Biomimicry in the Oude Hortus

How to design a biomimicry activity for the Oude Hortus?

Written by: Thimo van Gurchom (6132138)

Supervision by: José de Wit (University Museum Utrecht)

Pauline Krijgsheld (Utrecht University)

Matthijs Roobeek (Utrecht University)

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Universiteits Museum Utrecht

Utrecht University

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Abstract

The Oude Hortus (OH) is the old botanical garden of Utrecht, and positioned next to University Museum Utrecht (UMU). UMU and the OH are currently closed for renovations, but will open their doors in September 2023. Before renovations started, the average visitor of the OH was relatively old. UMU wants to attract a younger audience to the OH. They aim to achieve this by making educative programs for their target audience (8-14 year old kids and their families) in the OH. This report explores the options of making a biomimicry program for UMU, which could be given in the OH. Biomimicry education shares similarities with inquiry and design based learning, thus fitting in with UMU's education style. During testing days in UMU, the target audience was observed to discover what is needed to keep them engaged. The most important findings from those observations was that children barely read instructions. Therefore, an assignment needs to be as intuitive as possible. To find out what the public wants to do in a (botanical) garden, families were questioned with a survey in the Botanical Gardens of Utrecht. Through the survey, it became clear that most people were not familiar with the term biomimicry, but it did spark an interest among the audience. By gathering information on what the audience needs and wants in an activity, four biomimicry activities were designed for families. These are standalone activities that should take about 15 minutes, with no required supervision. Three activities are about one specific example of biomimicry that can be found in the OH, these activities are called the *Klittige Klis, Natuurlijk, afval!, and Coole Cactussen.* One assignment (*Functie in de Natuur)* is more in general about biomimicry, and lets the participants pick their own examples from the OH. The assignments are on booklets in boxes, along with some materials needed to do the assignment. The activity lets the audience learn about the organism and the innovation it inspired through small research objectives. Two of these activities were tested, the *Klittige Klis* and the *Coole Cactussen.* The public liked doing these activities, and rated them with a score of 4,6/5. The report found that there was a gap in knowledge regarding biomimicry among the public, which they are interested in learning about. Therefore, these biomimicry activities would be a good addition to the OH.

Layman's summary

The Oude Hortus (OH) is the museum garden of University Museum Utrecht (UMU). The average visitor of the OH is relatively old. Therefore, UMU wants to make the garden more attractive to its own, younger target audience: 8-14 year old children (in school classes, or with their family). To make the garden more attractive to this public, UMU wants to make educative activities for the OH. This report describes how such activities, with a focus on biomimicry, could be designed for the OH.

In simple terms, biomimicry means learning from nature. Nature has had over 3.8 billion years to come up with the most efficient solutions to survive in the wild. Through looking at nature, humans can learn from it, and use it to make more efficient and sustainable innovations for everyday life. Biomimicry education often involves finding and designing a solution to a problem. This is similar to inquiry and design based education, two styles of education that UMU uses to design their programs. Therefore, a biomimicry program would fit very well within UMU programming. In biomimicry programs, students often get the chance to craft the design they made. However, the experience with UMU's biomimicry program is that a classroom gets messy with crafting materials during such exercises, something that is not allowed to happen in the OH. Therefore, crafting is not allowed outside in the OH. Drawing is also often used in biomimicry education, and is an activity that forces students to take a close look at an object and stimulates critical thinking. In addition, small research activities stimulate active learning and are often considered as fun by students. Therefore, these activities will be included in the activity.

The target audience was observed during testing days in UMU, to see how they act in a museum and what they need to keep being engaged in the activity. The most important learning point from those days was that explanations need to be very short, since children cannot keep their attention long enough to read long instructions. To find out what the audience wants to do in a (botanical) garden, ten families were asked to fill in a questionnaire in the botanical garden of Utrecht. Results from this questionnaire showed that most families wanted to do an activity with their own family, and not necessarily a guided activity. It also showed that although most people are not familiar with the term biomimicry, people do think that we can learn from plants.

Based on these findings, activities were designed around specific organisms that can be found in the OH. Two of these activities were tested, the audience liked them a lot and scored them with a 4,6/5. Based on feedback during testing, final improvement were made. Finally, four biomimicry activities for the OH were made for this report: *Klittige Klis, Coole Cactussen, Natuurlijk, afval!,* and *Functie in de Natuur.*

Introduction

This report is the result of a research-internship project at University Museum Utrecht (UMU). During my internship, I was part of the Education team, who develop the educative programs in UMU. The museum is currently closed for renovations, and will open its doors once again in September 2023. UMU's target audience are families with children (age 8-14) and school groups with children in the same age range. The museum garden, the Oude Hortus (OH), is also closed currently and will also open in September. Before closing, the average age of the public visiting the OH was considerably older than visitors of the museum. UMU wants to stimulate a younger audience to visit the OH as well, and therefore wants to develop educative programs for the OH.

University Museum Utrecht

UMU focusses on science education and communication and it stands out in the Netherlands by being a research museum. The focus of UMU lies on the methods of the scientific process of research, and not so much on the results like other museums. Therefore, not only successful results are exhibited, but prototypes that failed are also given a place, since they were important in the scientific discovery process. One of the goals of UMU is to make everybody science literate [''*Iedereen wetenschapswijs*''], which in short means that the public learns what science and the process of (scientific) discovery is (1).

The museum wants its visitors to actively ask questions, find answers, and wonder about the world around them and what role science plays in it. This is achieved by an interactive exhibition around the heritage of Utrecht University (UU), from old taxidermal animal collections, to one of the first heart-lung machine prototypes. Since UMU is strongly connected to UU, exhibitions are (almost) always related to a scientist that is or was connected to UU (1). In addition, educative programs are developed to teach and engage the public even more with science. Inquiry and design based learning are important in UMU's methodology, since this allows the public to actively think and play along.

Oude Hortus

The Oude Hortus (OH) is one of the former botanical gardens of Utrecht (2). The history of the botanical garden started in 1639, when Hendrik Regius started a botanical garden at stronghold 'Zonnenburg'. This botanical garden would be moved in 1723 to the Lange Nieuwstraat, and still remains here (Oude Hortus). From 1723 till hallway through the 20th century the garden and its accompanying buildings on the Lange Nieuwstraat were used for scientific research, conservation, and education. The garden originated as medical herb garden, *Hortus Medicus,* in which medicine students were educated in the medicinal properties of various herbs and plants (2). Two big orangeries were built in 1724 and 1768 to house (sub-) tropical plants during the winter. The pride of the garden, the *Ginkgo biloba*, also originates from this century . This tree is considered to be one of the oldest of its kind in Europe (3). The greenhouses have undergone multiple renovations over the centuries. In 1920, the title of Utrecht Botanical Garden moved to Baarn (along with some plants) (2). Even later, the title and most plants were moved to De Uithof. The move of the botanical garden and its personnel caused the OH to decline and deteriorate. A big portion of the garden was mainly used as parking space and there were plans to break it down completely. In 1996, UMU became located in the former Botanical laboratory and adopted the OH (3). The OH was renovated and restored to its former glory and now acts as a museum garden for UMU.

Biomimicry

The term Biomimicry became more common after Janine Benyus' book Biomimicry: Innovation Inspired by Nature. Biomimicry comes from two Greek words; bios (meaning life), and mimesis (meaning imitation) (4). According to Benyus, the three main principles of biomimicry are 'nature as

model', 'nature as measure', and 'nature as mentor'. Nature can be seen as a model in science, to take inspiration or to imitate from nature's designs and solve human problems. Nature should also be seen as a measure, since nature has learned what works best over 3.8 billion years of evolution (4). Organisms have to adapt to their surroundings to survive. Nature has learned what works, and what lasts. Finally, nature can also be seen as a mentor. We should look at nature to see how we can learn from it, not what we can extract from it. Through understanding the principles and strategies that nature uses, we can be guided to find more sustainable solutions for our problems. Therefore, nature's principles can be followed as guidelines (Figure 1). These principles indicate how nature's designs are sustainable, and are thus guidelines for designing more sustainably (4).

***Figure 1 – Life's principles**. How design in nature is sustainable is explained in these six principles (16).*

This internship

The goal and end product of this internship is an activity in the OH involving biomimicry. Therefore, the main research question of this report is:

How can Biomimicry be integrated in an educational program for the OH?

This program will be designed in accordance with current UMU programs, and will stimulate children to actively and critically think about various organisms that can be found in the OH. The integration of Biomimicry in this program allows the visitor to think about organisms in a different light than they are normally used to, and will (hopefully) make them more excited about nature and what we can learn from it. By performing small research tasks about biomimicry examples, the audience will learn more about the organism, and what innovation it inspired. In addition, it will teach them about the process of doing research.

Methods

To answer the research question and design a biomimicry activity, the needs and wishes of multiple stakeholders were taken into account. UMU, OH personnel, and the target audience were considered to be the most important stakeholders. The needs and wishes of these stakeholders were explored using the following methods:

University Museum Utrecht

Literature and internal documents

UMU wants a biomimicry program in the OH. Therefore, this program needs to fit in with the educational style of other UMU programs. UMU's *Educatieve meetlat* (1) contains a checklist of what an activity needs to have in order to be an authentic UMU activity. Inquiry and design based learning are two didactive techniques that UMU uses to design their programs. These techniques were further explored using literature. In addition, literature gave information on what works well in biomimicry education.

UMU meetings and feedback

Weekly meetings with UMU staff will give more background information that can be used for doing literature research, or designing the activity in general. By participating in these meeting, UMU's way of working will become clear and this will help to design the activity. In addition, feedback on the activity will be used to improve the activity. The acquired knowledge was not written down, but acted as background information that was used to design the activity.

The Oude Hortus

Garden personnel: short interviews

Through short interviews, the main gardener of the OH (Henk) and several garden volunteers were interviewed. These people know the OH best, some volunteers have been helping in the OH for more than forty years. They are a source of information regarding the current plants, but were also asked about the history of the garden, and what they want (or don't want) regarding educative activities. In addition, the volunteers and Henk helped to point out some practicalities that need to be taken into account when organizing an activity in the OH.

Literature

Biomimicry examples from the OH were used to as subjects for the biomimicry activities. Background information on these examples was found through literature research.

Target audience

Observations

The target audience was observed in UMU during testing days. This showed what worked well (or didn't) in activities, and evaluations of these test days were taken into account. The observations during the testing days gave an indication on how school groups work through activities and what kept their attention (or did not). How families worked their way through the museum was also observed, and if and how they work together was observed as well. These observations were used to identify what the target audience needs in order to be engaged in an activity.

Survey

To identify what families want to do in a (botanical) garden, a survey was conducted in the botanical gardens of Utrecht (Appendix 4). The survey gave information on what kind of activities and what form of activities the audience wants. Pre-existing knowledge about biomimicry was also tested, and short

interactions with the families afterwards showed that these question sparked an interest among the public.

The biomimicry activity

Throughout the report, various chapters will give more (background) information on biomimicry. Aspects that work well in biomimicry education, and biomimicry examples in the OH were explored. Finally, the biomimicry activity was designed by taking the needs and wishes of the three stakeholders into account, while also accounting for the things that work well in biomimicry education.

Designing the activity

The information that was gathered about biomimicry and the stakeholders was taken into account to design a biomimicry activity for families. Designing the activities was an iterative process, in which new discoveries about the stakeholders caused shifts in the design of the activity. Multiple options for an activity were explored (e.g., interactive tour, design workshop), but ultimately the choice was made to focus on standalone activities: the family boxes.

Testing activity

Two of the designed family boxes were tested during *Operatie Breinbreker*. Families could take one of the boxes, and go through the activity themselves. During testing, some observations were made on what worked well, and what could still be improved. In addition, families were asked to fill in a short evaluation form (Appendix 5) to give feedback on the activity.

After testing the family boxes and analyzing the feedback, final changes were made to the designed activities. Finally, four biomimicry activities for the OH were delivered (Appendices 6-9).

Results

Didactive techniques in UMU

UMU designs their educative programs through various methods in order to actively engage their public to discover the scientific process. A checklist is used to ensure that all of their programs have the values of the museum and educate visitors in UMU style (1):

- Programs should tie in to prior knowledge and own experiences of both parents and children. Relevancy of science in their own life should become more clear after a visit to UMU.
- Curiosity should be sparked, visitors are stimulated to inspect (objects) and discover things on their own. Activities should not be predictable and should lead to wonderment.
- Different methods that researchers have used over the years to make scientific discoveries should become clear. Steps from the research cycle should be present in some form (making a research question, making a hypothesis, designing/performing an experiment, collecting data, formulating conclusions based on observations, presenting/reflecting of conclusions).
- Research(ers) from Utrecht University should be central.
- Visitors are stimulated to learn with one another through social interaction.
- Visitors are actively involved, and can do their own 'research' with the help of interactive exhibitions.
- Visitors should become more science literate after a visit to UMU. Aspects from the Nature of Science are highlighted throughout the museum and will help visitors to reflect on what they're doing.

Nature of Science

To make visitors more science literate, aspects of the Nature of Science (NOS) are part of UMU education style. The aspects that are used help to explain science to visitors and should give them some insight into how scientific knowledge is discovered. The ideas and interpretation of the average visitor about science can be close to reality, but can also differ from it. Ideas like 'A scientist is always an atheist', 'An observation is always faithful and true', and 'A scientific theory is not to be trusted, since it is just a theory' are examples that knowledge of and about science is still not known to everyone (5). Therefore, UMU uses the following aspects from NOS to help their visitors learn more about science (1):

- *Context*: Researchers have to make decisions during their research, these are often influenced by their own historical, cultural, economic, political, and/or religious context.
- *Uncertainty*: Knowledge can change over time. New observations can contradict old theories, which have to be updated. A scientific theory can be certain, until proven otherwise.
- *Social*: Scientist often work in research groups. There, ideas can be exchanged and people can decide to continue (or use) research of their colleagues.
- System: Scientist perform research through an organized approach. Methods should be clear, when the same experiment is performed again, results should be the same.

UMU focuses on the previous aspects of NOS. However, there are more aspects of science that can be clarified. In addition to UMU's focus points, the following points make up aspects of NOS according to *Wetenschapsreflex* (6):

- *Creativity*: For (groundbreaking) discoveries, scientists often have to create something that didn't exist before. For example, creativity is necessary for innovating new designs or instruments, that can be used to discover something new.

- *Empiricism*: Research is based on observations. Without observations, there can be no science.
- *Technology*: Science can help to develop new technology, while technology can also help to further scientific research.
- *Ethics*: Scientific discoveries can often be used for good reasons, but can it also be used for a bad purpose?
- *Subjectivity*: Scientists can be more interested in a certain field. Therefore, their subjectivity can help to further develop this field of science.
- *Interpretation*: Two scientists can look at the same results and observations, but interpret data differently.
- *Research methods*: Often, the 'Scientific method' is named as the universal roadmap for doing research. However, there is no single roadmap, since science often is a complex process of going back and forth.

By using NOS aspects to explain science, UMU shows that science is not something that can only be done in a lab, but instead is present in everyday life.

Inquiry based learning

Social interaction is important during inquiry based learning. Students can learn from and with one another through social interaction (1). To develop an inquiry based lesson, Arends describes two planning tasks that are required: determining goals for the learner and identifying a suitable problem for inquiry (7). New knowledge should be acquired by students through the inquiry process. Students should also learn the processes involved in inquiry, especially scientific inquiry, to develop a positive attitude towards inquiry and the processes of investigating problems. The second planning task lies in identifying the problem or question that starts the inquiry process, for which discrepant events are often used (7). These are surprising situations that amaze students and sparks their curiosity, therefore motivating them to engage in the inquiry process. After the inquiry focus is sparked, students should be encouraged to ask questions as to why this event happened, essentially making their own hypotheses. After finding a hypothesis, the inquiry process should be further stimulated to let children test their hypothesis.

The primary role of a teacher in conducting inquiry based lessons is to guide students along the phases of the inquiry process and motivating them to think critically. Inquiry based lessons do not always consist of six phases, but most approaches consist of these six phases (8–10):

Gaining attention of students and explaining the inquiry process. It is important to explain the goals and overall flow of the lesson to students. Explaining that learning skills and processes that are associated with the inquiry is the most important goal. Furthermore, it is important to have the attention of the students and motivate them in their learning process.

The presentation of the inquiry problem (or discrepant event). The presentation of the problem should be clear, but should also spark an interest among the students. The problem can be presented with a video, but also with a demonstration in the classroom.

Help students to ask the 'why' question and to formulate a hypothesis. Formulating a hypothesis is an important part in the inquiry process. This is the step where students think about why the problem is occurring, and this is what they will test and explain in later phases. It is important that all ideas are accepted at this point.

Let students research and test their hypothesis. Having students test their hypothesis with experiments and collecting data might be a possibility. If experiments are not possible, the teacher might provide some extra data that can be used by students to wonder how this new data affects their hypothesis.

Help the students to formulate explanations. Students should be asked to explain the data that results from their experiments. All explanations are accepted, but teachers are encouraged to challenge the explanation of a student and let them consider rival explanations. This can be achieved be asking probing questions (e.g., 'How do you compare your answer with [Student X]? In what manner are they different and why?).

Stimulate students to reflect on the problem and thinking process. Students should be encouraged to reflect and think about the process they just went through. The students' reflection will emphasize what was learned during the inquiry based process. Questions that might be asked to stimulate reflection in students include:

- Did you change your mind during the inquiry? If yes, why did you change your mind?
- What about [X] makes you curious?
- What will you tell your parents about [X] tonight?

Design based learning

In addition to inquiry based learning, UMU also has a strong affinity with design based learning. This is seen in the educational programs they give, for example the program *Ontwerpen naar de Natuur.* This program focusses heavily on having the students design an article of clothing, based on their findings from nature. Design based learning is a process that stimulates creativity and allows students to use their imagination to design an (often physical) object (8). The goal is to design something that doesn't already exist. In order to teach this process to students, the design cycle is often used. This cycle is a series of steps that guides students through the design process (9).

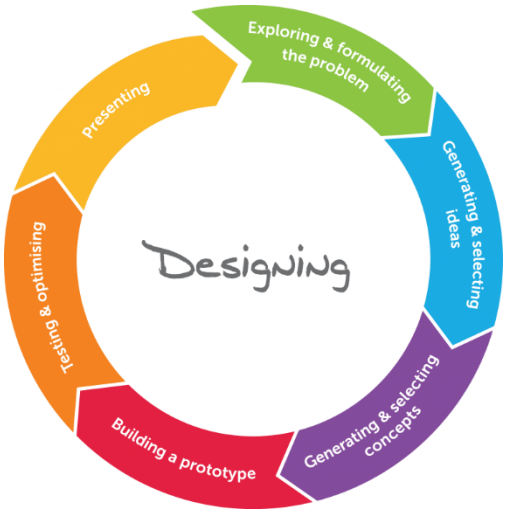


Figure 2 – Design cycle. *The same series of steps is often followed during a designing process. In design based learning, students are stimulated to works through all of these steps (9).*

Exploring and formulating the problem. Every design process starts with a problem or wish. Students can come up with a problem of their own, or the teacher can hand it to them. During the exploring phase, it is important to gain an understanding of the problem and who or what other factors are involved. Finding out the background of the problem is important for the remainder of the process, since this is based on what is found during this first step. Based on what is found during the exploration phase, a problem can be formulated. The problem formulation should be in line with the wishes of the teacher or client. A client can be added to make the problem more real.

Generating and selecting ideas. During this phase, students are encouraged to come up with as many ideas as possible, there are no wrong ideas. Students should be stimulated to approach the problem from different angles. It can help to formulate sub-problems, which can make the problem smaller and more manageable. These sub-problems can lead to sub-solutions, which can help to solve the bigger problem. After the brainstorm session ideas can be clustered into different categories. It can help to go over the wishes of the teacher/client once more. It is encouraged to take some risks in choosing an idea, since this can stimulate students to choose an original idea.

Generating and selecting concepts. Via drawings, simple 3D-models, and texts, concepts can be generated to show how a product should look like and function. In this phase, different sub-ideas can be combined to show the bigger picture and create a coherent concept. More technical knowledge might be necessary for generating the concept, this can be supplied through research on the internet. Another manner in which this can be supplied, is through showing multiple products and models that shows simple technical features. Making a workplan can help to describe what the product should look like and what it should do, but can also include a list of necessary materials.

Making the prototype. Prototyping the first version of the product can lead to new insight. The prototype can show if (various sub-) concepts work well together. It can be made on actual scale or on a smaller scale to gain a proof of concept. Through making a prototype, decisions in a design may be adapted to work better.

Testing and optimizing the design. The prototype should also be tested by the students. During this testing phase, the design is checked on whether all appointed goals are achieved. If the prototype fails to achieve one or more goals, it should be analyzed why this goal is not achieved and how the prototype can be improved. Through improving the prototype, some steps from the design cycle can be repeated in order to get a better product.

Presenting the product. By presenting the product to their peers, students learn how they can convey information to other parties and inform them about their ideas. Students should be thought to give a convincing, but also honest presentation about their product. They should be honest about the flaws of their product and give information on what might be done to improve these shortcomings. Another interesting angle would be to ask and let students reflect on what they thought about the design process.

Science and technology & 21st century skills

Stichting Leerplan Ontwikkeling (SLO) is the Dutch center of expertise where educational plans are designed. It decides what students should be thought, and what skills they need to learn in different fields. Science and technology education is one of those fields, most of UMU's programming falls under this umbrella term. Subjects like geography, history, science, technology, biology, and physics are included in science and technology education (11). According to the SLO, learning by inquiry and design are two important facets of science and technology education, in line with UMU's programming. Through the methods of science and technology education, children are also taught important 21st century skills (12). These skills are:

- Critical thinking
- Creativity
- Problem solving
- Computational thinking
- Information literacy
- ICT skills
- Media literacy
- Communication
- Collaboration
- Social & cultural interaction
- Self-regulation

These skills are important to learn, and help students to prepare for the ever changing world. These skills can be differentiated from normal academic skills, since they are not directly linked to acquiring

knowledge. Instead, they can be referred to as soft skills. Incorporating some of these skills into the activity would therefore be a good thing to do. Some of these skills, like problem solving and creativity, are inherently part of inquiry and design based thinking. Therefore, the activity will actively try to invoke some of these skills in students.

Gamification

Although gamification is not specifically mentioned as being part of UMU's didactics, it is most certainly present in the museum. From the game-like interactives to doing research on the mysterybox, gamification is connected to UMU. It is not only present in UMU, but gamification is present almost everywhere in daily life, from games that can be played on a smartphone to more traditional boardgames (13). However, games find their way into increasingly more fields. Gamification can be defined as using game dynamics, mechanics, and frameworks to promote desired behavior.

Gamification in education can help to motivate students. For example, making small objectives through which hints or other rewards can be earned can help to engage students (14). In addition, challenging students can also help to increase engagement. Preferably, a student is challenged on their exact skill level, and challenges increase in difficulty as the students skill level progresses as well. Games often provide multiple routes to success, which allows students to choose their own sub-goals in a larger learning-goal. This can also involve steps from the research cycle. Players of games often have to experiment in order to progress. They observe the results and use this to plan a next move. The game Angry Birds is a good example of such a game (Figure 3).

Figure 3 – The game Angry Birds is a good example where experimentation is used in gaming*. Players have to knock down pigs using their birds, which all have specific powers. The pigs are protected by various types of materials. The player launches a bird, observes the results, and plans their next move based on these results (Angry Birds, 2009).*

Doing well in games can invoke emotions like joy and pride, but also frustration or anger when it does not go the player's way. Since games are often designed to involve repeated experimentation, repeated failure can occur as well. Games use short feedback loops, where failure is a learning moment and can directly be used to overcome the challenge. The player can keep failing until they succeed, meaning that very little risk is involved. This is different in school environments, where risks are higher and feedback cycles are long. Students have limited amounts to try a challenge (exam or assignment), with high stakes involved. This often causes students to experience stress and anxiety if they are given the opportunity to fail. A well designed gaming-like learning experience might help to motivate and engage students more, and might help to change their view of school and learning in general.

Takeaway points

- Activity should comply with UMU checklist, e.g., stimulate working together (also a 21st century life skill).
- Design activity with elements of NoS, inquiry based learning, and design based learning.
- Discovery process can be playful, thus engaging students more.

Biomimicry education

Biomimicry fits well within the science and technology education term of the SLO. Biomimicry starts with looking closely at how nature works. From there on, the learning process starts and can be educative in fields like technology, biology, mathematics, physics, and science. It can be used as a learning method that encourages students to think in a sustainable manner, but also to acquire knowledge and (soft) skills. Sustainability is closely connected to biomimicry (4). Since this is one of the big problems the world is currently facing, it speaks to the imagination of students, making them more likely to actively engage with the topic. Through biomimicry education, various of the 21st century skills are encouraged (15). Critical thinking, creativity, problem solving, communication, and collaboration are skills that are closely connected to biomimicry (12). In biomimicry thinking, students are often asked to solve a human problem with a solution that can be found in nature. Students can be guided in this process by following the same series of steps (Figure 4) (16):

- Scoping
    - Define context
    - What is needed? Identify the function
    - Which of Life's Principles fit best?
- Discovering
    - Discover which natural model would fit best. These models are analogies from nature: form, process, or system analogies.
    - Abstract biological strategies.
- Creating
    - Brainstorming bio-spired ideas, translating concepts from nature to design.
    - Emulate: combine ideas from the brainstorming phase and design (prototype) concepts.
- Evaluating:
    - How did it work? Are Life's principles incorporated?

Interestingly, these steps are very similar to the steps that are used in inquiry and design based learning (17,18).

***Figure 4 – Biomimicry design lens**. In solving a problem with biomimicry, the same series of steps is often followed, although sometimes in another order (16).*

In order to understand complex ideas, but also to critically think about an observation, drawing is a very good exercise. Drawing forces a student to observe well, and critically think about the most important parts to display in their illustration (15). It also serves as a tool for communication with others, by letting other discover the observations of another person. It can also be used connect various ideas or concepts. In biomimicry, it also helps to better understand a mechanism that is being mimicked.

Takeaway points

- Biomimicry goes hand in hand with inquiry and design based education.
- Incorporate drawing and/or crafting exercises.
- Incorporate small research activities.

Target audience

The target audience of UMU are children aged from 8 to 14 years. This is split up in group 5 to 8 of primary education (*primair onderwijs, PO*), class 1 to 3 of HAVO/VWO and class 1 till 4 of VMBO of secondary education (*voortgezet onderwijs, VO*) (1,3). The abbreviations PO and VO (VMBO, HAVO, and VWO) are commonly used in the Netherlands, and will therefore also be used in this report. In addition, families with kids in the same age range also belong to UMU's target audience. Since the target audience is a relatively broad in age and level of education, educative programs (in school context) are specifically designed for: PO, VO (VMBO), and VO (HAVO/VWO).

Difference between educational programs in UMU

Primary education (PO)

Programs for PO are less complex, since students are younger. These programs play into the imagination of children in this age range and try to enthuse the children about a specific subject, and about research in general. The stimulate the students to work together to find out more about the subject through research.

Observation PO program: Bak vol botten (Group 6)

I had the opportunity to host the 'Bak vol Botten' program. In short, the program is introduced by telling the students that several bones were found in Germany by an UMU employee, and were returned to the museum. The students are asked to do research as to which animal the different bones belonged to. They are given source materials (books etc.) to do their research, and are asked to present their bone and research they did at the end of the program. Students were really enthusiastic about it, and were working vigorously to discover what type of animal their bone belonged to. It seemed that they really liked the hand on approach and the discovery process of finding out more information along the way.

Secondary education (VO)

Since students are older in VO, programs can be a little more advanced. There is a differentiation between VMBO and HAVO/VWO, since their educational is too far apart to give the exact same program. Programs for these educational levels are still similar, but the introduction presentation for VMBO students is often shorter and more simple than the presentation for HAVO/VWO. Most programs ask students to set up and perform their own research.

Observation VO program: Aandacht (HAVO 3)

I had the opportunity to host the 'Aandacht' program. This program is introduced with a presentation, including a video that shows that if you focus on one thing, you will miss other things that are happening at the same time. Students are explained that multitasking does not really exist and are asked to perform a small experiment. One person will perform a task (solving mazes, throwing sticks in a cup, etc.) once. The person has to repeat the same task, but is now distracted by another students. Students are asked whether there was a difference in performance between the first and second time of performing the task. Some performed better (practice or luck as given explanations), while others performed worse (distracted or bad luck as given explanations). In the end, we revealed that we had tried to nudge the students on certain things. However, this was not really understood by them, since they were already quite tired. The students really enjoyed doing their own research and this was definitely the best part of this program.

Takeaway points

- Let students perform research on their own, they like doing this.
- Make it really hands on, let the participants do stuff.
- Don't make the activity too long.

Biomimicry education in Dutch Science Centers

Not many other museums or botanical gardens in the Netherlands are educating in biomimicry. However, there are some programs that are closely related to the subject, while not explicitly mentioning it. These programs are shortly explained below to highlight some points that work well in biomimicry education, and can be taken into consideration for the OH activity.

Naturalis: Natuurtalent

The program Natuurtalent is aimed at children in group 5 and 6 (19). Children look at different animals on the tables, and try to find its specific talent (e.g., jumpers, speedsters, living in cold conditions). The children then go into the exhibition hall with taxidermal animals. They have to form quartets of animals with the same talent. After going back to the workshop room, the kids get a chance to use a microscope to look at small animals or shells. This workshop does not mention biomimicry, but it makes the children look at talents of different animals and plants, and makes them evaluate what the animal uses it for (19). This workshop can be seen as an introduction to biomimicry. There was an opportunity to observe this program, observations are described in Appendix 2. By giving the children microscope, they were stimulated to look at small objects. Since there were not enough microscope for everybody, children explained what they saw to one another. Not all animal objects were labeled, which stimulated the children to discuss with each what they thought it could be. Not giving away all information works well in that aspect.

De Hortus Amsterdam: Afkijken bij planten

This workshop is aimed at group 7 and 8 of primary education (20). It teaches them about biomimicry through various exercises. Students will do research into certain plants using microscopes. In addition, some experiments will be performed. They will discover interesting characteristics from plants which they will use to design something for a human problem (20). This aspects works really well according to educators from De Hortus, children come up with a lot of interesting and creative ideas.

UMU: Ontwerpen naar de natuur

This workshop is aimed at secondary education (21), and can therefore go more in depth about what biomimicry is. The program starts with a short introduction of the program and UMU itself. Then, one of the students is given an object and is asked what the object is, and what the specific function of certain parts are. For example: a student is given part of an elephant skin. The question should not be: What is so special about an elephant?; but rather: What is so special about the skin of the elephant? This will yield more specific answers and will stimulate students to think critically about their answers. After this introduction, a short presentation introduces the concept of evolution and how organisms adapt themselves to thrive in their specific environment. Next up, bio-inspired innovation is explained. Some examples of innovations that were inspired by nature are given, and students are told that they are going to design a garment by looking at nature. Students are divided in different groups and first have to fill out a worksheet, after which they will craft a prototype of their design.

According to *publiekbegeleiders* (PB'ers), this program is well thought-out and works very well for HAVO/VWO. The starting presentation is a little on the long for certain groups, but that's different with each class. Students work really enthusiastically when they get to the design stage. Students are really creative in their designs and come up with out of the box ideas. VMBO students are also creative during this stage, but are mentioned to have a harder time starting up. They are unsure what they have to do and, according to PB'ers, this should be clarified more during the introductory presentation. The PB'ers believe that the design phase is the best part of this program. Students are allowed to work in groups and think creatively. They also get to bring their ideas to reality by crafting a prototype. A complaint by the PB'ers is about the aftermath of the crafting, which turns the classroom really messy. Craft supplies get everywhere, and from time to time teachers ask the PB'ers to clean everything.

Although designing and crafting a prototype is seen as the best part of the program, translating this part to a program in the OH will be (almost) impossible. If students are allowed to craft in the OH, there is no doubt that crafting supplies will be scattered around the garden, which is not allowed to happen. Smaller design exercises might be possible, but should be concise. Designing something by drawing it would still be a possibility.

Takeaway points

- Biomimicry education actively engages students.
- Doing research with instruments like a microscope is quite intuitive, and stimulates students to do their own research.
- Designing and crafting something works really well. However, crafting cannot be translated to an activity outside in the OH, since crafting materials would get scattered around the garden.

Practicalities of a (biomimicry) program in the OH

Influence of seasons

Since the activity is to take place in the OH, the assortment of plants (in bloom) will change with the seasons. This is important to take into account, since certain plants might not be available for periods of the year. For example, during winter and the start of spring, the Burdock and *Victoria amazonica* are not present in the garden. The garden looks more full with life in general during the spring and summer. During these months, a lot of plants are full (and in bloom), which also attracts lots of insects. In turn, the increase in insects brings more birds to the garden. A heron frequents the pond in the

garden and a kingfisher can sometimes be spotted as well. In addition, during some periods (autumn and winter) cold weather and rainfall is expected. Those conditions are not ideal for organizing activities outside.

Location for the activity

Since the to be designed activity is focused on the OH, the wish is to let students explore the OH. There are some possibilities to go inside (for example, when it rains), either into the Orangery, the greenhouse closest to the Museumcafé, or maybe even into UMU. However, as long as weather conditions allow it, students should explore and do the activity in the OH, since it is a unique place of nature and history in the city center of Utrecht.

Children in the OH

UMU wants a younger public to visit the OH. The main gardener of the OH, Henk Nokkert, raises one main point of concern, which is that the OH should not become a playground for kids. They should have enough supervision to prevent them from either falling in a pond or climbing in a tree, and also to prevent them from destroying plants. This is an important point to make, since plants are living organisms, and kids can be somewhat rough in handling objects. In addition, children are often quite loud which would be of annoyance to 'normal' OH visitors, who often go there for some peace and quiet. The same concerns are present among the garden volunteers.

Henk also highlights a positive point of educating children in the OH. From his experience, children have fallen out of touch with nature. Educating them in and about nature should help to get the children some hands on experience with nature. Although designing and prototyping are important parts of the design phase in Biomimicry, crafting a prototype/design will not be possible. Students will leave their place behind as a mess, something that is bad indoors, but is not something that can happen in the OH, since it is hard to clean and bad for nature. If a prototyping stage is present in an activity, it should happen indoors, where it will be easier to clean up and won't cause direct harm to nature.

Takeaway points

- Don't encourage children to touch the plants.
- Education about and in nature has a positive effect.
- Crafting/prototyping designs is not possible in the OH.

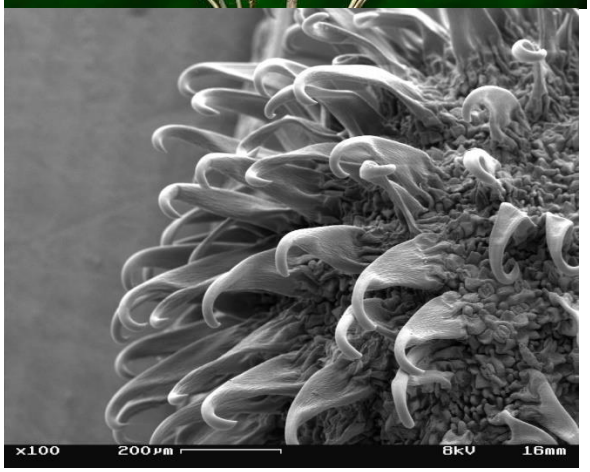
Biomimicry examples in the OH

A lot of plants (and other organisms) are present in the OH, including species that have inspired men-made innovations. The following will be a description of three examples of biomimicry that can be found in the OH, these are the examples that were eventually used as subjects of an activity. Twelve other examples can be found in Appendix 3. A short description of each organism is given, after which the function, strategy, and design principle are explained. This allows for a better understanding of the organism, and the innovation it inspired.

Cacti species – Regulating temperature
Cacti have evolved to live in a hot desert climate. Many species have evolved to have alternating ridges, prickly spines, and bulbous stems. The ridges have peaks, which provide shade to the throughs, thereby reducing the heat to which the cactus gets exposed (4,5). The spines help to provide the same effect. These ridges have another benefit for the cactus. The air in the through stays cooler, since they are shaded (23). Therefore, this air can absorb more warmth from the cactus' body than the surrounding warm air could (22). When the air in the through gets warmer, it rises upwards through the troughs where it dissipates with the wind.

These bumpy ribs also help to make the air around a cactus more turbulent, allowing more wind to flow along it. Therefore, more air is able to dissipate heat (22).
Architects that designed the office building for the minister of Municipal Affairs and Agriculture in Qatar were inspired by cacti, and covered the building in shades that look like the spines on cacti. These shades help to control the light that enters the building, helping to limit the heat that enters the building, and helping rooms to be filled with natural light (24).

Function:	**Strategy:**
Keeping the plant cool.	Ridges and spikes create shadow for the plants. Hot air can rise through the troughs.
Design principle:	**Connection to Oude Hortus:**
Protrusions (edges, ridges, spikes etc.) that create shadow and thus keep a place cooler.	Cacti are present in the greenhouses.
Figure reference: A barrel cactus up close (25).	



***Arctium lappa* (Great Burdock) - Velcro**

Arctium species are commonly referred to as burdock and can be found around the world, but is mostly found in Europe (26). Some plant species need help from animals to disperse seeds, this is known as zoochory. When seeds are dispersed via attachment to an animals fur or feathers, it is known as epizoochory (27). These seeds often have special structures, like sticky secretions, spines, hook, burrs, and detach without much effort from its parents plant. The burdock uses this tactic to disperse its seeds. The bracts end in small hooks that grab onto the fur of passing animals. The hooks become operational quite early in the year, first acting to defend the developing seeds. The attachment of the seed to the plant is the highest during the growing phase of the plants, which allows the seeds to mature. After a couple months, the plant desiccates and the seeds' attachment loosens. When an animal passes and makes contact with the seeds, the hooks will attach to the animal and the seeds will be dispersed (27).

Burdock seeds are purported to be the inspiration for Velcro, designed by engineer George de Mestral (28). The story goes that while De Mestral was walking his dog, the seeds stuck to the dog's fur. After removing several burdock seeds from his dog, the engineer was curious as to why these seeds were so difficult to remove. He researched the seeds and saw the tiny hooks that were able to bind to different types of surfaces. This led him to develop the 'zipperless zipper' that is now known as Velcro, and can be used to fasten two sides of fabric (28).

Function:	**Strategy:**
Spreading of seeds.	Spreading the offspring of plants by having seeds stick to passing animals.
Design principle:	**Connection to the Oude Hortus:**
Tiny hooks on the end of the bracts of the seeds. These hooks get attached to the fur of passing animals.	The Great Burdock can be found in the Regiustuin.
Top figure: The Great Burdock plant (29).	**Bottom figure:** The tiny hooks of a Burdock's Burr underneath a Scanning Electron Microscope (30).

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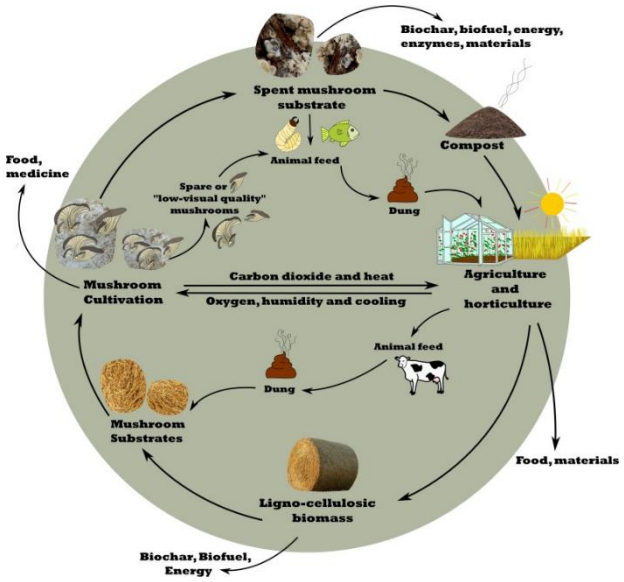
<td> 
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<td>Fungi – recycling waste
Humans produce a lot of trash that we consider useless. Nature on the other hand, produces (almost) no trash, since the ‘trash’ of one organism can be used by other organisms. For example, trees will drop their leaves in Autumn, since they cost more energy than they supply. Leaves are considered trash for the tree, but are a tasty resource for micro-organisms such as fungi (31,32). Fungi tap into all kinds of resources, including ones that others organisms often do not want (e.g., dead animals, manure of animals, and other materials humans consider as waste). They break down the organic compounds in the ‘waste’ materials to feed themselves (32). Fungi have even shown to be able to break down artificial compounds, and break down toxic substances into harmless ones (33).

Fungi can be used to create more sustainable materials (34,35). Fungi can grow on e.g., sawdust, creating connections between individual sawdust grains, eventually forming a block. This fungal block can for example be used to replace conventional isolation materials (35). When the fungal block is no longer useful, it can be reused to grow fungi on, thus limiting waste.</td>
</tr>
<tr><td>Function:</td><td>Strategy:</td></tr>
<tr><td>Upcycling of ‘waste’ materials.</td><td>Breaking down materials into useful resources.</td></tr>
<tr><td>Design principle:</td><td>Location in OH:</td></tr>
<tr><td>Using old materials to create new, better materials.</td><td>Fungi can be found in the OH, mycelial threads mainly in the ground, fungal spores mostly in the air.</td></tr>
<tr><td colspan="2">Note: We can learn from fungi to deal better with what we consider trash, and be more circular with our materials. However, using fungi to create materials (such as suggested in the activity) is closer to bio utilization than to biomimicry. The concept of using trash again can be considered process biomimicry.</td></tr>
<tr><td colspan="2">Figure: Visualization on how fungi (mushrooms) can recycle waste streams (36).</td></tr>
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Results: Observations UMU testing days

In April of 2023, UMU started testing their programs in a renewed museum. Testing in the OH was not allowed, since this is still considered a building site. Therefore, the target audience was observed during the testing of UMU's programming. Different educative programs and workshops were tested, which gave an insight in how the target audience acted in UMU. These observations will be used to see what is needed to keep an audience engaged, and what other aspects should be taken into account. The following are three observations of testing groups during these testing days, three more can be found in Appendix 1.

Evaluation research tour Group 6 (19-4-2023)

The introduction was about 13 minutes in total. There was a two minute video in it, in which some kids lost focus and started looking around. The group was split in half after the introduction, and both groups started in different locations. The kids were divided in pre-made groups, and each group got one card with an assignment they had to do. This was linked to the mystery boxes that are located in the hallways. Something that became clear is that children often do not read instructions that are given in texts next to an exercise. Children start the exercise and then get stuck because they had not read the instructions. They then try to solve this on their own, and often only read instruction after they are hinted at to do so by instructors. If an exercise is too long (the 5 minute mark), kids started to get distracted and wanted to see more of the rooms they were in.

Evaluation research tour + workshop Makers studio VMBO 3 (19-4-2023)

These kids were older and were therefore allowed to move through the museum more freely. They were given three cards with exercises present in three different (already operating) exhibitions. No way signs were present in the museum, which caused some groups to get 'lost' trying to find their exercise. After about an hour, the kids started to get rowdier and exercises were performed less seriously. In addition, they managed to break some things in the exhibition halls. They didn't like that they never found out what was in the mystery box. One of the teachers gave the following as feedback regarding this: ''These kids are used to being wrong, so at least give them the chance here to get something right.''

After the research tour, they still had to do a workshop. This workshop was in theory well aimed at these kids, since they are go to a applied/design school. However, as soon as the worksheet was shown, a big sigh could be heard from the kids. There was lots of text on this sheet, and the audience did not have the patience to read it all carefully. Teachers had to calm the class every five minutes, and the workshop was eventually cut short. Feedback from teacher was the following: ''There is way too much information on the worksheet, even I couldn't make sense of it. Go to the design and making part sooner, that's what's fun about this workshop.''

Evaluation museum with families (25-4-2023 & 26-4-2023)

The museum was also tested with families. They got an introduction about the museum, and how it is not yet finished. The goal of this test was to see how families move through and (inter)act in the museum. They started in the main hall with the mysteryboxes on columns. When a mysterybox is picked up, an introductory video starts playing. However, no instructions to pick it up are given, so most families wait for a while until one family (usually one of the kids) picks it up. The video starts playing and most people watch it to the end, but some get distracted by the box. After the video ends, visitors start picking up the mysterybox and shake it, to figure out what is in it. After this initial research, the families look at their guide and ask what to do, since there are no instructions. They are

guided upstairs and start their research regarding the mysteryboxes. Kids pick it up and start shaking it on intuition. They often use research tools that are located next to the box to hit the box. Some parents tell their kids to read the instructions on the wall, and the children will follow these instructions and understand the different research questions that link the box to the different exhibitions.

Parents also stimulate their kids to read instructions in the exhibition halls, and this helps children to get through exercises. Kids and parents also split up sometimes to look at different things, parents often reading texts, while a kid wants to do something.

During the outro, families can vote on the object which they think is in the box. In the outro room, different objects are displayed in between two screens. On these screens, a deduction game can be played based on the different research tasks that were performed previously. However, this is not instructed, and some families start with voting what they think and then go to one of the screen. When you vote on an object, it lights up and you can see what other people have voted. However, this is located low by the ground and is not seen by everyone.

Takeaway points

- Students don't (want to) read. Explanations need to be very short or they will be skipped. This resulted in students not understanding the assignment.
- Make assignments intuitive.
- Objects that come with the assignment should not be easy to break, therefore the use of living plants should be avoided.
- Assignments should not be too long; the attention span of students is very short.
- Let students do something themselves (research/design/craft).
- If parents are present, they stimulate their kids to read explanations and take their time to do the exercise.

Results: Survey Botanical Gardens Utrecht

To gather information about what the target audience would want to do in a garden, a survey was conducted in the Botanical Garden of Utrecht. Several questions about a visit to a (botanical) garden were asked to families with kids in age of UMU's target audience (Appendix 3). In addition, some (indirect) statements about Biomimicry were given to see the target audience had some familiarity with the topic. In total, ten families filled in the survey.

Things to do in a (botanical) garden

People were most interested in doing a scavenger hunt, this was chosen by 80% of the families. Playing games, learning something, and just walking around the garden are also considered as appealing activities, and were chosen by 60% of the families (Figure 5).

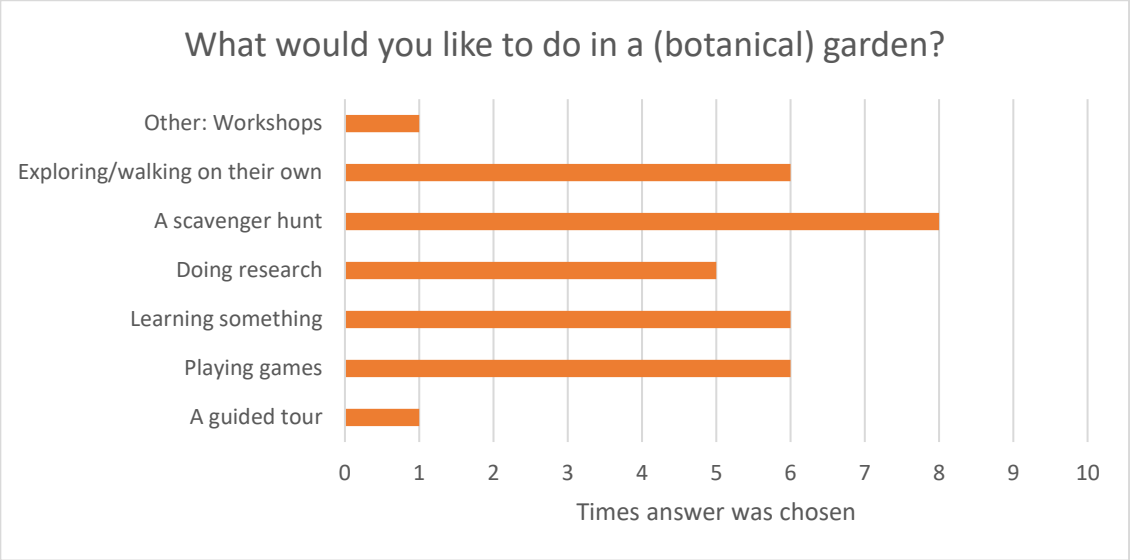


Figure 5 – Families were questioned on what they wanted to do in a (botanical) garden. People were allowed to tick multiple answers.

Learning possibilities

Most families just wanted to take a look around themselves, 80% of the families gave this answer (Figure 6). Other popular answers were reading information on boards around the garden, and completing the scavenger hunt. Some people mentioned that the scavenger hunt was no longer available during that day, so this number might have turned out even higher.

From these two previous questions it seems that most families just want go around the garden individually with their family. This was also confirmed with six families in short conversations after filling in the survey.

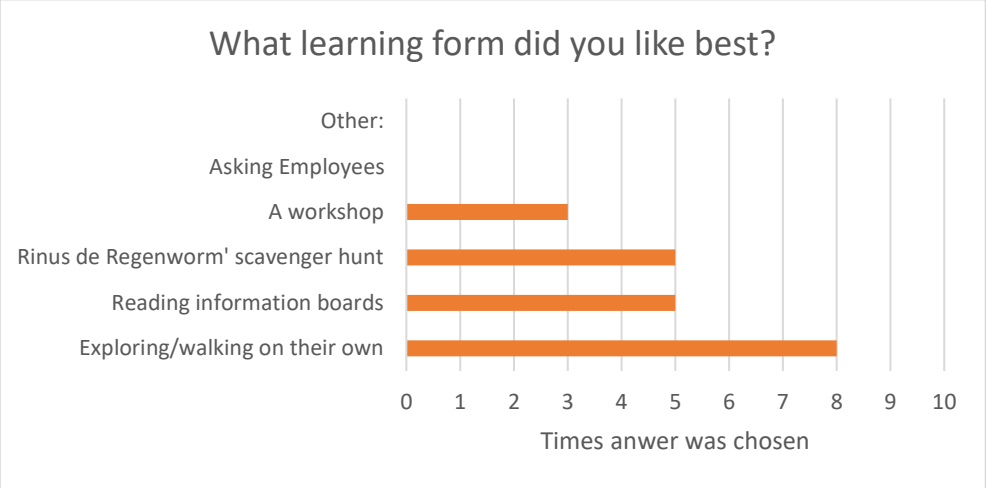


Figure 6 – Various learning activities are possible in the botanical garden. People were questioned about which form of learning they liked best.

Time spent on activity

Before asking this question, the predication was that people would spend about 10-20 minutes on an activity. However, only two families (20%) chose this answer, with the other all choosing to spend a longer time on an activity (Figure 7). 40% of the families would spent 20-40 minutes on an activity, whilst one family said they would spent over an hour on the activity. However, based on a discussion with them, it seemed like they included the entire visit to the garden, and not just the time for the activity.

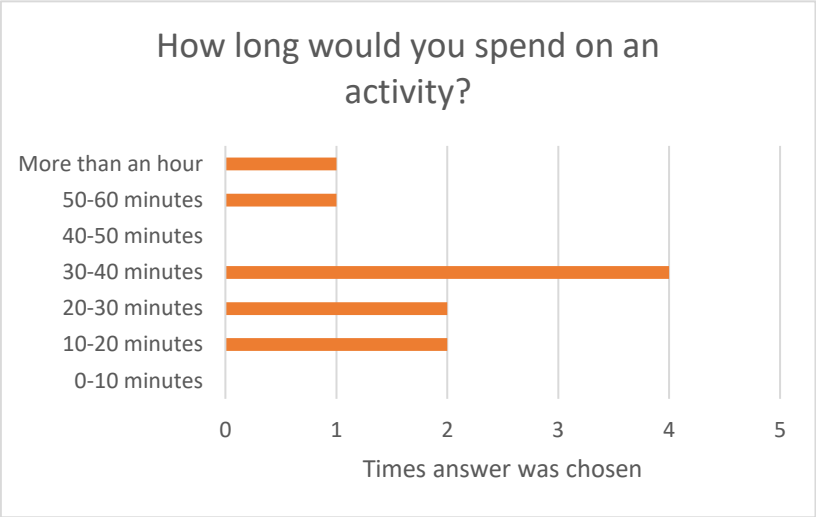


Figure 7 – People were questioned on how long they would maximally spend on an activity during a visit to a (botanical) garden.

Families are open to learn from nature

Some questions about biomimicry were asked, to see if and how familiar the target audience was with some of the topics (Figure 8). Three out of ten families said they were familiar with the term

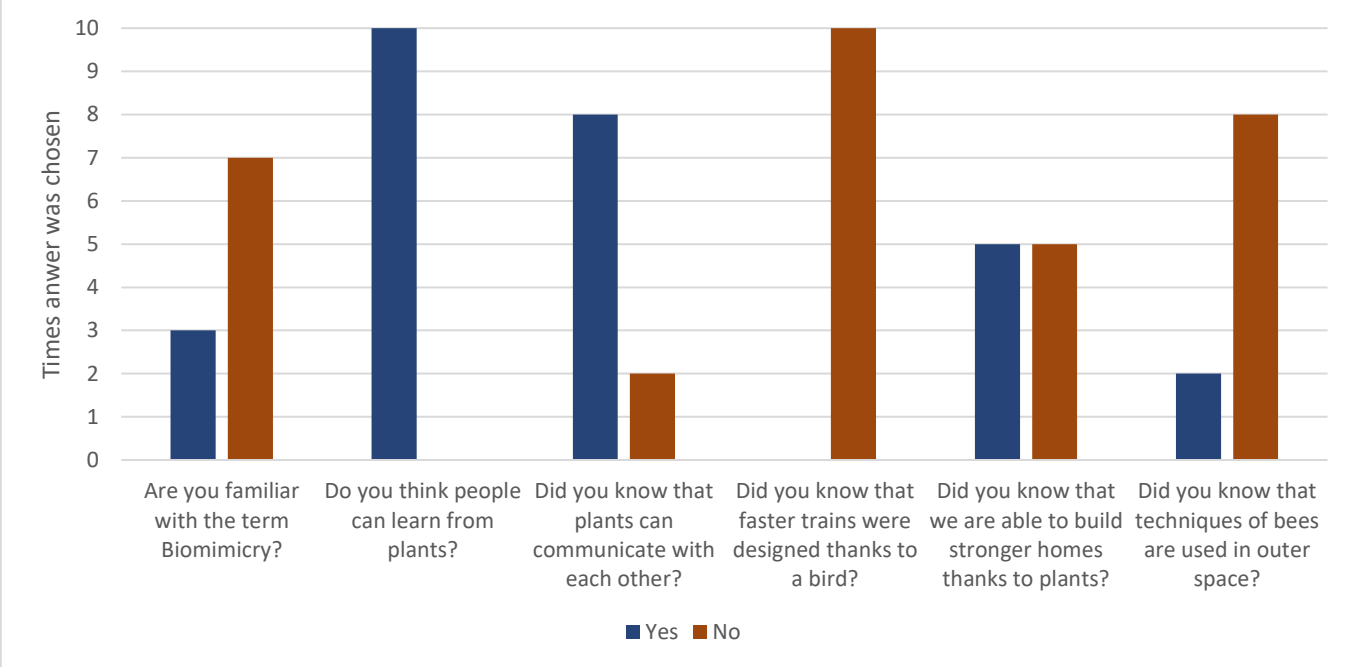


Figure 8 – Families were asked a couple of questions to test their familiarity with biomimicry.

biomimicry, but it were only parents that knew this term. However, all families think the humans can learn things from plants, which is a nice starting point for the to be designed activity. 80% of the families knew that plants are able to communicate with one another, and it was mostly kids that answered this question, they said that 'Klokhuis' recently had a video about this topic. In contrast, no family was familiar with the connection between the Shinkansen train and kingfishers. The two other question were a little more divided. These questions did spark some interest in both parents and children in four families. They were interested in how some of the examples were connected and asked for more examples of biomimicry.

Takeaway points

- Families want to do an activity with their family (just looking around, scavenger hunt), preferably not with others (like a workshop, or asking employees).
- Doing a scavenger hunt is popular.
- Time families want to spend on an activity was diverse, but most families estimate they want to spend about 30 minutes.
- Not many families were familiar with the term Biomimicry, but it did spark an interest. In addition, all families thought we can learn something from plants.

Family boxes concept

Previous points were taken into account to make the activity suitable for the target audience. Not the entire UMU target audience was considered for this activity, it is focused on and designed for families. The aim was to make short research exercises that can be done with the family, without supervision or help from someone else, in line with results from the survey in the botanical gardens. These exercises entail the inquiry based learning style that UMU designs their programs with, and stimulates children to do research. The concept is an activity that is kept in a box, which also holds the other materials that are needed. During the activity, teamwork is encouraged, but people should also be able to work through the activity individually. The activity should take approximately 10-20 minutes, which should be short enough to keep the attention of children. If the activity sparks the interest of the family, they can take another box to learn more about and from another organism. This also allows them to do activities for a longer time, since most people in the botanical gardens said they would like to spend about 30 minutes on an activity.

Family boxes structure argumentation

Programs are designed according to the same structure. In addition, the programs are designed in accordance to the UMU checklist (1). The following will explain the structure of the activity. Points from the UMU checklist will be highlighted using: ✓. The global structure of the activities, points from the checklist, and other considerations and explanations are explained through the example of the *Klittige Klis:*

Through ‘’*Ga aan de slag!* ‘’, audience is invited and stimulated to start the activity.
Title and background are related to the subject.
Title is preferably attractive through alliteration, or through a play on words.
In the final design, this should be present on the box, so families know which subject they are choosing.

Subject is introduced.
They are introduced to a researcher (not always by name).
Audience is invited to perform research alongside a ‘researcher’.
✓ Stimulates curiosity.

Audience is asked early on to pick up an object from the box, which they have to inspect. They will have to draw what stands out to them about the object, which encourages them to critically think about what they are seeing.
Object which they have to research is relatively robust, making sure that the children don't destroy plants while performing research.

Short explanation is given.
Audience will perform a small research assignment, often to compare two or multiple objects with each other, or with the first object, for what purpose could the object be used?
✓ Research cycle: comparing/performing an experiment.

Audience is asked to reflect on what they discovered during their research.
Audience is asked to think about the function (of part) of the organism, why is it useful for the organism?
✓ Audience is actively involved
✓ Social interaction is stimulated (also NOS aspect)

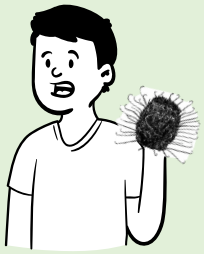
Function is revealed. Audience is asked whether they know something that works in the same manner.
✓ Audience is actively involved
✓ Social interaction is stimulated (also NOS aspect)

Innovation from nature is revealed.
Audience is asked how this innovation can help them at home, to play into their imagination.
✓ Plays into own experiences of parents and children.

Stel je voor…

Je wordt wakker en je handen zijn veranderd in een Klisbolletje.

Wat zou hier handig of juist onhandig aan zijn?



Audience is ‘reconnected’ to the original subject. Circle of the activity is now complete.

Leren van de natuur

Hopelijk hebben jullie iets over, en ook van de Klis geleerd!

Studenten aan de Universiteit Utrecht leren ook van de natuur. Door onderzoek te doen, komen ze meer te weten!

Zijn jullie benieuwd wat we nog meer van de natuur kunnen leren? Pak dan nog een andere box!

General close-off of activity. The connection to Utrecht University is made. They are told there are other boxes which they can do.

✓ Connection to Utrecht University is made.

Testing at ‘Operatie Breinbreker’

Testing of the activity was not possible in the OH, since it is considered a building site. However, an opportunity arose to test activities during *Operatie Breinbreker*. Three boxes of the *Klittige Klis* were tested, and one box of *Coole Cactussen* was tested (Figure 9). Only one *Coole Cactussen* box was tested for practical reasons, there was only one moveable cactus available. Families were told that they could take the boxes and go through the activity themselves somewhere quiet. Therefore, not all families that did an activity were observed. The children got a worksheet on which they could draw and make

Figure 9 – A family testing the Cool Cacti activity during Operatie Breinbreker.

notes. The back of this sheet was an evaluation form (Appendix 5), which they were asked to fill in alongside their parents.

Observations *Operatie Breinbreker*

During *Operatie Breinbreker,* two prototype family boxes were tested. These boxes held the assignments and some objects necessary to do the research, including magnifying glasses. The magnifying glasses really grabbed attention of the children. The magnifying glasses were originally not in the Cactus box, but children grabbed it from the one of the Burdock's box. Children were laughing during the activity, but were also working their way through the booklets. Kids mentioned that performing the small research tasks was the best thing about both activities. Some parents dropped off their children to do the activity, these kids sometimes had a harder time working through it, since they were alone. Children that worked together with their parents were working through the activity better in my opinion. Parents helped their children to read through the booklet, which has some pages with relatively a lot of text. Since this was a prototype of the activity, the Burdock box included some cuddly toys, which were stand-ins for animal furs. Not all children understood what they had to do with these toys. However, these toys also enticed children to come towards the box and look what was inside it.

The worksheet that allows kids to draw works well. Children start researching the plant up close, and mostly take their time doing this. Two kids even drew a summary of what they had learned from the cactus (Figure 10).

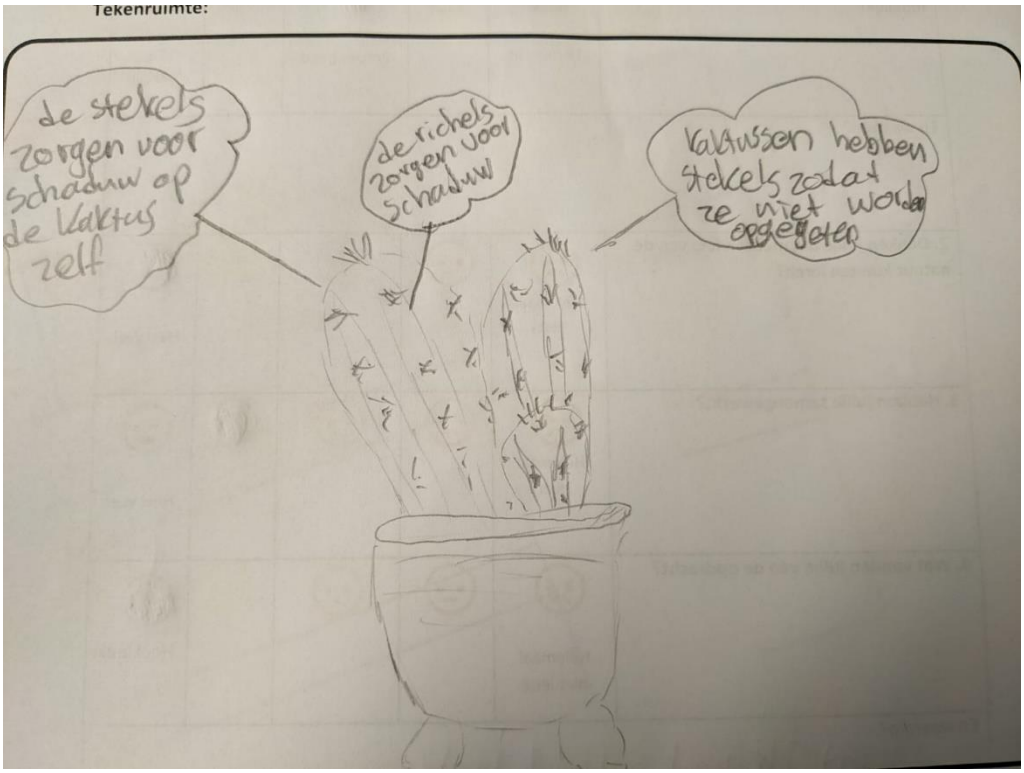


Figure 10- A graphical abstract drawn by one of the children that did the Cool Cacti activity.

In addition, the materials in the boxes allowed children to work intuitively without the booklet. Kids started looking at the burrs/cactus with their magnifying glass even without reading what they had to do. When opening up the tiny box that held the burrs, kids started experimenting what the burrs did. Most found out quite soon that they stuck to things, resulting in them testing to what kind of materials

it stuck. One kid compared his own shoes (with Velcro) with the burrs. The families that were observed worked their way through the activity in about 10-15 minutes.

Evaluation *Operatie Breinbreker*:

Children were asked to fill in how old they were on their evaluation sheet, in order to see how age plays an influence on their experience with the activity. However, not all children filled in their age, which will hereafter be referred to as the 'no age' category. In total, 27 evaluation forms were turned in after doing the test.

Difficulty:

The difficulty of the assignment was scored from 1 to 5, with 1 being too hard, and 5 being too easy. Overall, the difficulty of the assignment scored well with a mean score of 3,2 (Figure 11). Some kids found it too hard, while others said it was too easy. The older the children get, the easier they find the assignment.

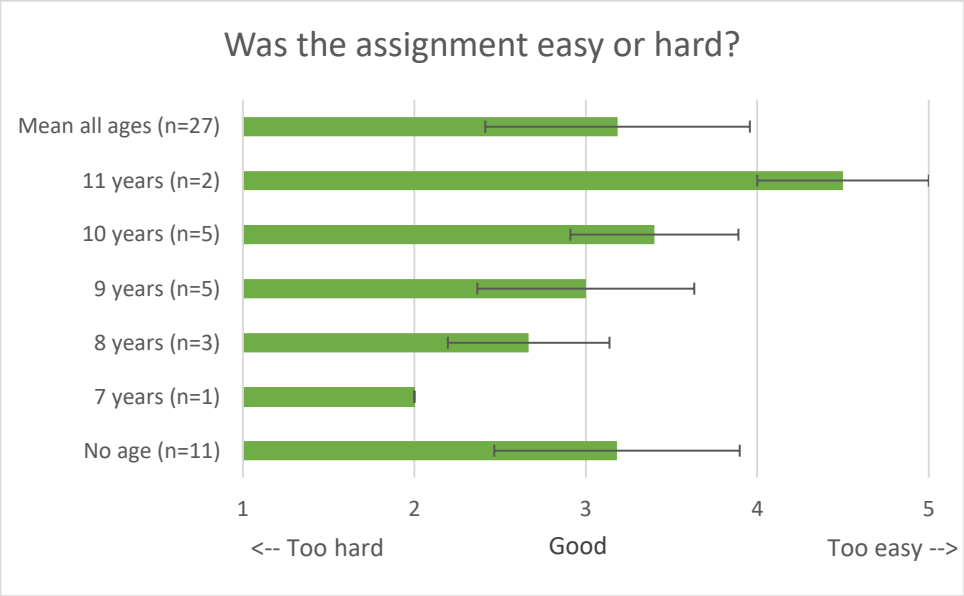


Figure 11 – Participants could score whether they found the assignment too hard (1), good (3), or too easy (5). Participants scores were grouped within the same age category, number of participants (n) is given per age.

Teamwork:

Overall, most kids said they worked together to complete the exercise (Figure 12). Only one kid (7 year old) said they didn't work together with anybody. Since families should be able to complete this exercise without a PB'er, it is good to see that children already say that they're working together to complete it. Working together with others is a good skill to develop at a young age, so it is good to see that this activity stimulates working together.

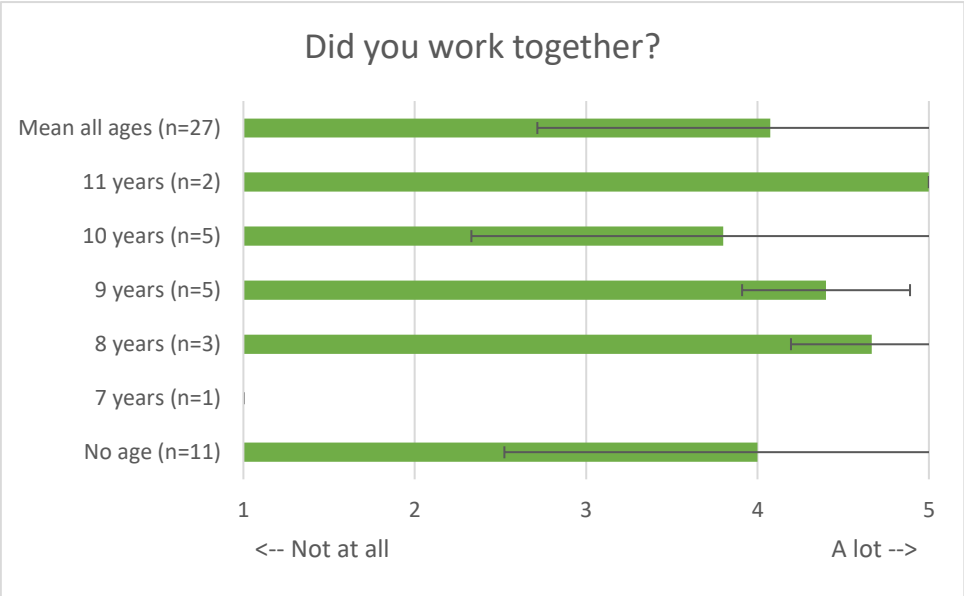


Figure 12 – Participants could score on how much they worked together with other people. Participants scores were grouped within the same age category, number of participants (n) is given per age.

What did you think of the assignment?

Something that all ages agreed on, was that the activities were really fun. A mean score of 4,6 out of 5 was given (Figure 13), so it is safe to say these kids liked doing activities like this.

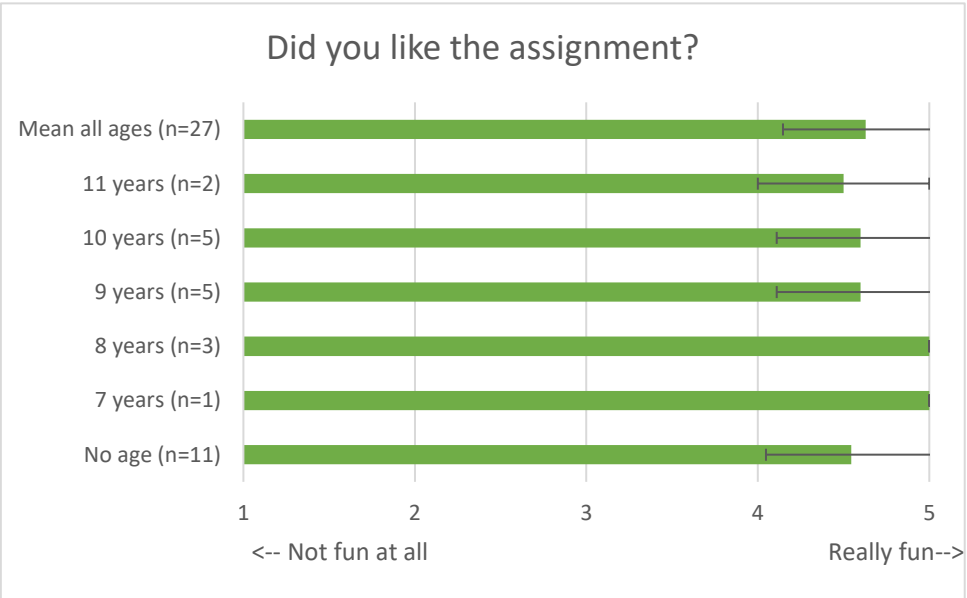


Figure 13 – Participants were allowed to score how they liked the activity. Their score could range from ''not fun at all'' (1) to ''really fun'' (5). Participants scores were grouped within the same age category, number of participants (n) is given per age.

Learning from nature:

From the survey in the botanical gardens it became clear that most families think they can learn something from nature. After doing these activities, kids also scored that they can learn from nature. Almost all kids thought they could learn a lot from nature, the mean score here was a 4,7 (Figure 14).

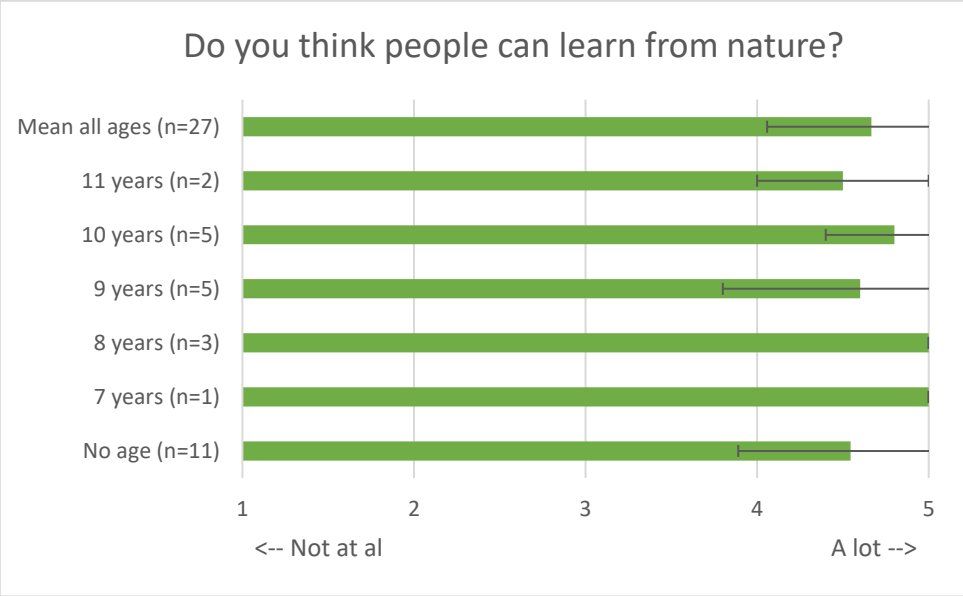


Figure 14 – Participants were allowed to score on how much they think we can learn from nature. This score ranged from ''not at all'' (1) to ''a lot'' (5). Participants scores were grouped within the same age category, number of participants (n) is given per age.

What can be improved & other remarks:

The evaluation sheet also asked the kids to report what they thought could be improved on the activities. Some children didn't write anything down, while some said that nothing could be improved. One kid made a remark that she didn't understand what the stuffed toys were for, and someone said there were too many hints in the activity. Two kids said they wanted to do just a little more research.

There was also room for other remarks. Two filled in once more that they enjoyed doing the activity. There were no other remarks.

Takeaway points

- Concept of family boxes works well. Only supervision that is needed is telling them the booklet will guide them through their research.
- Materials in box lets children perform research on intuition.
- Difficulty is relatively good, take away some of the hints.
- Length of the activity is good.
- Make instructions/texts even shorter.

Final design

Taking the observations and evaluations from testing the activities into account, final changes were made. Most points from the ''Family boxes structure argumentation'' section remained the same. However, some sentences were made even shorter, and some of the hints were taken away to increase the difficulty of the activity. The following will be short descriptions of the four activities, full activities and the materials that are needed can be found in Appendices (6-9).

Great burdock [*Klittige Klis*] (Appendix 6):

Audience is introduced to burrs of the Great Burdock. They are asked to inspect it and discover what it can do. They can research its functionality by using different objects from nature, such as animal furs. They are asked if they know something that functions similarly, eventually leading to reveal that Velcro was inspired by the burrs.

Cool Cacti [*Coole Cactussen*] (Appendix 7):

Audience will discover how cacti can keep themselves cool in the warm desert. Through using a small flashlight, they will discover that a cactus' spikes (and other attributes?) will help them create shadow, thus keeping more cool in the hot desert environment.

Nature's waste [*Natuurlijk, afval!*] (Appendix 8):

Nature has (almost) no waste, everything can be used again. This is explained through cycles and will include fungal materials. The biomimicry system level concept of how waste can be turned into useable material using fungi is explained.

Function in nature [*Functie in de natuur*] (Appendix 9):

This activity is designed to be more general. Audience is asked to inspect a plant and choose a highlight. They are asked to think about the function of their highlight, and how it achieves this. They will do this again with an object that was previously hidden. One person is blindfolded and has to use their senses to find out the function of the object. The audience is then asked to design a 'super' animal/plant with function they think fits best.

Proposed content of the box:

Each box has a different organisms as subject, therefore specific materials change with each box. However, the boxes also share a lot of similar materials. This choice was made in order to give all activities a similar structure. The following will explain these materials and will serve as an argumentation for why the choice for this material was made.

- Box:
    - Holds the materials needed for the activity.
    - Box should be attractive and reveal the subject (organism) of the activity on the outside.
    - Box should be open, so people can look in the box and be enticed by the materials in it.
    - Allows for easy transportation of a small activity, which gives the option to find a quiet spot for the activity.
- The activity:
    - Booklet with instructions printed on hard, A5-sized material (e.g., wood).
    - Booklet format allows to structure the activity. By working through the booklet, more information is gathered and new discoveries can be made.

    - Stimulates to perform research tasks, and gives information about the organism.
    - Stimulates participants to discuss what they think, and stimulates them to do research together.
- Small whiteboard + pens
    - This allows participants to draw, which stimulates them to look critically at what they're seeing.
    - Can be used more than once, unlike a paper worksheet.
    - Pb'er (or other employee) might have to erase some boards when boxes are returned.
- Magnifying glasses:
    - This allows children to look at an organism up close.
    - Allows children to intuitively perform research, as seen by observations during Operatie Breinbreker.
- Objects needed specifically for the activity, such as a flashlight or a burdock's burrs.
    - Allows for small research tasks not involving actual organisms, thus preventing harming of said organisms.
    - It lets children perform research intuitively, as seen by observations during Operatie Breinbreker.
    - Specific for each activity, list of necessary materials is described along with the activities, in Appendices 6-9 .

Discussion

In order to design the biomimicry activities, the main question at the start of this project was: How can biomimicry be integrated into an educational program for the OH? This section will discuss the results that followed from this question, some limitations of the study, and why certain choices were made during the design process.

A few activities that are often used and work well in biomimicry education are drawing, designing, and crafting a prototype (15,37). These activities fit well within inquiry and design based learning, two techniques UMU uses to design their programs (7,9,10). Crafting the prototype is also one of the better aspects of the *Ontwerpen naar de Natuur* program according to UMU PB'ers. However, in the current format of the family boxes, the choice was made to omit crafting. This choice was made since crafting does not translate well to the OH, crafting materials would likely get littered around the OH. Currently, no indoor place (protected from weather conditions) in the OH is allocated for school activities. Once a place is allocated, the boxes could be adapted (or new boxes could be designed) to allow for exercises that include crafting a prototype as a solution to a problem. This would be a valuable addition for biomimicry education in the OH. Drawing was also considered as an important aspect in biomimicry education by studies (15,37). During the testing of the activities, it was shown that drawing indeed worked well and stimulated children to look well at their object. In addition, magnifying glasses were really popular and stimulated children to intuitively research their object, and will therefore be included in all boxes.

Testing the concept boxes was possible inside Tivoli Vredenburg, during *Operatie Breinbreker.* The boxes were rated highly by the public. Testing was now done indoors, it would also be interesting to test the boxes outside, to simulate how the boxes would be used in the OH. When observing the public during UMU testing days, children sometimes got distracted by other people or by the exhibitions. It would be interesting to see whether the OH environment helps to keep their concentration, or if they get distracted by plants or animals around them.

Structure/form-based biomimicry is often relatively easy to explain, the structure or form of an organism can directly be translated to act in the same manner as it does for the organism. Process and system based biomimicry are harder to explain to a younger audience (37,38). In addition, some form-based biomimicry examples are based on micro (or even nano) structures. Micro (and nano) levels are introduced to students in secondary education (39), meaning that this pre-knowledge is not present among the (entire) target audience. Therefore, some examples such as the Lotus, got stuck in development, since no good explanation or experiment was found that could visualize how the lotus' structures work on micro-level. The term biomimicry was omitted from the family boxes, and was instead replaced by learning from nature. Only 30% of the families in the botanical gardens were familiar with the term, and a previous report also advised against using the term in education (40).

In order to adapt the family box concept easily for school classes, one activity was designed to be more general, and not have a specific topic (*Functie in de Natuur*). School classes can start with the *Functie in de Natuur* box, after which they can continue with one of the boxes about a specific example. Two activities (*Coole Cactussen* and *Klittige Klis*) were tested and revised. Two others (*Functie in de natuur* and *Natuurlijk, afval!*) were not tested due to time restrictions. Therefore, testing and further development of these boxes would be recommended.

During the survey in the botanical gardens, it was revealed that most of the public was not really familiar with biomimicry or some examples of it. However, the examples did spark an interest among the public, and they also said they thought humans can learn from plants. This was further exemplified during the evaluation after testing the family boxes at *Operatie Breinbreker,* where most kids said that

people can learn a lot from nature. In addition, the evaluation showed that the boxes scored highly on almost every question. Most children said they worked together, showing that the boxes allow for collaboration and contribute to that specific 21st century skill and NOS aspect (6,12). This was also suggested by previous reports (15,17,18). Furthermore, these results show that there is a gap in knowledge among the public, which they are interested in and are open to learn more about.

Conclusion

This research shows that a biomimicry program in the OH fits well within the programming of UMU. Biomimicry thinking and education is inherently connected to inquiry and design based thinking (8,10,15). In addition, it promotes 21st century skills such as collaboration, as suggested by the evaluation of the family boxes, as well previous research (15,17,18). Furthermore, the general structure of the boxes are in line with the elements that should be present in UMU activities, as seen in the 'Family boxes structure argumentation' section. Since the activity takes place in the OH, some limitations were discovered, the most important one being the exclusion of designing and crafting a prototype. However, there are talks that one of the greenhouses or the Orangery in the OH could be used for educational activities, which would be great locations for crafting a prototype.

The *Klittige Klis* and *Coole Cactussen* boxes were tested during *Operatie Breinbreker.* The evaluation that participants filled in showed that they liked the activity a lot (score of 4.6/5), and worked together with others (score of 4.1/5). The difficulty of the assignments was relatively good (score of 3.2/5, score of 1 being too hard and a score of 5 being too easy), some hints were removed to increase the difficulty for older children. Since designing (science) education is an iterative process, the boxes most likely still undergo some rounds of improvements before they are implemented in the OH. The evaluation also showed that most participants thought humans can learn from nature. The survey in the botanical gardens also showed that families thought humans can learn from nature, even though most of them were not familiar with the term biomimicry or most of the biomimicry examples mentioned during the same survey. These results show that there is a lack of knowledge regarding learning from nature, but that (almost) everybody is open to the idea of learning from nature. Therefore, these biomimicry family boxes would be the perfect opportunity to let people learn from nature in the OH.

Future recommendations

- Develop and test the family boxes even more. The *Natuurlijk, afval!* and *Functie in de Natuur* boxes have not been tested yet. Testing these boxes might reveal that families run into unforeseen problems. Giving families a choice between multiple activities would be good, and it might work as an incentive for them to come back and try the other activities.
- Develop more boxes. Five other boxes with different subjects were stranded at some point during their development. Therefore, these activities for these subjects don't have to be started from scratch. Most of these boxes were stranded since the working mechanism was deemed too hard to explain to a young audience. This might be an opportunity to make boxes that are suited for secondary education.
- Develop other activities for the OH. For example, scavenger hunts were really popular among the families in the botanical gardens, such an activity could also be made for the OH. Other activities could also be designed to connect the OH and UMU more strongly.
- Repurpose UMU's *Ontwerpen naar de Natuur* program for the OH, aimed at education for school classes. The design aspect of biomimicry is missing in the family boxes. However, this is an important aspect in biomimicry education (37) and would stimulate design based learning (8) and creativity among the students.

- Make a plan for the OH. Currently, a lot is still unknown regarding the function or goals of the OH. Establishing such a plan would make for a more streamlined approach to make educative programs in the OH.

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Appendices:

Appendix 1: Observation and Evaluation UMU testing days

Evaluation research tour + workshops Makers studio and Fossils Group 8 (20-4-2023)

The entire class started with the research tour. The group was split in two, and both groups went to different exhibitions to do exercises. This went quite well, apart from reading instructions that are given. The kids seemed to enjoy doing the exercises and looking at the exhibitions.

During the makers studio workshop, the kids (and teacher) said that the worksheet had too much text. Time that was given for their initial research was relatively long when compared to the designing and prototyping phase.

The fossils workshop was linked to the 'Grondig Speuren' exhibition. The kids got to compare samples from the workshop to exhibited samples. Furthermore, kids were assigned roles with different skills that they could do specifically. This encouraged them to work together, and introduces interdisciplinary work to some extent.

Main takeaway points: less text, get to the make/design phase sooner, assigning roles works well.

Evaluation research tour + workshop Attention VMBO 3 (21-4-2023)

A different program was followed this time. The class was split in two groups; one group did the full research tour; one group went to one exhibition and did the Attention [Aandacht] workshop. The groups were relatively small and could therefore to the exercises in the exhibition halls without being interrupted by another group. Therefore, they had more concentration to read instructions and could follow exercises better then groups before them. However, exercises with long introductions were sometimes skipped.

The group that went to one exhibition hall and did the Attention workshop also did well. They started with some across the line challenges, in which the kids had to choose between two options. At first, the group went to the same side of the line, but after a couple of questions the kids felt save enough to show a different opinion. Furthermore, this workshop fit well in the assigned time.

Main takeaway points: without distractions, kids of this age can read the instructions well. However, don't make this introductions/instructions too long.

Appendix 2: Visiting Naturalis

Naturalis – 10-3-2023

March is the 'maand van het meekijken' (month of watching along) in the Netherlands. This means that museums and science centers open their doors for fellow educators from other museums. I had the opportunity to visit Naturalis and watch along with one of their programs. The program was called natural talent (natuurtalent) and had some aspects of biomimicry, even though it wasn't mentioned explicitly. The program was two hours long, significantly longer than the to be designed activity for UMU.

The two educators received the children in the main hall of the museum. The children immediately got enthusiastic about the stuffed animals that the educators had brought along. The group was guided along to the workshop space, where they were asked to gather around a tv screen and sit on the ground. An interactive introduction was given, in which pictures of multiple animals were on the screen. The children had to guess what talent the different animals had in common. The next exercise was explained, and the kids were asked to go sit around a table. There were taxidermal animals on the tables. The children had cards with talents (e.g., jumping, hiding) on their tables and they had to match talents to the animals. In the next exercise boxes with (parts of) animals were put on the tables, and children had to match talents to these objects.

Another short presentation was given, and the next exercise was explained. The children had to make quartets of animals with the same talent. Therefore, they could also go into the Life exhibition room, where a lot of taxidermal animals are exhibited. After making the first quartets, the kids went back to the workshop room. An explanation about microscopes was given, and the kids were given the opportunity to use microscopes to look at small animal objects. They could then draw what they saw to make more quartet cards. Afterwards, the kids were gathered around the tv screen for a short final presentation. It was explained how different games can be played with their set of cards, for example 'Guess who?'. A quick round of this game was played to finish up the workshop.

It was fun to see the enthusiasm of the children in regards to the animals that they saw. One of my points of critique was the ending of the program. UMU ends its activities with a moment of reflection on what was learned during the activity. The ending of the Naturalis program was not a reflection, but rather another fun explanation for the children. UMU has more focus on learning, and has therefore a higher educative value.

Appendix 3: Biomimicry examples in the Oude Hortus

Bees – Hexagonal structure

Honey bees build their nests in very recognizable shapes, they use hexagons. Apart from honey storage, the hexagons are also used as cradles in which bee larvae can develop. The hexagons are made from wax, which the bees have to be frugal with (41).

A hexagon is a very efficient shape to use for the scarce wax, since it is the way to fit the most area within the least structure (42). In addition, hexagons can be stacked together easily. A single hexagon can be surrounded by six others, resulting in a high compression strength (43).

Since hexagonal shapes are very space-efficient, they are often used in human-made structures. For example, hexagonal shapes are found in architecture, furniture, and in biomedicine (43).

Function:	**Strategy:**
Material efficient cradle chambers / honey storage.	Building the chambers in hexagonal structures.
Design principle:	**Connection to Oude Hortus:**
Building structures in hexagonal shapes is the most material efficient way of building.	Beehive is present next to the pond.

Trees – Adaptive growth

Trees can grow tall when under the right conditions. They can also adapt to mechanical stresses such as wind, but also to the heavy weight of their own branches (44,45). They optimize the distribution of their cells based on mechanical stresses. If a branch grows a lot and becomes very heavy, the tree will grow its trunk cells more in this direction to compensate for the stress of the weight (44,45). This causes the trunk to not be completely round, which can be observed by looking at the annual growth rings of a tree.

The lesson of optimization of distributing the cells in a tree has been used by engineers to optimize performance in fiber-composite materials (45,46).

Function:	**Strategy:**
Create strength under stress.	Growing more cells on side with stress to compensate for stress.
Design principle:	**Location in Oude Hortus:**
Optimize distribution of material to create a stronger (and often lighter) material.	Practically every tree, it may be nice to put out some cut-through tree trunks.

Spiders – Strong, UV coated threads

Spiders build webs to capture prey. They build these webs using spider silk, which possesses the same strength as artificial materials such as Kevlar, but is still elastic (47). This is useful, since it allows the web to survive insects flying into it at high speeds without breaking. After stretching out, the web can recover while not becoming loose.

In addition, spiders can also incorporate stabilimenta into their webs. Silk that is used make stabilimenta isn't used to capture prey, but rather to scare away birds (48). This silk has a special UV coating that birds can see, preventing them from flying into and thus destroying the webs. This has also some disadvantages: birds can be alerted through the web and hunt for the spider, and some prey is scared away by it as well (48).

Function:	**Strategy:**
1. Preventing destruction of web while capturing prey. 2. Scare away birds to prevent destruction of web.	1. Very strong, yet elastic threads prevent breaking of the web. 2. UV coating and 'decorations' in web warn birds from flying into it.
Design principle:	**Location in Oude Hortus:**
1. Making threads with parts that easily detach to extent itself, but also easily come together again. 2. UV coating to alert birds from flying into something.	Spiders are present in Oude Hortus

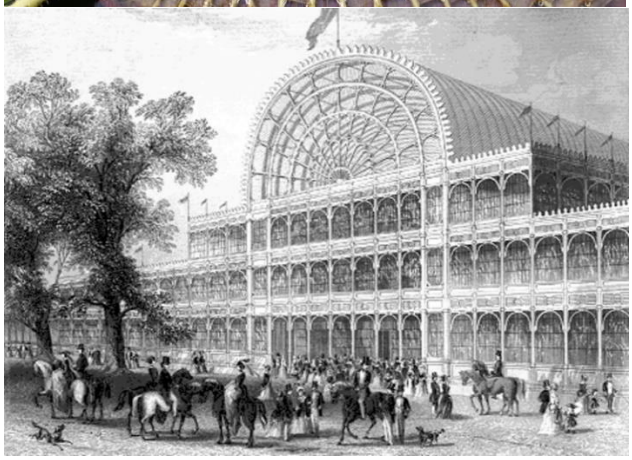
Ants – Pheromone communication

Ants are eusocial insects that live together in large complex societies (49). The size and social complexity differs between colonies. Colonies can range in size between a few hundred to millions and can include one or multiple queens. These colonies often work through self-organizational processes. Individual worker ants often operate through information they obtain from the local environment or from ants around them. For self-organization, it is important to have a repeating pattern of interactions, and positive feedback loops that result in escalation effects from interactions with their surroundings or other ants (50). A good example for self-organization in ant colonies is food foraging. Foragers initially set out on different paths when no information is present. Once a forager finds food, it will emit pheromones on its way back to the colony (51). Other ants can sense this chemical signal and follow it to the food source. Since other ants that find the food source also emit pheromones, which further amplifies the signal (51). This allows the entire colony to converge on the food source. Additionally, when the colony can quickly switch away from the food source when it depletes through negative feedback loops (52).

Interactions between these social insects have inspired models in a range of network and computing applications (e.g., programming robotic systems for autonomous exploration (53), algorithms for communication and/or transportation networks (54).

Function:	**Strategy:**
Conveying information to other ants.	Using pheromones to spread information across an ant colony.
Design principle:	**Location in Oude Hortus:**
Conveying information to others through the use of positive and/or negative feedback loops.	Ants are present in and on the ground in the Oude Hortus.

<table>
<tr><td>  </td><td>Pitcher plants – Slippery surface
Pitcher plants are carnivorous plants that trap insects (55–57). These insects are trapped in the tall pitcher with digestive fluids. The surface that surrounds the pitchers is called the peristome. This is a very slippery surface, causing insects to fall into the pitcher (55). Two different factors help to enhance the slippery surface of the pitcher’s rim. Firstly, overlapping epidermal cell make up the surface, giving the surface a directionality into the pitcher. This makes it easier to slide into the pitcher than out of it, making an escape out of the pitcher very difficult. Secondly, a thin watery film quickly forms on the microtextured surface (56,57). This film can arise when there is a source of liquid, e.g. rain, or the plant’s own nectar. The film reduces friction between an insect’s feet and the plant, making it more slippery (56).
These principles have inspired various coatings with self-cleaning surfaces (58).</td></tr>
<tr><td>Function:</td><td>Strategy:</td></tr>
<tr><td>Prevent insects from exiting the pitcher plant.</td><td>A textured surface gives directionality into the pitcher plant. In addition, the rim of the pitcher is easily wettable and thus slippery, making it easier to slip into.</td></tr>
<tr><td>Design principle:</td><td>Location in Oude Hortus:</td></tr>
<tr><td>Overlapping epidermal cells give the surface texture directionality. The wettable rim makes it even more slippery.</td><td>Was present in the greenhouses, might return.</td></tr>
</table>



***Victoria amazonica* – Interconnected structures**

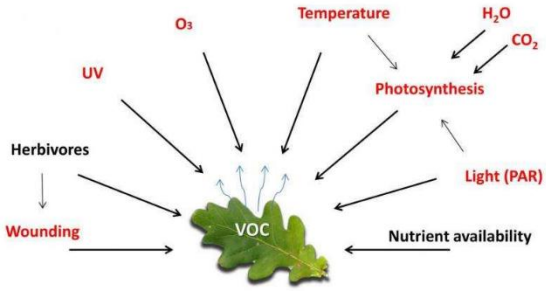
Plants get energy through photosynthesis, a process that takes place in a plant's leaves. A plant needs more energy to grow, optimization of photosynthesis capabilities is a way to achieve more energy. This can be achieved by enlarging the surface area of leaves exposed to the sun. The *Victoria amazonica* is a plant that floats its leaves on the surface of rivers. It grows leaf that can grow up to several meters across to maximize exposure to the sun (59,60). However, the massive leaves also make it also more difficult to stay afloat. Therefore, an interconnected support system can be found underneath a leaf. A main rib is located in the center, from which other ribs radiate. The ribs are filled with air, which reduces the amount of material needed, and also help to keep the leaf afloat. The leaves and ribbing system are strong enough to hold a small child (60).
The Crystal Palace was designed after this plant, where large glass areas are supported by iron framework (61). It might also help to inspire new systems that help humans to build on water.

Function:	**Strategy:**
Providing strength to support the leaf to stay afloat.	Interconnected ribs filled with air.
Design principle:	**Location in OH:**
Interconnected hollow pipes across a large area.	The *Victoria amazonica* is present in the Victoria-greenhouse.

Bamboo – Distribution of material

Bamboo has often been used as building materials in Asian countries. It grows fast and more importantly, is strong and also light. Bamboo is light since it has a hollow structure. The strength of the plants originates from the spatial distribution of its fibers, these are not equally distributed in the wooden parts of the plant. The fiber density is higher on the outer surface when compared to the inner surface (62). When bamboo is tested, the fiber distribution is almost the same as a theoretical, optimal fiber distribution. It was found that bamboo can adjust the distribution of fibers to obtain the maximal flexural rigidity using the smallest volume of wood (63).
Mimicking the distribution of dense material on the outside and less dense on the inside, can result in stronger (building) materials, that are also lightweight.

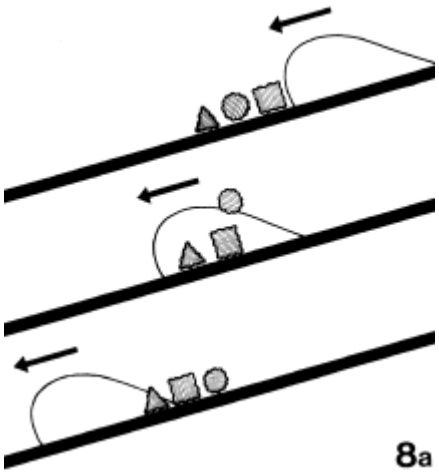
Function:	**Strategy:**
Keeping the plant strong to protect against influences such as weather.	Having a higher density on the outside than the inside, while also having a hollow inside.
Design principle:	**Location in Oude Hortus:**
Having dense outsides to make a strong material. Material can still be hollow in order to limit the weight.	Was present in the Dickonia greenhouse, might return.

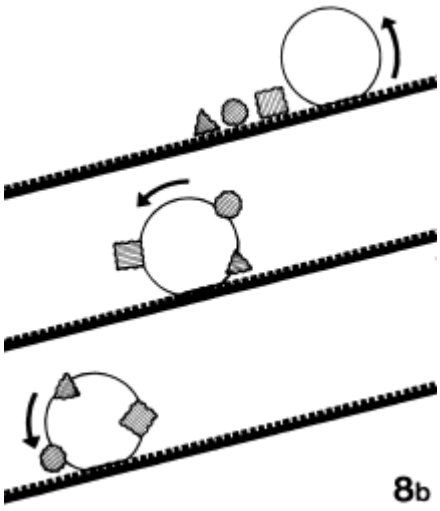
<table>
<tr><td> 
</td><td>Volatile Organic Compounds – Exchanging information
Volatile organic compounds (VOCs) can be used to battle fungi, and protect plants from infection. However, these molecules can also be used to exchange information with other plants. More than 1700 VOCs are known to relay information about a plants' identity and physiological condition with other plants (64). VOCs can be considered as the best cues in plant neighbor detection, since they are constantly present as opposed to periodical cues such as mechanical contact and light (65). VOCs can differ in their volatility, the ones with a high volatility are often limited for plant interactions at short distances, while less volatile compounds can transfer information across longer distances (66).
All kinds of information can be conveyed using VOCs. A specific class of volatiles are herbivore-induced plant volatiles (HIPVs). Excreting these compounds stimulates neighboring plants to adjust their defenses against herbivores eating leaves. In addition, these plants become more attractive to carnivores by providing them information that prey is present around these plants (67,68).</td></tr>
<tr><td>Function:</td><td>Strategy:</td></tr>
<tr><td>Exchanging information with other plants.</td><td>Using VOCs to convey information to other plants, for example about an incoming attack of bugs.</td></tr>
<tr><td>Design principle:</td><td>Location in Oude Hortus:</td></tr>
<tr><td>Chemical cues can be used to exchange information in unconventional ways.</td><td>VOC's will be present when there are plants.</td></tr>
</table>

(**Oregano) VOC's – Combatting fungal spores**
There are a lot of spores floating around in the air. When these fungal spores land on something, they can germinate under the right conditions. Therefore, when you leave food out in your kitchen, fungi will often start to grow on it. Some plants have found defense mechanisms against fungal attacks. These are often in the form of signal molecules that evaporate into the air called volatile organic compounds (VOCs). These VOCs can harm the fungus, but can also warn surrounding plants (69). Surrounding plants can then activate their own natural defense mechanisms in order to be ready to sustain an attack.

These VOCs can also interact with the fungal cell membranes. For example, thymol and carvacrol are both found in oregano, can adopt electrons from the cell membrane (70). This causes the membrane to fall apart, thus harming the fungus. These compounds can be used to prevent food spoilage, potentially replacing synthetic fungicides, which are often used at the moment. Synthetic fungicides often leach into groundwater and soil, where they can be harmful to a range of organisms. In addition, fungi can become resistant against the fungicide over time. Therefore, more of the chemical would need to be used to have an effect, worsening the environmental impact. Oils and VOCs from plants can remain shorter in soil and water, and are therefore less harmful.
These plant derived VOCs are currently being researched for their potential use in food packaging. This could extend the expiration date on our food, resulting in less food waste, while also being the better alternative for the environment.

Function:	**Strategy:**
Protecting the plant.	Using VOCs to break down fungal cells membranes, thus preventing infection.
Design principle:	**Location in Oude Hortus:**
Designing molecules similar to it can provide more sustainable alternatives to fungicides.	Can be found in Regiustuin.

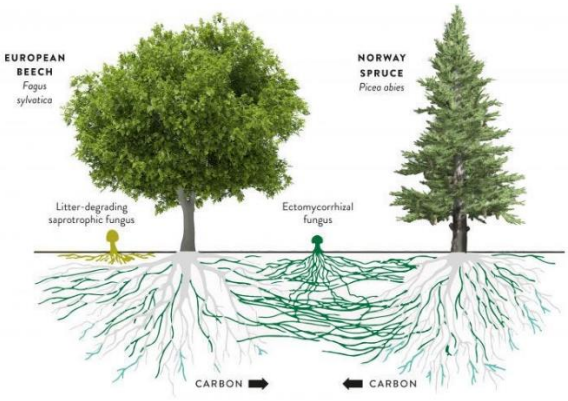




Lotus – Superhydrophobic surface

Most plants are at least somewhat hydrophobic. The leaves of the lotus plant can be called superhydrophobic. This plant typically lives in muddy waters and uses this hydrophobic ability to stay clean. This ability is used by the plant to keep the leaves clean. The hydrophobicity is achieved by the micro-topography on the leaf (71). There are micro structures present on the leaves, which have air in between. The adhesion of a particle to a solid surface is stronger than the adhesion between the particle and a drop of water. However, since there are micro structures present on the leaf, the interfacial area between the particle and surface is minimized. The particle is only in contact with the tips of the microstructures and the air in between these structures. In this case, the adhesion between the particle and water droplet is greater than the adhesion between the particle and the structured surface. Therefore, the particle adheres to the water droplet, and moves along with this droplet removing it from the leaf's surface (71). This effect not only helps to keep the plant clean, it also plays a role in the defense against pathogens. Toxic inorganic particles, and spores and conidia from pathogenic microorganisms can land on the leaves (71). They can be removed by the same effect as dirt particles. Even more, the hydrophobic effect ensures that spores and conidia are deprived of water, therefore preventing them from germinating. This effect can be mimicked by people to create surfaces with a similar ability, thus preventing items from getting dirty.

Function:	**Strategy:**
Keeping leaves of the plant clean.	The surface of the leaves has microscopic protrusions, which prevents water from being on it.
Design principle:	**Connection to Oude Hortus:**
Tiny protrusions keep air trapped in between. This creates a super hydrophobic layer. Other particles (dirt, pathogens, etc.) have a greater adhesion to the water droplet and will thus stick to it and roll of the leaf.	Lotus plant will be present in the Victoria greenhouse.



Mycorrhizal network – Communicating strategies

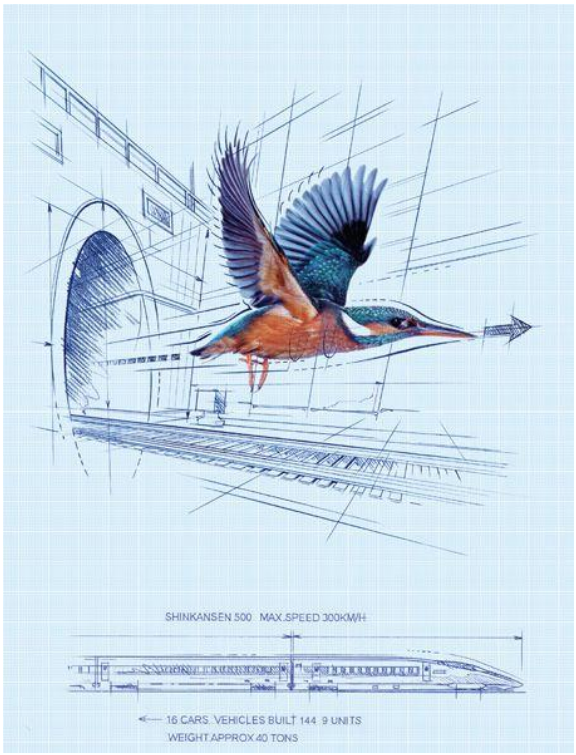
There are worlds around us that we cannot see easily. Some because they are too small, other because they are underneath the ground. In this case, mycorrhizal fungi are the main character. Underneath the ground, there are enormous networks of thin threads: mycelia. Mycorrhizal fungi can live in a mutualistic relationship with trees (and other plants) (72,73). Mycelial threads can connect trees over long distances, and are found to have various functions. These threads allow trees to exchange information, and transport water and nutrients with one another (72,74). This network has also been dubbed the 'wood wide web' (75), since it can be compared to an internet network.

The internet works thanks to nodes, which are individual computers that networks use to move information around. There are also hubs, which are places that are at the center of nodes and connect them with one another. Nodes can be compared with individual trees in a forest, in which the oldest trees are often the hubs, since a lot of connection run through them (76).

In the wood wide web, mycelium connects nodes with one another and with hubs. Mycelium can grow closely around tree roots, allowing for the exchange of (signaling) chemicals, water, and nutrients (72,74). A tall tree might get more sun than smaller trees, and might therefore get more energy than it needs. It can send out some sugars to surrounding trees via the mycelium network, from which the mycelium profits by keeping small amounts of sugars for itself. Next to sharing resources like nutrients and water, the network can also pass along stress signals. If leaves from one tree are getting targeted by caterpillars, the network can send out a warning signal to surrounding trees. These trees can then adapt and strengthen their defenses, for example by making their leaves more bitter (72,74).

The mutualistic relationship between trees can reveal efficient ways of communication and also the importance of maintaining relationships. In addition, it can show us how we can improve how we care for our forests, and help it to retain their underground networks.

Function:	**Strategy:**
Spreading information.	Moving nutrients and other signal molecules are passed along the mycorrhizal network to spread information among plants.
Design principle:	**Connection to Oude Hortus:**
A vast network with hubs and nodes of information, which is passed along through connections.	Although not directly visible, roots of different plants are connected to one another.

<table>
<tr>
<td> 
</td>
<td>Kingfisher – Bullet train
Bullet trains in Japan travel at high speeds, ranging from 240-320 km/hr. When this train was first designed, the speed it travelled at caused an atmospheric pressure to build at the nose of the train. When passing through tunnels, this pressure would be released when exiting the tunnel. The release of pressure resulted in a loud ‘tunnel boom’, causing nearby citizens to be startled (77,78).
When looking at nature, engineers found that the kingfisher has the ability to dive into water while barely making a splash. After mimicking the shape of the kingfisher’s beak and integrating this into the front of the train, it eliminated ‘tunnel booms’ and also helped to reduce noise in general. Even more, it allowed the train to travel more efficiently: it could travel 10% faster while using 15% less energy (78).
Birds in general are relatively buoyant due to the avian air sac system and the layer of air that is trapped between the body and the feathers (insulation). The kingfisher dives into water to catch fish as prey. To overcome their buoyant bodies, they evolved to have streamlined bodies (77).</td>
</tr>
<tr>
<td>Function:</td>
<td>Strategy:</td>
</tr>
<tr>
<td>Overcoming its buoyancy to dive into the water.</td>
<td>Streamlined beak to dive into the water at high speed.</td>
</tr>
<tr>
<td>Design principle:</td>
<td>Connection to Oude Hortus:</td>
</tr>
<tr>
<td>Streamlined front which reduces the drag and creates an aerodynamic movement.</td>
<td>While not always present, a kingfisher can be seen occasionally around the ponds.</td>
</tr>
</table>

Appendix 4: Survey Botanical gardens Utrecht

Wat zouden jullie graag willen doen in een (botanische) tuin? (meerdere antwoorden mogelijk)

- Een rondleiding
- Spelletjes
- Iets leren
- Op onderzoek uit
- Een speurtocht
- Rustig rondlopen en kijken
- Iets anders, namelijk:

_____

Welke manier van 'leren' vonden jullie het fijnst? (meerdere antwoorden mogelijk)

- Zelf rondkijken
- Informatie bordjes lezen
- Rinus de Regenworm speurtocht
- Een workshop
- Iets vragen aan medewerkers
- Iets anders, namelijk:

_____

Als jullie tijdens je bezoek een activiteit zouden gaan doen, hoe lang zouden jullie hier dan maximaal aan willen besteden?

- 0 – 10 minuten
- 10 – 20 minuten
- 20 – 30 minuten
- 30 – 40 minuten
- 40 – 50 minuten
- 50 – 60 minuten
- Langer dan een uur

Een aantal losse vragen:

Ben je bekend met het begrip biomimicry?	Ja	/	Nee
Denk je dat we als mensen van planten kunnen leren?	Ja	/	Nee
Wist je dat planten met elkaar kunnen praten?	Ja	/	Nee
Wist je dat er snellere treinen gemaakt zijn dankzij een vogeltje?	Ja	/	Nee
Wist je dat we sterkere huizen kunnen bouwen dankzij planten?	Ja	/	Nee
Wist je dat er techniek van bijen wordt gebruikt in de ruimte?	Ja	/	Nee

Appendix 5: Evaluation prototype activities

LEEFTIJD KIND:

1. Vonden jullie het makkelijk of moeilijk?	 Te moeilijk		 Precies goed		 Te makkelijk
En waarom?					
2. Denken jullie dat mensen iets van de natuur kunnen leren?	 Helemaal niets				 Heel veel
3. Hebben jullie samengewerkt?	 Helemaal niet				 Heel veel
4. Wat vonden jullie van de opdracht?	 Helemaal niet leuk				 Heel leuk
En waarom?					
5. Wat kan er beter?					
Extra ruimte voor opmerkingen:					

Appendix 6: Klittige Klis

Benodigde materialen:

- Box voor alle spullen
- Klapboekje met de opdrachten (zie hieronder)
- Drie vergrootglazen
- Drie kleine whiteboardjes
- Drie whiteboard stiften + microvezel doekjes
- Bakje met klisbollen
- Stukjes dierenvacht: lang, middellang, en kort
- Iets waar het niet makkelijk aan blijft plakken, bv. stuk hout of slangenleer

Op een dag liep George de Mestral met zijn hond door het bos. Thuis merkte hij dat er delen van een plant aan zijn broek en hond waren blijven plakken.

Dit is een bolletje van de **Grote Klis.**
Pak er ook maar een uit het doosje.

Om iets te **onderzoeken**, starten we vaak met heel **goed kijken**, laten we dat ook met de **Klisbolletjes** doen

Wat valt jullie op? Teken het!

Als jullie heel goed kijken, zie je dat er aan de uiteinden kleine **haakjes** zitten.

Waar is dit handig voor?
Gebruik materialen uit de bak om het bolletje te **onderzoeken**!

Wat hebben jullie ontdekt?
Waar zou de plant dit voor kunnen gebruiken?
Bespreek dit met elkaar.

Zaadjes van de Klis zitten in het bolletje. Het bolletje blijft haken aan langslopende dieren, zo worden de zaadjes verspreid.

Door goed te **kijken** naar de Klisbolletjes heb ik er iets van **geleerd** en een uitvinding mee bedacht.

Wat werkt op dezelfde manier als de Klisbolletjes? **Bespreek** dit met elkaar.

Klittenband!

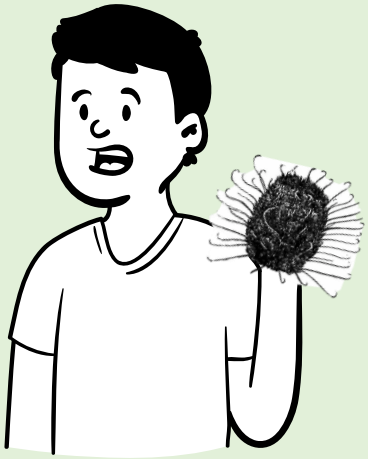
Heeft een van jullie weleens klittenbandschoenen gehad?

Bedenk nog **drie** dingen waarbij klittenband in jullie huis handig zou kunnen zijn.

Stel je voor…

Je wordt wakker en je handen zijn veranderd in een Klisbolletje.

Wat zou hier handig of juist onhandig aan zijn?



Leren van de natuur

Hopelijk hebben jullie iets over, en ook van de Klis geleerd!

Studenten aan de Universiteit Utrecht leren ook van de natuur. Door onderzoek te doen, komen ze meer te weten!

Zijn jullie benieuwd wat we nog meer van de natuur kunnen leren? Pak dan nog een andere box!

Appendix 7: Coole Cactussen

Benodigde materialen:

- Box voor alle losse spullen
- Klapboekje met de opdrachten (zie hieronder)
- Drie vergrootglazen
- Drie kleine whiteboardjes
- Drie whiteboard stiften + microvezel doekjes
- Een ‘hoofdcactus’
    - In de kassen moet worden aangegeven dat dit de cactus is waar het onderzoekje gestart kan worden. Deze cactus moet stevig zijn, en op goede hoogte staan, zodat deze goed te onderzoeken is. Kleine pilaarcactus of bolcactus zal hiervoor het beste werken.
- Andere cactussen
    - Om te vergelijken tussen de trucjes die de cactus heeft om schaduw te creëren.
- Zaklamp
    - Aan staaldraad vastleggen naast de cactus, om te voorkomen dat deze meegenomen wordt.

Coole cactussen
Ga aan de slag!

Hoi! Ik studeer biologie en ik mijn leraar zegt dat cactussen best bijzonder zijn.

Laten we **onderzoeken** waarom ze zo bijzonder zijn!

Bij de start van een onderzoek beginnen we vaak met **heel goed kijken.** Laten we dat ook bij deze cactus doen.

Wat valt jullie op? Teken dit op het werkblad.

Jullie hebben vast al gezien dat er veel stekels aan de cactus zitten!

Waarom zou de cactus **stekels** hebben?
Bespreek dit met elkaar!

Door stekels wordt een cactus minder snel opgegeten. Dat is niet het enige waar stekels handig voor zijn

Onderzoek met de zaklamp of jullie nog iets anders kunnen ontdekken waarvoor de stekels handig zijn.

Hint: doe alsof de zaklamp de hete woestijnzon is.

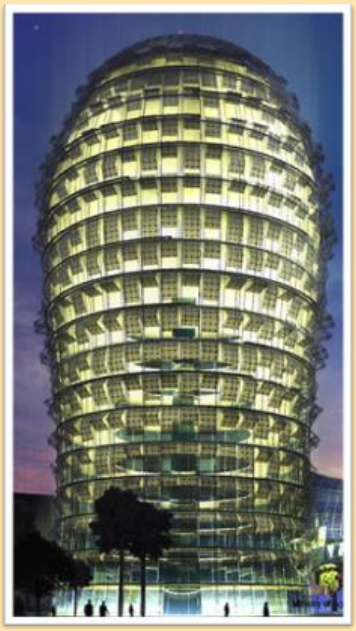
De **stekels** zorgen voor **extra schaduw.** Niet heel veel natuurlijk, maar in de woestijn helpen alle beetjes om ervoor te zorgen dat de cactus **niet te warm** wordt.

Zien jullie bij andere cactussen nog trucjes voor extra schaduw?

Er zijn inderdaad meer opties, hebben jullie bijvoorbeeld de richels gespot?
Bespreek met elkaar of stekels en richels ook voor mensen handig zouden zijn.

Bij dit gebouw zorgen de opstaande luiken voor meer schaduw, net als de stekels bij een cactus.

Zou dit bij jullie huis ook handig zijn, of juist niet?



Leren van de natuur

Hopelijk hebben jullie iets over, en ook van de cactus geleerd!

Ben je benieuwd wat we nog meer van de natuur kunnen leren? Pak dan nog een andere box!

Of kijk op de achterkant van het werkblad om zelf nog meer te leren!

Appendix 8: Natuurlijk, afval!

Benodigde materialen:

- Box voor alle losse spullen
- Klapboekje met de opdrachten (zie hieronder)
- Drie vergrootglazen
- Drie kleine whiteboardjes
- Drie whiteboard stiften + microvezel doekjes
- Twee à drie schimmelblokjes
    - Gegroeid op stro is waarschijnlijk het beste, stro blijft relatief goed te herkennen. Blokjes zijn op verschillende momenten afgedood (gestopt met groeien)
- Kaartjes van bijlage: Natuurlijk, afval!
    - Bijlage is te vinden onder deze activiteit

Natuurlijk, afval!
Ga aan de slag!

Hoi! Het valt me op dat mensen veel afval maken, terwijl de natuur dat bijna niet doet. Hoe doet natuur dat eigenlijk?

In de natuur sterven dieren soms, waarna hun lichaam blijft liggen. Toch zie je in bos niet heel vaak gestorven dieren liggen, weten jullie hoe dit komt?

In de bak liggen kaartjes, wie eet wie? Maak een voedselkringloop.

De dieren worden opgegeten door schimmels en bacteriën. Dat kunnen ze doen met ‘’afval’’ van planten en dieren. Eigenlijk is er in de natuur dus geen afval.

Wat zou er gebeuren als je het kaartje van de schimmels weghaald?

Aan de Universiteit Utrecht wordt onderzoek gedaan door schimmels op afval te laten groeien. De onderzoekers kijken of we afval kunnen gebruiken om iets handigs mee te maken.

De blokjes in de bak zijn van schimmels en afval gemaakt, pak ze maar eens op!

Kunnen jullie zien wat voor afval er in het blokje zat?

Zien jullie verschil tussen wat de schimmel is en wat het afval was?

Teken wat jullie opvalt!

Door schimmels te groeien op stro konden deze blokjes gemaakt worden. Iets dat normaal wordt weggegooid (stro) kan dus eigenlijk nog goed gebruikt worden.

Waarvoor zouden schimmelblokken gebruikt kunnen worden?

De schimmelblokken kunnen bijvoorbeeld gebruikt worden als bakstenen om te bouwen, of als isolatie.

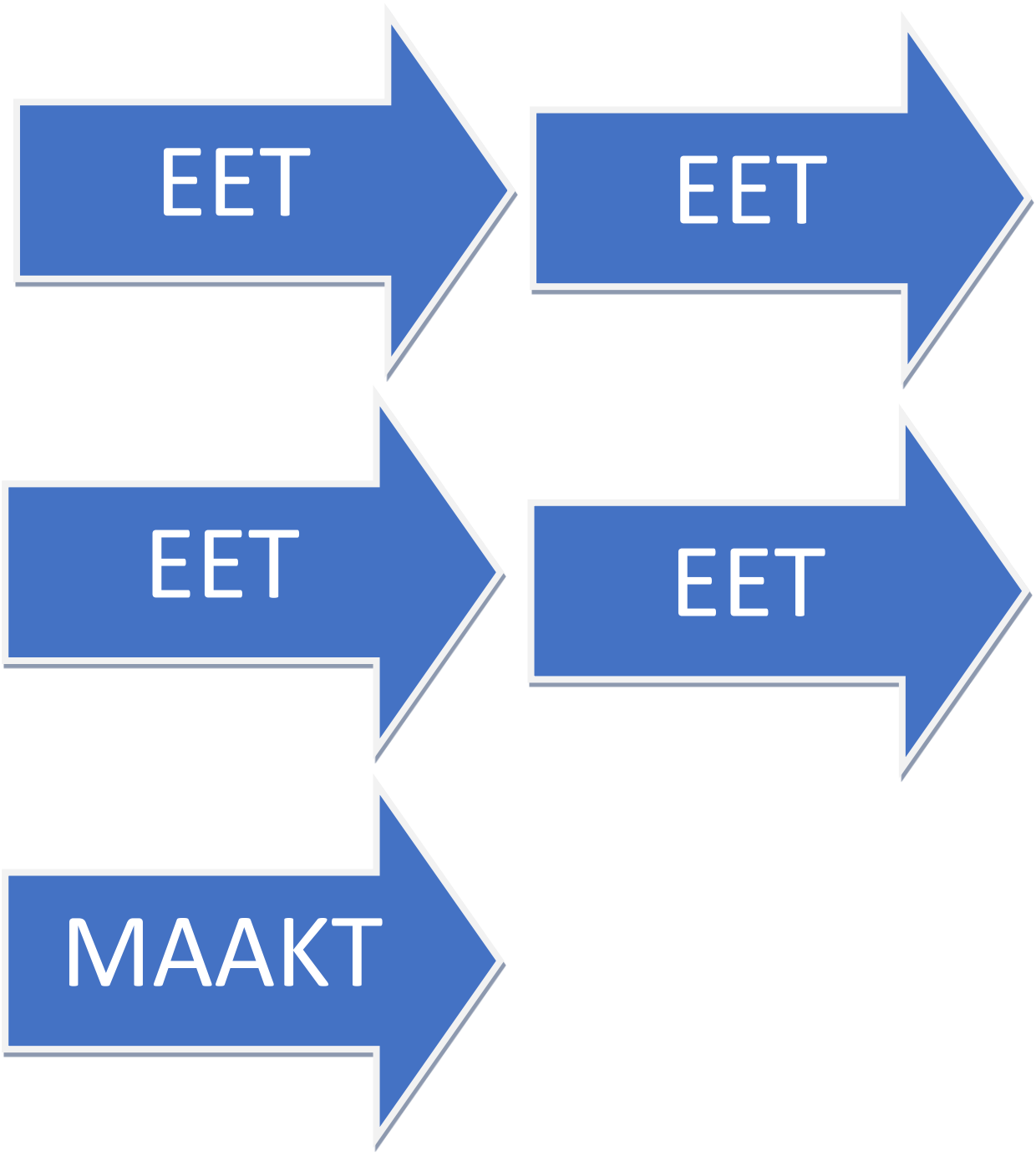
Zouden jullie in de toekomst in een ‘schimmelhuis’ willen wonen?

Leren van de natuur

Hopelijk hebben jullie iets over afval in de natuur en van schimmels geleerd.
Studenten aan de Universiteit Utrecht leren ook van de natuur. Door onderzoek te doen, komen ze meer te weten!

Zijn jullie benieuwd wat we nog meer van de natuur kunnen leren? Pak dan nog een andere box!

Bijlage: Natuurlijk, afval!



VOGEL

PLANT

SCHIMMEL

VOEDINGSSTOFFEN PLANTEN

RUPS

Appendix 9: Functie in de natuur.

Benodigde materialen:

- Box voor alle losse spullen
- Klapboekje met de opdrachten (zie hieronder)
- Drie vergrootglazen
- Drie kleine whiteboardjes
- Drie whiteboard stiften + microvezel doekjes
- Functie kaartjes; zie bijlage onder activiteit
- Rollen kaartjes; zie bijlage onder activiteit
- Blinddoek
- Blackbox met dierlijke materialen
    - Schapenvachtje
    - Haaientand

Functie in de natuur
Ga aan de slag!

Veel planten zien er anders uit. De ene plant heeft stekels, de andere vlekken, waarom zijn er zoveel verschillen?

Loop maar een stukje door de tuin en kies allemaal een plant uit die jullie verder willen onderzoeken.

Wat is er zo bijzonder aan je uitgekozen plant?
Kijk er eens goed naar en **teken** wat je opvalt.

Stekels zijn handig voor een plant om zichzelf te beschermen.

In de bak liggen functie-kaartjes. Welke functies hebben de onderdelen van jouw plant? Kun je nog meer functies bedenken?

Laten we nog een onderzoekje doen, maar dan met onderdelen van dieren.
Er zijn hier twee rollen.

Begeleider

Testpersoon

Welke rol kies jij? Volg de aanwijzingen op het kaartje.

(Bijna) alles in de natuur een functie, dat kan ook heel simpel zijn.

Kijk maar eens naar je eigen lichaam. Welke functie hebben je handen? En je haar?
Kunnen jullie iets bedenken dat geen functie heeft? Waarom?

We hebben nu allerlei planten en dieren bekeken. Stel je zou een superplant of dier maken, welke onderdelen van planten of dieren zou je dan willen gebruiken?

Leren van de natuur

Hopelijk hebben jullie iets over, en ook van de natuur geleerd!

Studenten aan de Universiteit Utrecht doen dit ook. Door onderzoek te doen, komen ze meer te weten!

Zijn jullie benieuwd wat we nog meer van de natuur kunnen leren? Pak dan nog een andere box!

Bijlage Functie in de Natuur

Zaden verspreiden	Beschermen
Veranderen van vorm	Insecten lokken
Stevig/sterk zijn	Blijven drijven
Voeding opnemen	Zonlicht opvangen
Temperatuur regelen	

Begeleider: Kies een van de voorwerpen uit de zwarte doos en geef deze aan de testpersoon. Vragen die je kunt stellen: Wat denk je dat het is? Wat valt je op? Waar zou dit handig voor zijn?	**BEGELEIDER**
Testpersoon: Je krijgt een blinddoek om en gaat blind een voorwerp onderzoeken.	**TEST-PERSOON**