? During rain, it cannot evaporate since the air already contains all the water it can possibly hold. It is said to be saturated with water. Either the rain seeps through the surface, which is called infiltration, or if it rains very hard or the soil is completely filled with water, it flows at the surface, which is called surface runoff.

If water can infiltrate therefore depends on how many pores (or holes) are in the soil and how these pores transport the water downwards. It also depends on how much water is already contained in the pores and how much more water fits into the soil. Some surfaces hardly have any pores or the pores are not connected so water cannot flow through. Here water cannot infiltrate. We call these sealed soils or sealed surfaces.

A sealed surface dries off quickly after a rain and gets hot when the sun shines, because there is no cooling effect of evaporating water anymore. Thus, going barefoot on a sunny day is much more enjoyable on a lawn than on a tarred surface. The lawn lets water infiltrate which can later evaporate the tarred surface does not.

Tasks

Get together in groups of two or three people. Half of the groups will work on task 1, the other half on task 2.

1. Create a drawing that shows what happens to solar radiation when it reaches a surface. Also, think about what happens to the surface. Do not forget to label the drawing.
2. Create a drawing that shows all three explained ways of the water and do not forget to label the drawing.

Now find a partner group that worked on the other task. Mutually explain your drawing to the other group.

Next, look at the four boxes of the Cool City Lab and …

3. … put your heads together with your partner group on how the ways of the water differ between the boxes. Which fraction of the water goes which way? Consider what you learned about radiation and reflection.
4. … put your heads together with your partner group on how radiation and reflection differs between the boxes. Consider what you found out about the ways of the water.
5. … set up hypotheses for the following questions:
   a) In which box will be the highest temperatures?
   b) At which box, the most seepage water will accumulate in the seepage water collection bottle?

   It may help to first consider what the situation would be like if there was only radiation or only water. Then try to combine the two.

Make sure to write down the results of your work.

4. Analysis of the measurements

Preparation of the measurement data

Before the actual analysis can begin, the measurement data must be prepared. It is often helpful to have a graphical representation of the data in diagram, a visualization. The easiest way to do both is to use a spreadsheet software on a computer such as Open Office Calc, Microsoft Excel or others. **Remember to always write down what you have done with the data.**

When using a digital thermometer to measure the temperature inside the boxes, the data are often already provided in a computer-readable form, i.e. in a digital file.

1. At first, import the temperature data into a spreadsheet software. Make sure, that the numbers and the timestamp (date and time) are displayed correctly in the spreadsheet.
2. Organize the data so that one column shows the timestamp of the measurements and the four columns next to it show the measured temperatures of the four boxes. You can color the columns in the colors of the boxes.
3. Display the data as curves in a diagram. On the x-axis of the diagram (horizontal axis, at the bottom) you have the time and on the y-axis (vertical axis, left hand side) there is the measured temperature. It is best to display the temperatures of all four boxes in a single diagram, to make it easy to compare them.

Now, the data on the seepage water has to be prepared. Presumably, these data were read from the seepage water collection bottles or the bottles have been weighed at several points of time and have been written into a table.

4. Transfer the data in an empty sheet in your spreadsheet file. Let another person check the transferred data by comparing it to the written table. When typing from a paper table, mistakes can easily happen. Pay special attention to transposed digits, i.e. numbers that are mixed up in their order.
5. Display the seepage water data as a diagram like you did with the temperature data.

Maybe it was possible to measure additional weather data like air temperature, precipitation or radiation. If not, you can skip the next points.

6. Import the weather data into the spreadsheet file, at best on a new sheet.
7. Display the weather data as diagrams as explained above.
8. Add the measured air temperature to the diagram from point 3. Doing this, you can easily see how the temperature in the boxes compared to the air temperature.
9. Add the measured precipitation to the diagram from point 5. Doing this, you can see how the amount of seepage water developed compared to the precipitation. Probably the measurements of the seepage water and the precipitation have different units. You probably measured the water in the bottle as a volume in milliliters. The precipitation is usually given in millimeters. This refers to the height

to which the water would stand if it neither infiltrated nor evaporated. To convert this into a volume, the value must be multiplied by the base area. Be sure to calculate the area in square millimeters. First, consider the origin area of the seepage water originates.

Data can always be incorrect. Errors do not only occur when reading the amount of seepage water. Even electronic measurements can be wrong. Therefore, the next step is to check the data and to make sure that only good data is included in the analysis.

10. First, you check the temperature data if they are reasonable or if they exceed the expected range. Think about what range of temperatures can reasonably occur and discuss that with others. Delete wrong data from the table and make a note of which data you deleted and why.
11. For the seepage water, it is best to check the course of the curve. Since water can only go into the bottle but cannot leave it, the amount of water can only increase or stay the same. If that is not the case anywhere in the curve, the measurement needs to be checked again. If the value in the spreadsheet is the same as in the written table, it has to be deleted.

The preparation of the data is finished now and you can proceed with the analysis.

<u>Analysis of the measurements</u>

Do you still remember the beginning? It was about different temperatures in different parts of the city. The hypothesis was that due to different surfaces different places have different temperatures. That is why the Cool City Lab consists of four boxes with different surfaces. The next step is now to learn something about temperatures and surfaces from the measurements. **Again, always remember to write down what you have found out.**

We start with the temperature data. Have a look at the curves in the diagram and try to answer the following questions:

- What is the course of the curves over time? Is there something that happens repeatedly for all boxes? If yes, how may this regular course be explained?
- How do the curves of the individual boxes compare to each other? Where is it warmer, where colder? Are always the same boxes warmer or colder, or does that change over time?
- At what time are differences between the boxes the largest, at what time the smallest?
- If applicable, how does the course of the temperature of the boxes compare to the course of the air temperatures?

The same questions arise for the seepage water:

- What is the course of the curves over time? Is there something that happens repeatedly for all boxes? If yes, how may this regular course be explained?

- How do the curves of the individual boxes compare to each other? Where is more seepage water, where less? Is that always the same, or does it change over time?
- At what time are differences between the boxes the largest, at what time the smallest?
- If applicable, how does the course of the seepage water compare to the course of the precipitation?

The next step is to combine what you have learned for the temperature and seepage water measurements and what you have learned about the processes.

- Read again in chapter 3 what you have learned about the processes.
- Can you see a connection between the temperatures and the seepage water?
- Can you explain why it is warmer in one box than in another?
- Can you explain why there is more seepage water at one box than at another?

Finally, remember that this is about testing hypotheses using the measurements.

- First, recall the hypotheses you wrote down when working on chapter 3.
- Do the measurements confirm your hypothesis on the highest temperatures?
- Do the measurements confirm your hypothesis on the largest amount of seepage water?
- What about the general hypothesis that "the different surfaces in the city make it feel warmer or colder in some places than in others"? Can you confirm this hypothesis based on your data and insight? Can you explain now, why that is?

5. Using the results

Temperatures have become an important issue in recent years. In the context of climate change temperatures on earth rise. Of course, this also affects the temperatures in buildings. Possibly, it also has become hot in your school building in summer more frequently.

In addition, it is warmer in cities than in the countryside anyway. You can find clues as to why this is the case in what you have learned. Climate change, thus, has a strong effect in the cities. This can be a problem for people living there, because health problems can arise if it is too hot.

Therefore, the question arises, what can be done to prevent buildings or the whole city from heating up so much. Think about the results of the experiment with the Cool City Lab. What could be used to reduce the warming of the city in summer?

Here are some questions that might give you some ideas:

What can be the role of green spaces and fresh air corridors?

What can be the role of roofs, their color, and their material?

How can the albedo of the city be changed?

What can be the role of water?

Many considerations on these questions and on the ideas for solving the heat problem raise new questions. It is often difficult to answer these questions by yourself. Think about who might have knowledge about it. Approach others who might be good advisors. Contact these people to present your ideas and get answers to your questions.

If you have a good idea and you learned a lot about the topic from your consultants' answers, you can continue to think about how you could make your idea a reality. Again, many questions arise:

Is it possible to simply do what I propose with my idea?

Do I perhaps need permission to do so?

What would it cost to implement my idea and who would pay for it?

Again, it is good to ask those, who are experts in the issues. This could be the local administration, a politician, or someone from an organization that is concerned with the future development of cities. Architects and urban planners are also familiar with these topics.

Write down everything you found out about the temperatures in the city and about ideas on how to keep them down in summer. You can also create one or more posters on your results. In the end, we want to present the results in school. We will invite parents and guests from outside the school to the presentation. Maybe even the mayor will be there.

Teacher information: Experiment with the Cool City Lab (for beginners)

1. Temperature measurement

   Temperature sensors must be placed inside the box to investigate the effect inside. Additional sensors such as an IR-thermometer may be help to investigate the effect of energy fluxes at the surface. We recommend using inexpensive iButtons to measure the temperature inside. These can be programmed and there is no need to open the box during the experiment. Alternatively, Arduino or Raspberry Pie microcontrollers are a good alternative to measure inside of the box.

2. Importing temperature data into a spreadsheet

   Importing the data into a spreadsheet software from a text-file generated by the digital thermometer may be challenging to some students. The format of the file and the data often differs from the standards expected by the spreadsheet software. It can save time having the teacher do this.

3. Checking the temperature data

   In addition to checking the reasonable temperature range, the course of the curve should also be checked. Sudden changes of temperatures or spikes in the curve hint at erroneous measurements.

Building instructions for a radiation shield

Authors: Karl Kemper, Tim G. Reichenau, Karl Schneider

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1. Introduction

What is a radiation shield and why do we need it?

A radiation shield is required to host a thermometer. Have you ever touched a metal surface (such as a car) standing in the blazing sun in the summer? The surface is a lot warmer than the air surrounding it! The same happens with a measuring device. When positioned in the sun, it heats up because it absorbs shortwave radiation. However, if you want to measure the air temperature you need to avoid direct radiation on the thermometer. Therefore, we have to make sure that the measuring instrument is protected from direct sunlight.

Now imagine the car was in a closed tent to protect it from the radiation.
In the tent, it also becomes warm and stuffy.

Therefore, while we need a protection from radiation, the measurement instrument must be well ventilated.

Look at the design of the radiation shield on the front page: It keeps solar radiation from reaching the instrument inside but it allows air to flow through and reach the thermometer.

The radiation shield is white because white reflects the shortwave radiation best and the radiation shield does not heat up as much.

The device we use to measure the temperature in the radiation shield in our example is called an iButton. However, there are other small devices to measure temperature, which can be used as well. The iButton not only measures the temperature, it also stores the measured data, so we can measure temperature continuously and automatically. Since it is quite small, a small radiation shield is quite sufficient.

Here we explain how to build a radiation shield.

In the picture, you can see how small an iButton is compared to a 50 cent coin.

2. The pages to take to the hardware store

2.1. List of materials

1. 5x plant saucer, plastic, diameter 8 cm (see picture below)
2. 50 cm white plastic tube, inner diameter: 0.5 cm, outer diameter: 0.7 cm
3. 1x aluminum flat bar 1.5 cm wide 0.2 cm thick 30 cm long
4. 10 cm white plastic tube, inner diameter: 0.8 cm, outer diameter: 1 cm
5. 1x cable tie
6. 1x Styrodur panel about 5x5 cm
7. 1x paper clip
8. A temperature sensor, e.g. an iButton

Bolts and nuts:

1. 1x M6x30 bolt
2. 4x M4x60 bolt
3. 4x fitting nut (M4)

In the picture, you can see one of the plastic plant saucers required to build the radiation shield.

2.2. List of tools

1. A cordless screwdriver
2. Drill bits of 3 mm, 4 mm, 6 mm, and 7 mm diameter
3. A 40 mm hole saw (attachment for the cordless screwdriver, shown in the picture below)
4. A fine saw
5. Scissors
6. A ruler or folding rule
7. A sharp pencil
8. A pointed knife
9. A hot glue gun
10. A compass (to draw circles)
11. A hacksaw
12. Possibly superglue
13. A screwdriver, wrench bit, or ratchet for each of these:
14. the big bolt
15. the four small bolts
16. the four nuts

This is an example of a hole saw attachment for a cordless screwdriver.

2.3. Replacement options

Not all hardware stores stock all things you need. Therefore, we made a short list showing what can be used as a replacement for missing things and what needs to be considered.

<u>The plant saucer:</u>

The plant saucers are probably the items most difficult to get. At the same time, they are the most difficult to replace. They can be a little bigger, but make sure that they are really "white", or "sand" or "cream". The light color is important, as described in the introduction!

<u>The tubes:</u>

The tubes can be replaced by somewhat smaller or bigger ones. However, there are some issues to consider:

- The small tube needs to fit into the big tube!
- The long M4x60 bolts need to fit loosely into the small tube!
- The short M6x30 bolt must fit tightly into the small tube so that it cannot be pulled out. If it is not completely tight, you need a drop of glue.
- The drill holes have to be adjusted to the diameter of the bolts.

<u>The bolts:</u>

Bolts may also be replaced if the points relevant to the tubes are considered. However, the long bolt must be 60 mm long. The short one may be somewhat shorter or longer than given in the list, if it still fits tightly into the small tube. The kind of bolt head is not important as long as you have the right tool to tighten it.

<u>The aluminum bar:</u>

The aluminum bar has to be adjusted anyway so that it fits the way you want to hang the radiation shield! The material, width and thickness may also vary as long as the holes for the bolts can still be drilled safely into the bar.

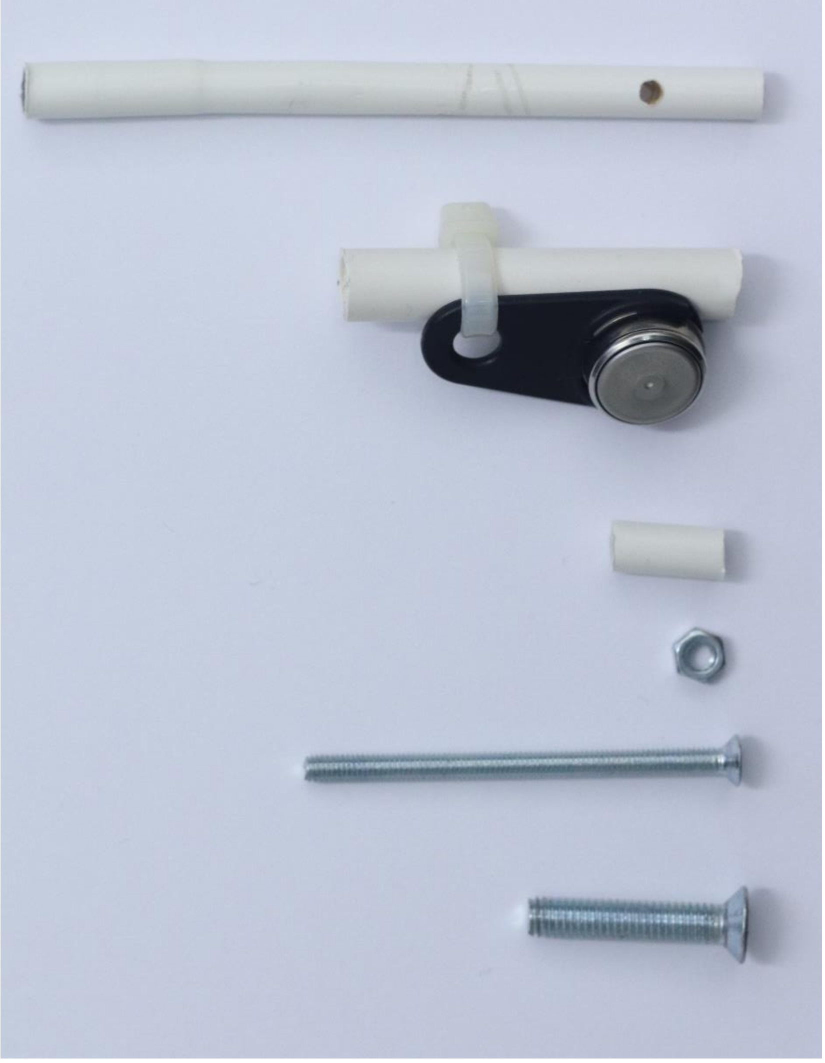
<u>The Styrodur:</u>

Regarding the Styrodur, it is important that the material is firm and stable. You can also use a packaging material or something similar. However, the material must have good insulating properties.

Styrofoam or other coarse-grained materials are not very suitable, since they are very crumbly and, therefore, microplastics can be released into the environment!

3. List of parts to be build

You can lay down the next two pages and place each completed part onto the photo. When all parts are completed, you can continue!



1x central tube

1x pull-over tube with iButton

12x spacer

4x nut M4

4x bolt M4x60

1x bolt M6x30

1x aluminum bar (caution, not shown in original size)

1x bottom disc

1x top disc

3x middle disc

4. The tubes

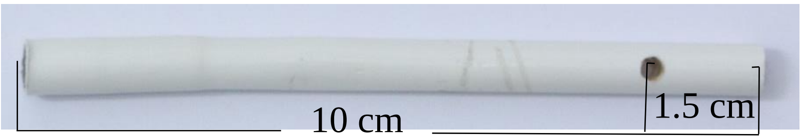
You need:

1. The tube with inner diameter 0.5 cm and outer diameter 0.7 cm
2. The tube with inner diameter 0.8 cm and outer diameter 1 cm
3. A cable tie

And tools:

1. The cordless screwdriver
2. The drill bit with a diameter of about 3 mm
3. The fine saw
4. The scissors
5. The ruler or folding rule
6. The sharp pencil

4.1. The central tube



This tube sits in the center of the radiation shield. The tube with the iButton will be sled over this tube. Finally, the paper clip will keep everything in its place when it is put through the hole.

- You will need the tube with the inner diameter of 0.5 cm and the outer diameter of 0.7 cm, the ruler, the pencil, and the fine saw.
- Measure 10 cm from the pipe and mark this point.
- Saw off the tube at the mark using the fine saw.
- Mark a point 1.5 cm from one end of the tube.
- At this mark, drill a hole straight through the tube using the 3 mm drill bit.
- You can now put the tube to the completed parts.

Tip:

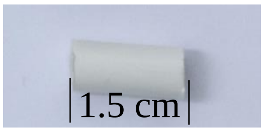
Clamp the tube or fix it with a screw clamp on the table, then you can work easier and do not hurt yourself!

4.2. The pull-over tube

The pull-over tube will be pulled over the central tube. It is removable, so that the iButton can be taken out and data can be read.

- You will need the tube with the inner diameter of 0.8 cm and the outer diameter of 1 cm, the cable tie, and the iButton. Of the tools you will need the scissors, the fine saw, the ruler, and the pencil.
- Measure a 5.5 cm piece from the tube and saw it off.
- Then you attach the iButton to the tube using the cable tie. Cut off the extra piece with scissors.
- You can now put the tube to the completed parts.

4.3. The spacers



You need these twelve spacers to separate the discs from each other.

- You will need the tube with an inner diameter of 0.5 cm and an outer diameter of 0.7 cm, the ruler, the pencil, and the fine saw.
- Measure twelve 1.5 cm sections and mark them with the pencil.
- Saw off the twelve spacers.
- You can now put the twelve pieces to the completed parts.

Tip:

Take a close look at the saw. If it has a very thick saw blade, it is better to measure and saw the twelve pieces one after the other. Otherwise, the pieces become too short by the thickness of the saw blade.

Tip: Make sure that the tube sections are as accurate as possible to 1.5 cm! Otherwise, the radiation protection will become crooked!

5. The discs and the aluminum hanger

You need:

1. The 5 plant saucers
2. The Styrodur
3. The aluminum bar

And Tools:

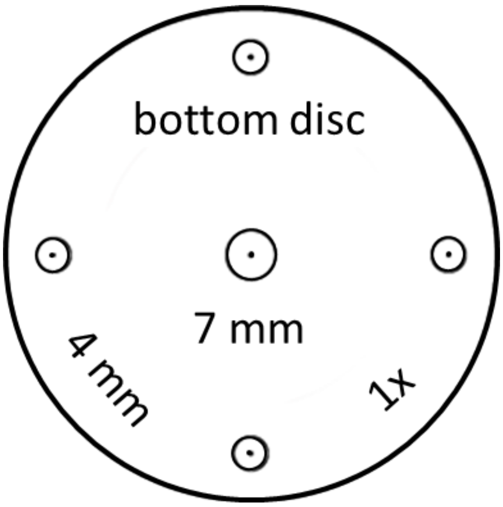
1. The cordless screwdriver
2. The drill bit with 4 mm diameter
3. The drill bit with 6 mm diameter
4. The drill bit with 7 mm diameter
5. The 40 mm hole saw
6. The sharp pencil
7. The scissors
8. The pointed knife
9. The hot glue gun
10. The compass
11. The hacksaw

5.1. The bottom disc

In the end, the bottom disc will be pushed onto the central tube and thus closes the radiation shield.

- You need a plant saucer, the cordless screwdriver, the 4 mm and 7 mm drill bits, the scissors, the knife, and the drilling template “bottom disc“ shown below.
- Cut out the drilling template with the scissors and make a small hole in the middle of each of the five marked drill holes with the tip of the knife.

Drilling template “bottom disc“



Tip:

Before you cut out the drilling template, check that it has a diameter of 6.5 cm. If not, something has gone wrong when printing. In that case, print this page again with the print setting “Original size” or “100 %”.

- Put the drill template into the plant saucer and draw a point in each of the holes you made with the knife.
- Use the 4 mm drill bit to drill a hole at each of the four outer pencil marks.
- Use the 7 mm drill bit to drill a hole at the pencil mark in the middle.

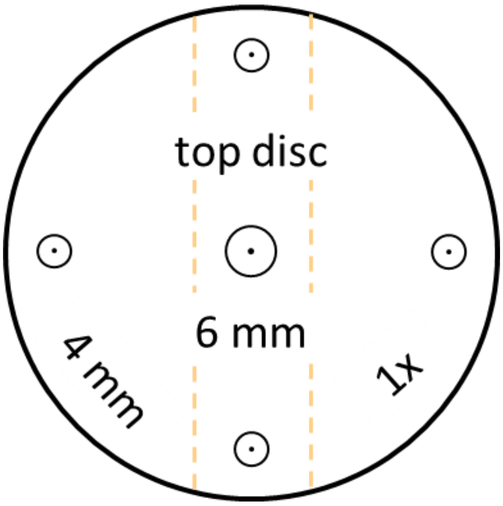
- Now you have to cut out the Styrodur disc and glue it in place. To do this, you need the Styrodur, the knife, the compass, the hot glue gun, and the knife.
- Draw a circle of about 4.5 cm diameter on the Styrodur with the compass and cut it out with the knife. (Alternatively, you can use the 40 mm hole saw here). The exact size and shape is not important here, the disc can also be smaller, larger or angular!
- Glue the cut out Styrodur part into the plant saucer using the hot glue gun.
- Finally, drill into the central 7 mm hole in the plant saucer again, so that it goes through the Styrodur.
- You can now put the bottom disk to the completed parts.

5.2. The top disc

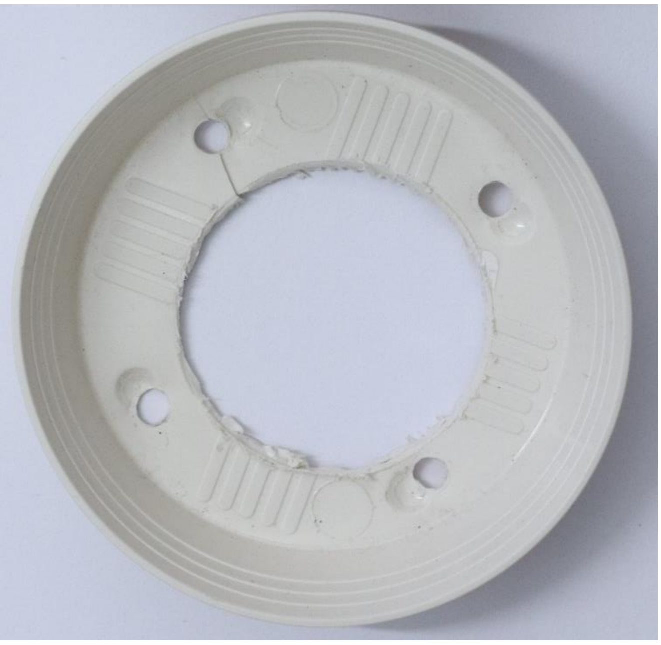
In the end, the top disc will be screwed to the aluminum hanger. It holds everything in its place.

- You need the cordless screwdriver, the 4 mm and 6 mm drill bits, the drilling template “top disc”, the knife, and the scissors.
- Cut out the drilling template with the scissors and make a small hole in the middle of each of the five drilling marks with the tip of the knife.
- Put the drill template into the plant saucer and draw a point in each of the holes you made with the knife.
- Use the 4 mm drill bit to drill a hole at each of the four outer pencil marks.
- Use the 6 mm drill bit to drill a hole at the pencil mark in the middle.
- You can now put the top disk to the completed parts.

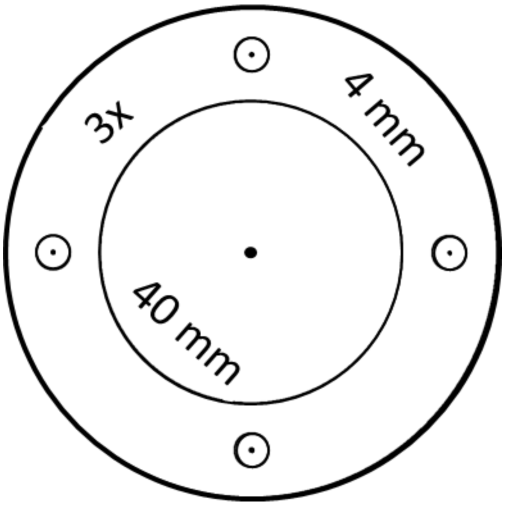
Drilling template “top disc“



5.3. The middle discs



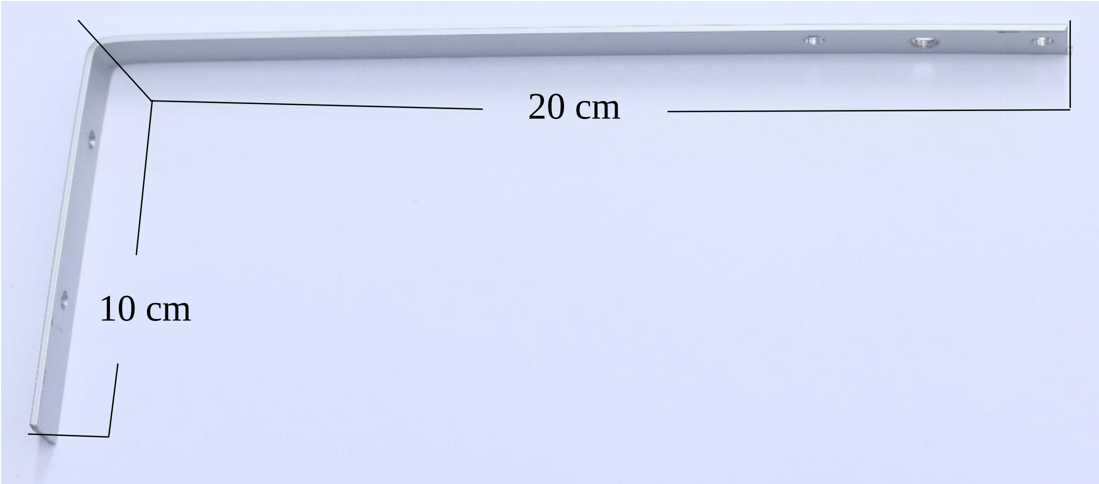
Drilling template “middle disc“



In the end, the three middle discs will be fixed to the top discs by the four long bolts.

- You need the cordless screwdriver, the 4 mm drill bit and the 40 mm hole saw.
- Cut out the drilling template with the scissors and make a small hole in the middle of each of the four outer drilling marks and the center of the disc with the tip of the knife.
- Put the drill template into the plant saucer and draw a point in each of the holes you made with the knife.
- Use the 4 mm drill bit to drill a hole at each of the four outer pencil marks.
- Use the 40 mm hole saw to cut a hole at the pencil mark in the middle.
- Do the same with the other two middle discs.
- You can now put the three middle disks to the completed parts.

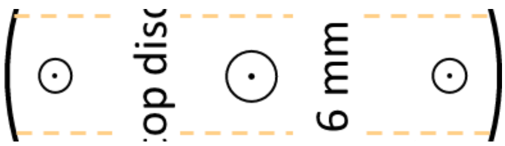
5.4. The aluminum hanger



(Caution, the aluminum bar is not shown in its original size)

In the end, the radiation shield will be mounted to something by the aluminum bar. Therefore, its shape and length may have to be adjusted.

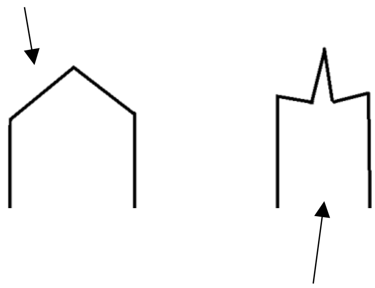
- You need the aluminum bar of 2 mm thickness and 1.5 cm width, the hacksaw, the cordless screwdriver with 4 mm and 6 mm drill bits, the ruler, the pencil, the drilling template „top disc“, and the scissors.
- Measure 30 cm from the aluminum bar and mark it with the pencil.
- Saw off the aluminum bar at the mark using the hacksaw.
- At one end of the bar, the top disc will be fixed. Therefore, you can use the drilling template “top disc”, which has to be cut out along the dashed lines using the scissors:



- Now the template looks like the figure above and fits on the aluminum bar.
- Move the template to one end of the aluminum bar and mark the three drilling holes.
- Drill the two outer holes with the 4 mm drill bit and the hole in the middle with the 6 mm drill bit.

Tip:

Make sure to use a metal drill bit for the aluminum! You can recognize it by the fact that the tip looks more like this in cross-section,



While they look like this with a wood drill bit.

- The other end of the bar is the end with which you fix it to a wall, a beam, a tree, or similar. On that end of the bar, you must therefore drill holes the way you need them! But it is practical, if you do it like this, for example:
    - Put your ruler on the end of the bar and make a mark at 3 and at 8 cm, respectively
    - At both marks, put the ruler rectangular to the bar and mark the middle of the bar.
    - Use the 4 mm drill bit to drill a hole at both marks.
- Now, the aluminum bar has to be bent.
- Put a mark 10 cm from the end with the two holes (<u>not</u> the end with the three holes).
- Place the bar over an edge, e.g. the edge of a table and bend it carefully until it has a right angle.
- You can now put the aluminum hanger to the completed parts.

6. The assembly

You need:

1. All completed parts!
2. The paper clip

And tools:

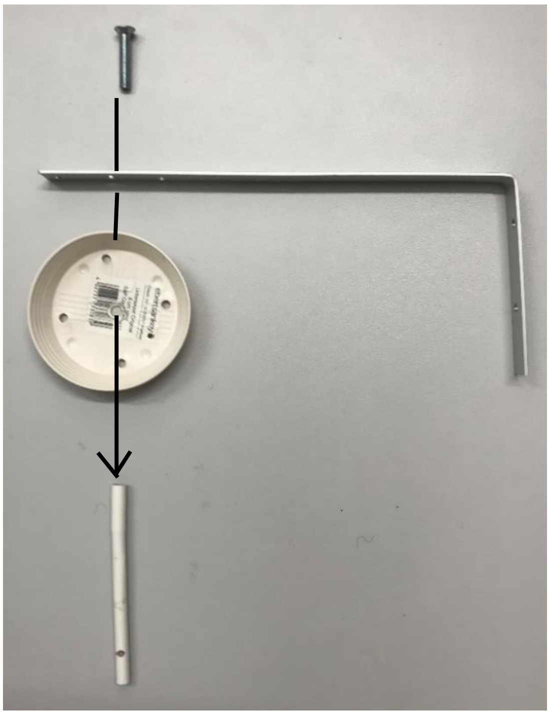
A screwdriver, wrench bit, or ratchet for each of these:

1. the big bolt
2. the four small bolts
3. the four nuts

and possibly superglue

Now the assembly of the radiation shield can begin!

6.1. The central tube



- Here, you attach the cantral tube and the top disc to the aluminum bar.
- You need the screwdriver, wrench bit or ratcher for the big bolt.

- Use the big bolt to attach the top disc to the aluminum hanger by screwing it through the hanger into the central tube.

6.2. The discs

- Here, the other discs and the temperature sensor (iButton) are added to complete the radiation shield.
- You need the screwdriver, wrench bit or ratcher for the long bolts and for the nuts.
- Put the four long bolts through the four outer holes in the top disc, which has been attached to the aluminiium bar in the previous step.
- Alternately, put the spacers and the middle disks onto the long bolts as shown in the figure.
- After the third middle disc, screw the nuts onto the long bolts.
- Pull the pull-over tube with the iButton over the central tube.
- Put the bottom disc on the central tube and close the radiation shield by threading the paper clip through the hole in the central tube.
- You can see if everything looks right by looking at the picture on the front of the manual.
- Now you can install the temperature sensor (iButton) with its radiation shield in a place you want to measure the air temperature.

Infiltration

Enter the results of the infiltration experiment in the table below:

Ground cover	**Result**
dense pavement	
Pavement with larger joints	
no pavement, compacted soil	
no pavement, loose soil	

Teacher information: Infiltration

There are different approaches to carry out the infiltration measurements. A simple method is to use a bucket with a defined volume of water and pour it on the ground. The first measure for the infiltration is the time it takes for the water to disappear. The second is the size of the spot the water causes on the ground. High infiltration makes the water seep into the ground fast. Only few water will run off thus causing a smaller spot. On less permeable or even sealed surfaces, the fraction of water running off will be larger causing a larger spot. The interdependency of the two processes infiltration and runoff makes understanding this method more demanding than using an infiltrometer as described in the following.

A more standardized method is to use a simple infiltrometer. With an infiltrometer, a defined amount of water is supplied above a certain area of soil or ground. The measure for the infiltration is the time it takes for the water to infiltrate. It is usually measured in millimeters per second. A common method is the ring infiltrometer where a ring with a known diameter is driven into the soil, water is poured into that ring, and the time required for infiltration is measured. Since this method causes an overestimation of infiltration due to lateral movement of the water into soil outside the area of the ring, a second ring can be installed concentric with the first ring. The second ring will also be filled with water, which prevents the water from the inner ring from lateral movement. Only the time, the water of the inner ring takes to infiltrate is used as the measure. This apparatus is called the double-ring infiltrometer. The disadvantage of these methods is that they cannot be used on tarred area or pavement.

Additional materials on infiltration from the PUCLCHRA Collection of Educational Materials are the Water Challenge (P13), the Wet City Lab (P33), and an introductory section to the Cool City Lab in P31.

Powering Cities without harming the Climate: An introduction

Energy is a matter of course for us. Often we do not even realize what we are using it for. We are permanently dependent on electricity. It begins in the morning with making coffee, brushing our teeth, and listening to music on the way to school. This list could be continued for the whole day. In addition, we heat our apartment in winter, cool our food in the refrigerator, and go by cars and trains. We fly by plane and light up our rooms and so on. Furthermore, all economic sectors such as agriculture, industry, trade, services and public institutions do also depend on energy.

What exactly is energy?

Energy is fundamental to all activities. Our body takes the energy we need to live from the food we eat. Energy, in the form of electricity, is also needed to charge the smartphone. In pre-industrial times, people used energy sources such as water, wood, and coal from their natural environment. Today, the development of new sources of energy enables us to have a modern economy and the technological progress we know. The newly developed energy sources include oil products such as petrol, diesel or heating oil, but also natural gas.

Physical basics

Energy is a physical quantity that can be measured and can therefore be clearly determined. In our everyday life, we use the term energy in various contexts that do not always agree with the definition of energy used in physics. For example, many will agree with the claim: "It costs me a lot of energy to get up in the morning". In fact, this means something completely different: "I have to outdo myself getting up in the morning because I would actually much rather continue sleeping". Physically speaking, getting up actually requires energy because the center of mass of the body has to be raised, i.e. the body changes its position. The energy created by lifting the body is called **potential energy**. The amount of energy required to do this is minimal. For an average person, it corresponds to the **chemical energy**, i.e. the energy taken from our food, contained in about 0.05 g of wheat mixed bread, i.e. about the amount of energy in one crumb of bread.

There are other forms of energy besides potential and chemical energy, for example:

- **Kinetic energy**, the energy of motion.
- The **thermal energy** or simply heat.

In short, energy is the ability to do work. In the physical sense, work is always performed when energy is converted from one form to another. In the example above, work is done when chemical energy is converted into potential energy while standing up.

In thermodynamics, two main laws play an important role:

1. The law of conservation of energy: Energy can be transformed from one form into another, but it can neither be generated nor destroyed. Even though it is often said

that we consume or generate energy, it is always just a matter of converting it from one form into another.

2. The second law states that certain processes are irreversible: Heat can only flow from a warmer to a colder body, never the other way around. Mechanical energy can be completely converted into heat energy, but the reverse process is impossible.

Sources of energy

Energy is obtained from various sources. A distinction is made between renewable energy sources and non-renewable energy sources. **Non-renewable energy sources** are finite; they are only available as long as natural reserves last. The use of these energy sources pollutes the environment, as these materials are usually burnt to generate energy. This produces carbon dioxide (CO_2), one of the greenhouse gas responsible for climate change on earth. More about this below.

Non-renewable energy sources include fossil fuels such as **oil**, **natural gas**, **lignite** and **hard coal**. They were formed over many millions of years from dead plants and animals and today are often located deep below the earth's surface. **Nuclear power** is also one of the non-renewable energy sources. Here atoms are split, releasing energy. The starting material is often the radioactive element uranium. The problem is that, in addition to energy, radioactive radiation is also released. This is harmful to humans, animals and plants. Common to all these energy sources is that first thermal energy is released, which is used to heat water. The resulting water vapor then drives a generator, which works like the dynamo of a bicycle.

> Task: Have you ever heard of Chernobyl? During an accident in a nuclear power plant, radioactive radiation leaked out and contaminated the environment. If you are interested in this, you can research the consequences of the accident on the internet.

Renewable energy sources are those, which are "refilled" automatically. They include **water power**, **solar radiation**, **wind power**, **wave power**, **geothermal energy** and **bioenergy** from sources like wood, pellets and straw. The first law of thermodynamics states that energy is neither generated nor consumed, but is converted. In the case of water, wind or wave power, for example, the kinetic energy is converted into electrical energy - i.e. electricity. In the case of geothermal and bioenergy, as with fossil fuels, this is accomplished via heat. Only solar radiation can be converted directly into electricity.

The share of renewable energies in the total energy used varies greatly between countries. Figure 1 shows this for the EU countries.

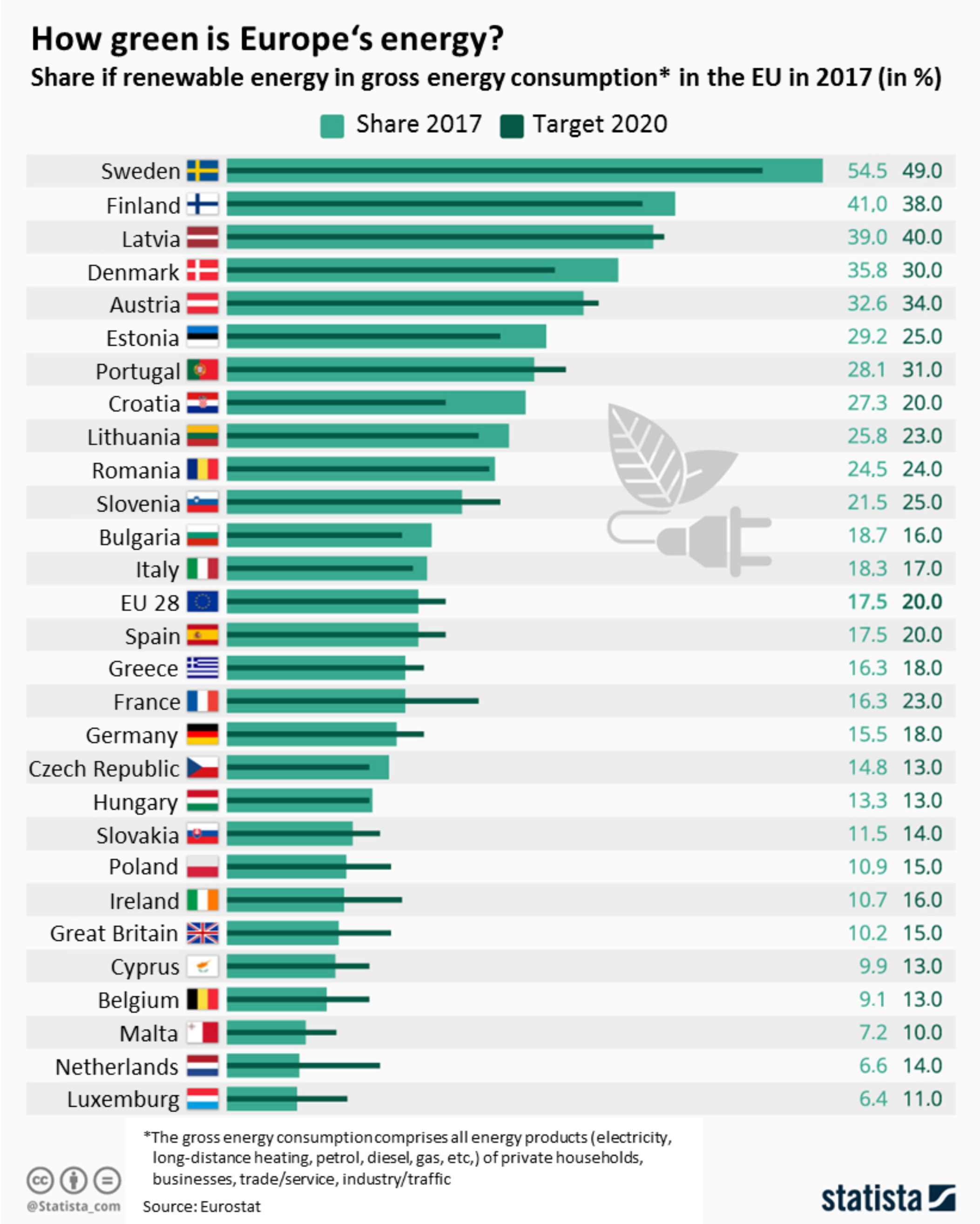


Figure 1: How green is Europe's energy? (Translated from: Statista: https://de.statista.com/infografik/18785/anteil-erneuerbarer-energien-am-bruttoendenergieverbrauch-in-der-eu/)

Tasks: How long will the system based on fossil fuels actually be able to withstand our high energy consumption? Oil, natural gas, uranium and coal deposits are finite. However, the financial, political and ecological costs are also increasing and are provoking tensions. In the long term, it is therefore essential to switch completely to renewable energies. Do research on the following questions:

- How has the share of renewable energy changed over the last 20 or 30 years?
- Why isn't the share of renewable energy greater?
- What needs to be changed in the area of energy supply and energy consumption in order to use 100 % renewable energy?

Electricity, electric energy and power

Every day we use electricity in the form of electric current. This current consists of electrons, small negatively charged particles. If too many negative charges are accumulated in one place and there is an electrical connection to a place with too few electrons, the particles move to balance the imbalance. This is what we call electric current.

> Task: You can generate electrical energy yourself by rubbing a wool sweater with a ruler, for example. In this way, the kinetic energy causes the ruler to be charged electrically and you can pick up pieces of paper with it.

How does the electricity get into our socket now?

The socket is connected to the power grid. The electricity that comes out of our sockets is generated in a power station. You can compare a power station to a dynamo on your bicycle. When you pedal hard – that is, when you apply force and do work – kinetic energy is converted into electrical energy and the light on your bicycle is illuminated. From the power station, the electricity is transported at high voltage via high-voltage lines. Transformer stations reduce the voltage and from there the electricity is transmitted to your home.

What does my socket have to do with the climate?

The greenhouse effect

We regularly charge our smartphone, our laptop, even our toothbrush via the sockets. Nowadays we need electricity for almost everything and the energy demand is constantly growing. Nevertheless, we quickly forget that conventional energy production is associated with emissions of greenhouse gases such as carbon dioxide (CO_2). Sustainable energy production therefore plays a central role.

Surely, you have heard of the **anthropogenically caused greenhouse effect**, the man-made greenhouse effect. Here is a short explanation: It is important that there is a **natural greenhouse effect**, which ensures that we on earth have pleasant temperatures to live in. This works because most of the radiation that the sun emits is short-wave. It penetrates the atmosphere and hits the surface of the Earth. The surface is heated, which causes the emission of long-wave thermal radiation. Various gases in the atmosphere, including carbon dioxide, absorb part of the long-wave radiation and radiate it back to Earth. In this way, it stays nice and warm on our planet. However, it becomes warmer when more greenhouse gases enter the atmosphere and thus more radiation is radiated back to Earth. One reason for the increasing amount of greenhouse gases in the atmosphere is, for example, the generation of energy by burning fossil fuels.

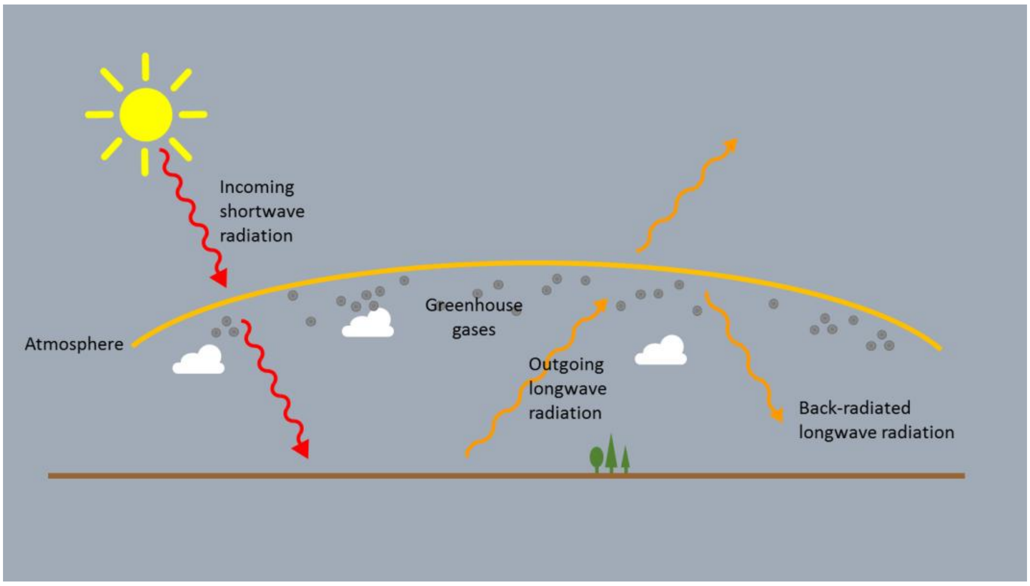


Figure 2: Greenhouse effect (simplified)

Tasks: The amount of CO_2 emitted into the air by a person is called the carbon footprint. How do you estimate your own carbon footprint? Create a CO_2 profile at

https://footprintcalculator.henkel.com/en

https://www.foe.ie/justoneearth/carboncalculator/

https://uba.co2-rechner.de/en_GB/

City climate

The climate in cities differs significantly from the climate in the surrounding area. On the one hand, the supply of fresh air and the exchange of air masses is hindered by dense housing, and on the other hand, radiation plays a special role. Sunlight is reflected several times by the walls of houses. Building materials typical of cities, such as asphalt and concrete, heat up quickly and store the heat, which is emitted later. In addition, the waste heat from households, industry and traffic contributes to the warming of the urban climate. Furthermore, the air in cities is particularly contaminated with trace gases, carbon monoxide, carbon dioxide, water vapor, soot particles and fine dusts. The long-wave thermal radiation emitted from the city surface can poorly penetrate the haze above the city and is radiated back. This results in an **urban greenhouse effect**.

Energy in my school and in my surroundings – What can we do?

Energy itself remains invisible, but we can realize it by its effects. Also at school, we constantly use energy. But where do we do that?

Tasks:

- Look around your classroom. Where is energy being used at the moment?
- What is the source of electrical energy in your school?
- How could your school save energy? What can the students do to help saving energy?
- You do not only use energy at school but also at home and when you are under way. Are there options to save energy there?
- Are there any disadvantages that arise from saving energy? How could these be compensated?

Apart from households, energy is used in many other places in the city. This leads to the release of heat and causes CO_2 emissions. This will also have to change in the future in order to keep the anthropogenic greenhouse effect within limits and to keep the city climate tolerable. The measures required here do not only affect private households but also the city's infrastructure. Here, major conversions always involve high financial costs. Therefore, it must first be investigated where energy can be saved particularly well. This information is then evaluated in a political process in which the needs of various groups such as residents, the economy and the companies responsible for energy supply must be taken into account.

Tasks:

- How much energy is needed to "run" a city?
- What is the energy used for? Who are the biggest energy consumers in a city?
- Where can energy be saved particularly well? Also, take into account who could have disadvantages as a result.

Authors: Marie-Madeleine Regh and Tim G. Reichenau, Institute of Geography, University of Cologne, 2020

Innovation for Social and Environmental Benefit: An introduction

Urbanization and growth of cities

If you live in a city, you belong to the majority of people on earth since 2008. Cities have long played a significant role in the influence that humans have on nature. Especially in the last century, the influence of cities has grown exponentially as cities grow globally in both size and number. This process is called urbanization. While in 2000 there were about 371 cities with more than a million people (globally), by 2018 there were 548, and by 2030 there will be about 706 (data: UN).

Tasks: What is it like in your area? Do you live in a city with a million inhabitants? Or where is the next city with more than a million people? And since when did it exceed the million people mark?

Of course, urban growth is closely linked to population growth, and thus part of urban growth is explained by the growing world population, which in 1950 was still around 2.5 billion people and is now 7.8 billion. Of these people, an increasing percentage live in cities. In 2018, for example, around 55.3 percent of the world's population lived in cities, and by 2030, it will probably be 60 percent (data: UN).

Tasks: What about the growth of cities in your country?

- How has the population in your country and/or city changed over time? Try to use data from official statistics or census here.
- How has the area of your city changed with time? Have a look at aerial photos or satellite images. How has the built-up or sealed area changed? How has the green space changed?

Effects of urbanization on people and the environment

Cities already account for a large proportion of greenhouse gas emissions. However, these emissions do not always take place in the city itself. E.g., the power plants that generate the electricity for a city are usually located outside of it. In addition, there are emissions that are indirectly caused by goods consumed in the city. Nevertheless, considerable emissions are also produced within the cities. Reasons are e.g. the dense road traffic with frequent stops in traffic jams or at traffic lights and also the heating systems of the buildings.

Tasks: Emissions: How do the CO_2 balances of urban and rural residents differ? Think about the living conditions and lifestyle of different people in the city and in the country. There are various calculators on the Internet for your personal CO_2 footprint (links below). Use one to calculate and compare the CO_2 footprint of city and country residents. Is it better to live in the country or in the city in terms of greenhouse gas emissions?

https://uba.co2-rechner.de/en_GB/

https://footprintcalculator.henkel.com/en

https://www.foe.ie/justoneearth/carboncalculator/

Exhaust gases do not only have an impact on the urban greenhouse effect and global warming, they also have negative effects on human health. Pollutants emitted besides the greenhouse gases such as nitrogen oxides and particulate matter also contribute to the negative health effects. The higher temperatures in the city caused by the effect of urban heat islands also lead to health problems and increased mortality rates, especially among the elderly and those who are already ill. A further health burden results from the constant noise pollution, as noise can have a negative effect on blood pressure and heart rate.

Tasks: What is the percentage of CO_2 emissions caused by cities (worldwide, in your country)? What is the share of your city in the emissions of your country?

How much more likely is it to suffer from a disease caused by dirty air in a city compared to the countryside? What about heat-related health problems?

What is the mechanism behind the urban heat islands? Here you can also contact PULCHRA schools that are working on City Challenges 2 or 3.

Against the background of climate change and the growing world population, agriculturally usable land and drinking water are very important resources. Both are in competition with cities, as the soil in the cities is sealed over large areas. Since cities were often founded where good agricultural conditions prevailed in the surrounding area, valuable land is lost to the growing cities. At the same time, rainwater can no longer seep into the soil and is therefore fed directly into rivers via sewerage systems. In this way, it no longer reaches the groundwater and it is missing from wells.

However, not only the physical and physiological processes are negatively affected in and by cities. There are also effects on a social and psychological level. For example, despite the high density of people in cities, there is a tendency towards social isolation. People who live in the city also suffer more often from stress.

Tasks: In this section, many negative effects of urbanization were presented. Can you think of any positive aspects? When it comes to living sustainably and being socially integrated, what opportunities does the city offer that are not available in the countryside?

Innovations for more sustainability

In contrast to the negative consequences of urbanization, there are also positive effects. Some of them you have certainly identified in the last task. Only two topics shall be mentioned here.

There are several trends towards food production in cities. In the private sector, "urban gardening" is becoming increasingly popular. Here, fruit and vegetables are grown on roofs, balconies or open spaces. There is usually no commercial background. Several city gardeners often join to form community gardens, with the positive side effect of counteracting the tendency towards social isolation in the city. Far beyond these small gardens is "urban farming". Here, agriculture in the city is practiced on a larger scale, often with an interest in profit. In urban farming, vegetables or cereals are usually grown in greenhouses, on open spaces, or on roofs. A special form is "Vertical Farming", in which the cultivation takes place on facades or several greenhouses are built in floors one above the other. The first working examples on a larger scale have been implemented in Singapore. It has also been shown that in connection with fish farming, it is possible to work in cycles in which plants clean the water and the excrements of the fish serve as nutrients for the plants.

All these approaches have the same main advantages. Emissions are reduced by eliminating longer transport distances. In addition, the additional plants in the city improve air quality. Furthermore, the loss of agricultural land through sealing is compensated for, since farming in the city requires virtually no additional land, but takes place on previously unused and often unusable space.

Apart from agriculture, other functions can also be integrated into cities. Solar plants (photovoltaic) and also special wind power plants can provide electric power directly in the city. This eliminates losses due to long cable runs and buildings heat up less under the solar collectors.

Tasks: Does urban gardening or urban farming also take place in your city? What about energy production in your city?

The city of Venlo in the Netherlands has a very innovative city hall. Find out which ideas have been implemented there.

Smart City

Another approach to address problems of cities is the concept of the "Smart City". Here, an attempt is being made to meet the strong urbanization and the many challenges it poses through innovative technologies and increased digitalization and networking. Holistic concepts based on advanced technologies are intended to make cities more efficient, more sustainable and at the same time more social.

In this context, futuristic-looking projects are often reported. For example, Amazon is testing drones to deliver parcels and Uber wants to offer "Uber Air" flight taxis from 2023. However, even if we leave out the all-too-futuristic sounding things, there are already examples today of how innovation and smart networking can help solve the problems of today's cities.

One example that many people use in their everyday lives is integrated city maps and navigation systems. The best known is probably Google Maps. In order to be able to offer the fastest possible routes in the navigation, the providers process GPS data from their users. This allows them to see where many smartphones are currently located. If, for example, many devices are moving slowly at one point or in stop-and-go mode, this can lead to the conclusion that there is a traffic jam. These places can then be avoided during navigation. Less traffic jams, reduced emissions, and less waiting time are the results.

This is an example for an already realized approach. In the Smart City concept, however, things are often thought some steps ahead. The idea is to bring together all accessible information about the city. In the field of traffic, this includes information on traffic lights or current positions of public transport vehicles. In the context of optimizing the energy supply, it can be information about the production and current consumption of electricity. In the event of overproduction of electricity from renewable sources, networked electricity consumers such as washing machines can then be started or electric cars can be charged. In this way, energy losses during intermediate storage of energy can be avoided and energy efficiency is increased.

However, the basic ideas of the Smart City also include active and creative self-initiative of the population and consistent citizen participation, e.g. in large construction projects.

Tasks: The Smart City approaches do not always have to be thought of as very big projects. Even in the personal sphere, access to and linking of information can help people to behave in a more sustainable way. Do you know technologies, such as apps, that can help? Are there any ideas in this area that promote sustainability and social interaction at the same time?

Many of the Smart City ideas are based on the evaluation and linking of enormous amounts of data. This is generally connected with the danger of data misuse. On the one hand, the collected data opens up possibilities to control people. What is technologically possible in this context is currently being tested in China, where people are given scores based on their individual behavior. Various aspects of social participation have been made dependent on this score. On the other hand, the partly uncontrolled use of data by private companies can also be a problem and is being strongly discussed. One example of this are the so-called smart speakers of the large internet companies. These devices constantly record the sounds of the surroundings to listen for instructions. Private conversations can also be recorded without the users being aware of it.

Tasks: Many people say, "I have nothing to hide" when it comes to whether they care about what information is available about them. Think about what information about yourself you would share with friends. Think further about what information you would make available to everyone, for example, by printing it on your T-shirt. Is there any information that is so private to you that you don't want anyone to know about it? How could important information be protected?

However, "smart" solutions do not necessarily have to be new technologies. Very practical approaches, which depend on the activities of the people involved, can also be innovative. Particularly relevant here are aspects of the "sharing economy", i.e. the joint use of things (e.g. car sharing). Food sharing, i.e. passing on food that is not needed, can also be mentioned here. In addition, there are approaches such as repair cafés, where people meet to repair things, which can reduce consumption and resource consumption. Here it is up to each individual to get involved and develop the possibilities of the Smart City in terms of sustainability and social participation.

Tasks: If the personal rights of the citizens are protected, great opportunities seem to lie in the Smart City approaches. How could the implementation of these approaches be encouraged? What are the plans already in place in your city? What data from your city is already available for use? Which parties and groups of the urban society are fighting for it, which are opposed to it?

Authors: Tim G. Reichenau and Karl Kemper, Institute of Geography, University of Cologne, 2020

Buildings for the Future City
A pathway towards a City Challenge: The case of cool materials

Which kind of a city do we want to live in?

More and more people live in urban areas. Until 2050, Europe's level of urbanization is expected to increase to more than 80%. Thus, most of us will live in urbanized areas. While we enjoy the advantages of these cultural, societal and economic centers, we also have to cope with the problems of urban areas such as traffic, pollution, climate effects and many more. Climate change puts another burden upon cities, which affects all, poses a particular challenge, and which requires the contribution of all members of the society. Thus, it is essential to develop ideas and concepts of our future cities and to help shape our own living environment.

Cities can be understood as living organism. They grow, change, have a metabolism and an own character. Cities shape many aspects of our lives ranging from **a**rchitecture / housing to **z**oological gardens, from culture to economics, from history to future, from local identity to global interaction. As many aspects and dimensions a city has to offer, as many city challenges are there to address. The PULCHRA project encourages the participants to use their own imagination, their creativity and their potential to make the school an open learning environment and to help shape the future of your own city.

While the relevant or interesting issues for each city and school may vary from place to place, climate change and climate adaptation is an issue, which affects all of us. Thus, we chose this topic to exemplify the development of a city challenge. This example may serve as a blueprint or just merely as an inspiration to start rethinking the societal role of schools based on the Open Schooling concept. In the process, schools become central sites for innovation and social participation, spreading new concepts for the future throughout society.

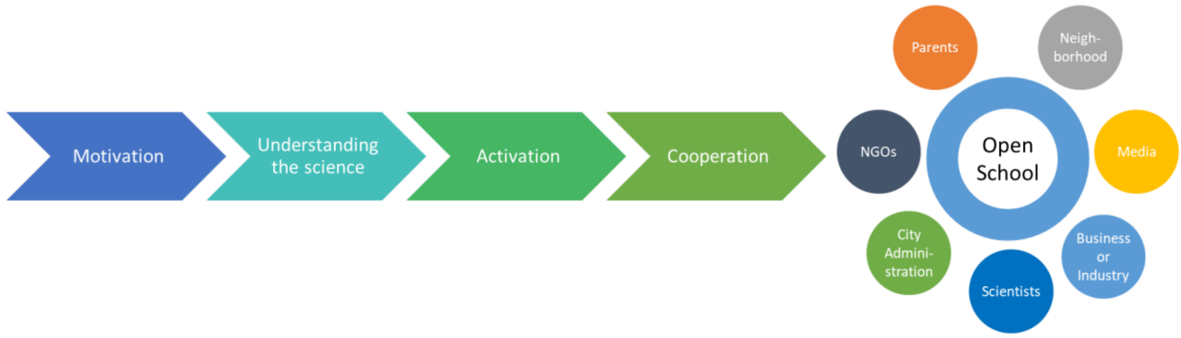


Figure 1: Concept of a city challenge

Thus, this example for a city challenge builds upon the above-described educational materials. Figure 1 provides an outline of the concept of a city challenge. Students are motivated and oriented towards an issue of interest. Here we chose the example of different types of urban surfaces and their effect upon the urban climate. This example shows how the different participants and stakeholders have an impact upon the urban climate. An owner of a house may choose to cover the property with a natural surface thus reducing the urban heat through evaporation or to build a tared parking lot. A city, businesses, NGO's etc. have similar choices to make and scientists help to understand the impacts and consequences.

Understanding the effects of the choice of different surfaces and materials used to build a city is a good example to apply an Open Schooling concept to illustrate the need for cooperation and participation and to provide a mechanism to facilitate active citizenship for all participants.

As the choice of materials used in a city has a decisive impact upon the local climate, all participants have the ability to help building a healthy and pleasant urban climate, which provides a good living environment. However, with climate change we will be faced with temperatures more frequently exceeding a comfortable range, with all its negative effects upon human wellbeing, health, economy, society and ecosystem functions. Mapping the school environment (educational material P12) is a good starting point to understand the different materials, which exist in an urban environment. Building and experimenting with the Cool City Lab (P30, P31) allows investigating the thermal effect of different surfaces in terms of energy transfer mechanisms and resulting heat in a building (or in the climate box of the experiment).

Figure 2: Conceptual design of the Cool City Lab

Figure 3: Picture of a Cool City Lab

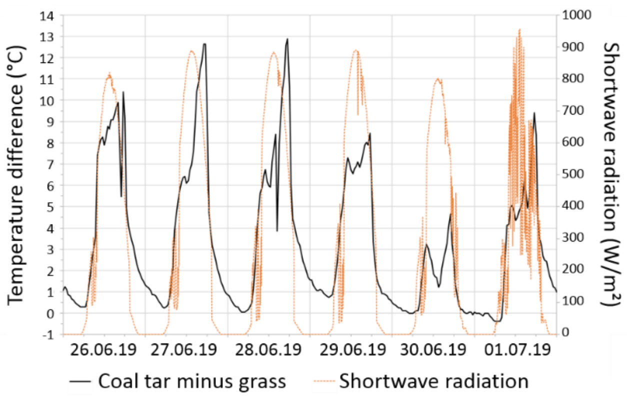


Figure 4: Example of the temperature differences in two box with different cover (black line) and shortwave radiation (orange)

Figure 2 shows a sketch of the conceptual design of the Cool City Lab. Figure 3 shows an image of such a lab.

> Tasks: Use an infrared thermometer to measure the different surface temperature and to investigate the effect of evaporation at the surface.

Particularly during a day with clear sky and lots of sunshine, a clear effect of the cooling by vegetation will be visible in the Cool City Lab (see Figure 4).

The temperature in the box will change as a result of the energy fluxes at the surface. In fact, the color of the box does not matter much, since the boxes are made of styrofoam, which is a well insulating material. Only the lid of the boxes are made of different materials (here tar, grass, sand, and stones). Students can easily exchange the surface used at the top and pursue their own hypotheses regarding different materials.

Task: Take a piece of aluminum foil and measure its surface temperature with an infrared thermometer. Take the measurement outside. While measuring, place the aluminum foil on a surface and hold it above your head, respectively.

Do you get the same result if you measure the temperature of the aluminum foil from below and from above? Why?

If done properly you will observe large differences in the surface temperature reading. Why is this the case? The answer is hidden in the physics of this measurement. Not all materials have the same ability to produce longwave radiation. This is called the emissivity of the material and the Stefan-Bolzmann law explains the relationship between actual temperature and radiation temperature that is measured by an infrared thermometer. Some materials can be apparently cool, while others really keep a city cool. The latter is the case, if the shortwave radiation energy is either reflected straight back into the atmosphere or if the absorbed radiation is used to evaporate water.

Based upon this understanding of science which connects physics, environmental sciences and chemistry (e.g. the choice of the kind of paint determines the reflection of radiation) students may explore their neighborhood and identify surfaces which either contribute to cooling the city during a heat wave or do not do so. Documenting their findings may lead to a discourse with parents, families, neighbors, scientists, city administrators and other stakeholders, which shape the development of the city. This discourse in an open schooling approach helps to develop the notion that it is possible, worthwhile, rewarding, and necessary to become an active participant of the urban society, regardless of age, gender, heritage or other criteria. Putting the schools into the center of a City Challenge underlines the role of schools in our society for all from student to city administrator, from parent to politician or businessperson.

Authors: Karl Schneider and Tim G. Reichenau, Institute of Geography, University of Cologne, 2020

Regenerating Urban Space to connect People in a Healthy Environment
From local action to regional impact

Open spaces, parks, water surfaces and pathways for ventilation

Building upon the conceptual understating of the role of different surface materials in a city shown in the description of City Challenge 2 in material P39-L, this example for a challenge in the frame of "Regenerating Urban Space to connect People in a Healthy Environment" connects individual places to the concept of space, neighborhoods, and an urban area as a whole. While we address in this example again the issue of urban climate, urban spaces are more than a physical environment in which we live. They are cultural environments, spiritual environments, historical spaces, and more. Thus, a livable and loveable city is more than a physically agreeable place. A park does not only affect the physical space in terms of its temperature, it provides a social space to connect and meet people, a cultural place to experience arts, and often a place to reflect on the past and develop ideas for the future. Thus the example for a City Challenge provided here is intended as an inspiration to conceptualize the own living environment as part of a whole and to stimulate the notion that changes in the own living environment have an impact on other areas and people and vice versa. Thus, we encourage students and teachers to develop a City Challenge which addresses their specific interests and needs.

Based upon the fundamental introduction into the method of scientific research (materials P1-P4), a school learning, exploring and activity path (LEAP, see chapter 2.2 of the PULCHRA Handbook of Educational Materials) is a good starting point to explore different environments, to understand and document their character and to share the findings with others using analogous or digital tools (materials P5-P12, P24). The different learning materials in paper form or as apps (material P28) may be used to guide the learning, exploration and activities, and to develop a research plan. Figure 1 provides an example of a LEAP concept, which integrated a school LEAP and a city LEAP that includes citizens as a whole. The LEAP stations are equipped with iButtons or other temperature loggers, which are housed in radiation shield (see material P35). The school LEAP allows easy access to facilitate regular visits in the frame of lectures or other school activities. The city LEAP stations may be placed where the students live or at other interesting locations which show the specific thermal characteristics. As iButtons are affordable devices it should be feasible to acquire the needed financial support

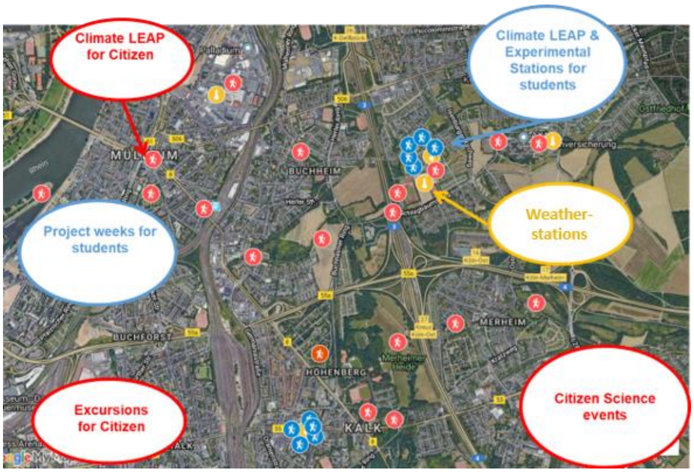


Figure 1: Example of the integration of a school LEAP with a City LEAP

from school associations, parents, NGOs, cities, or other supporting agencies or entities. Professional climate stations might also be available in the city as points of reference.

Students explore the climate of their school and their city and learn about the relationship of surface type / surface character and air temperature. This is particularly interesting and relevant during heat waves and high air pressure situations. Exploring the relationship of temperature patterns and wind direction or temperature and green area within the vicinity is essential to understand pathways to mitigate the increasing likelihood of excessive heat and to take appropriate measures such as create shadow, allow for evaporation, maintain a suitable ventilation in the city etc.

Again, as shown in Figure 1 of material P39-L, schools are envisioned as centers or hubs for learning, innovation and societal participation. Students define the City Challenge (here: identify pathways to prepare the city to reduce the impact of excessive heat) and define the research method (e.g. based upon the educational materials provided or on other resources available to the school). They analyze their data, report the findings, and cooperate with the public during the project and when communicating the results and discussing possible pathways for action.

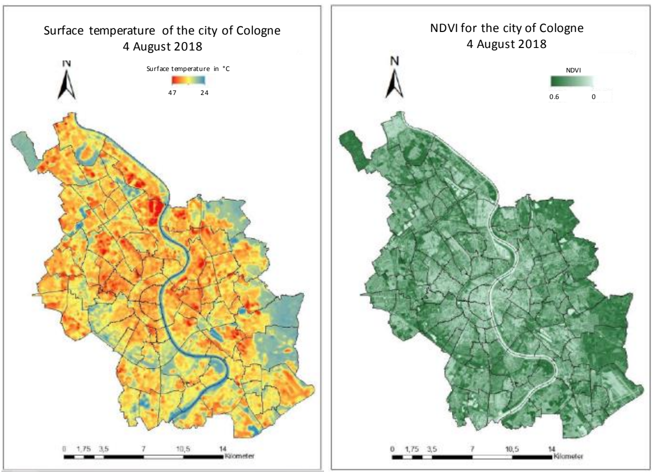


Figure 2: Example for the relationship of surface temperature and green area in Cologne/ Germany

Material to make the transition from local measurements to regional effects are freely available on the internet e.g. through European or NASA web sites[1]. Educational resources on satellite images to track changes over time are also available[2]. Also high-resolution images may be available for your city (e.g. through cooperation with local universities). Figure 2 shows an example of a surface temperature image in relationship to the existence of green surface area. The NVDI is an index, which yields high values is green vegetation

Authors: Karl Schneider and Tim G. Reichenau, Institute of Geography, University of Cologne, 2020

[1] https://cds.climate.copernicus.eu, https://worldview.earthdata.nasa.gov, https://climate.nasa.gov/earth-now/

[2] https://pubs.usgs.gov/gip/133/, http://www.esa.int/SPECIALS/Eduspace_EN/, https://www.esa.int/Education/Teachers_Corner/European_Space_Education_Resource_Office

The PULCHRA Collection of Educational Materials is part of the PULCHRA Handbook of Educational Materials. An additional document on approaches to evaluate the PULCHRA teaching methods of Open Schooling and inquiry-based learning will be published along with this document.

The initial version of the PUCLHRA Collection of Educational Materials was compiled by the PULCHRA team at the Institute of Geography of the University of Cologne in Germany in 2019 and 2020.

During the course of the City Challenges between 2020 and 2022, this collection will be extended by PULCHRA teams from the partner countries and by teachers and Science Teams at the schools of the PULCHRA Network of Schools.

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