Evaluation of BioLearning for the Future Project

Executive Summary

"If it was up to me, biomimicry should be a permanent part of every school."
(Dutch teacher)

BioLearning for the Future (BLF) has a broad vision based on an understanding that current approaches to achieving environmental sustainability and addressing climate change are not achieving change fast enough. Whilst a good first step, we need bolder approaches to tackling Europe's environmental and climate challenges. Biomimicry (innovation inspired by Nature) offers a bold approach, one based on the empirical success of 4 billion years of research and sustainable systems developed by Nature[1]. Biomimicry education has a strong track record supporting environmentally friendly innovation.

Using Nature's sustainable systems as a basis, BLF helps young people think about what sort of future they would like and how to achieve it. How can they contribute to that future? Can it become reality? BLF provides pupils with the core competences to observe and understand the technological significance of the natural world, to understand how Nature provides lessons for humans to live sustainability, and encourage pupils to become curious as to how they can learn from Nature to make a contribution to society's pursuit of sustainability.

The overall aim of BLF is to 'develop the core STEM and sustainability competences of young people, providing them with the platform of key skills to contribute to a sustainable Europe.' To action this aim, a BLF Learning Framework was developed to aid planning and reflection on what constitutes effective biomimicry learning within a STEM and sustainability setting (read framework here). The framework includes a self-reflection tool which us used in Annex 4 to reflect on the project as a whole.

Key successes of the BLF project include:

- A new suite of learning resources has been developed for upper primary education pupils (aged 8-12 years).
- 22 biomimicry exemplars (short activities connecting a 'talent' found in Nature with an application within the human world) have been completed, comprising "easy-entry" activities designed for teachers to readily adopt and implement with students.
- 35 learning activities (detailed activities or lessons which explore an exemplar in greater depth) have been completed.
- Pedagogical frameworks, that support competence-based curriculums, which are increasingly favoured by ministries of education.
- A new online biomimicry learning area has been developed, with translations into four different European languages ongoing.
- Five education organisations across Europe trained with the foundational skills and expertise to continue and extend this work.

[1] When referring to Nature, we are referring to the entirety of the Natural World of which humans are an integrated part, not a species set aside from Nature.

BLF has been very successful in developing a suite of learning resources which are unique not only in the world of biomimicry education, but within the larger landscape of education for sustainability. The exemplars are an excellent example of innovative teaching resources which are easy to teach and with content which is simple to grasp. The Biomimicry Day learning resources are also of good quality; however, pupil results are mixed. Pupils do grasp that Nature is an inspiration for human product or service design, but they are less capable at this time to create innovations for themselves. A number of factors are at play here including: teacher competence, classroom time, high level thinking skills, and content choices. A wider discussion is offered in section 4.7 below, and the partners will be well advised to spend time considering the implications of piloting and teacher feedback.

The reflections and assessment offered in this report are necessarily testing. As with testing any new approach to learning, critical feedback is essential to make genuine progress, and such paths are never smooth. The BLF partners should, however, take much credit for their work which is highly regarded by teachers, albeit with areas for further development, as the following quotes illustrate:

- BLF connects several subjects and makes it possible to see that science subjects are related and study the same phenomena, they just study them with different tools, we can also show the connection to life and underpin the relevance of the subjects in education. (Slovak teacher)

- Very nice teaching material. The students were particularly interested in the biomimicry experiments. The 'doing your own research' part was still difficult to understand for some students. Nice lesson! (Dutch teacher)

- There are rarely pupils who do not find at least "superficial" - without thinking about exactly how it works - inspiration after learning a topic - in group work they then learn to develop these ideas. Not all pupils were interested in the topic and the activities, so they found it harder to think about the biovations. (Slovak teacher)

- Absolutely! [This teaching approach] provides a good background, although a bit abstract. The new project is also better for 7-8th graders. For 5-6th graders it often "doesn't add up". It needs the "aha" experience. Need to be the conceptual framework behind it, which will come later. (Hungarian teacher)

- Yes, it is a good tool [for engaging pupils in sustainability issues]. The most efficient is to use more approaches and continuously talk about sustainability. The kids can admire Nature. It easily can be that some kids love these topics so much that they will choose it (biology, sustainability etc.) for profession. (Hungarian teacher)

- They learned and had the opportunity to explore something different, it certainly broadened their horizons and creative thinking. (Czech teacher)

BLF set itself four key objectives. These are reviewed throughout this report, and the impact synthesised below:

<u>Specific Objective 1:</u> Develop the competence of pupils to learn from Nature and apply biomimicry to understand sustainability challenges.

This has been partially achieved. Perhaps the largest barrier to this objective is the fact that it takes time for teachers to become efficacious at teaching biomimicry, both in their self-perception and in reality. So, the first step was to create materials designed for easy adoption and implementation, that create the desired effect and understanding on pupils.

To support teachers, the project developed 22 exemplars. These are a unique resource within biomimicry education; they are simple, effective and easy to use. They offer pupils (and teachers) a simple biomimicry example, helping to connect a specific 'talent' found in Nature with an application within the human world. Pupils clearly enjoy the exemplars and have good levels of recall when asked about their learning from the exemplars.

As discussed in 4.7 below, the ability of pupils to apply biomimicry to understand sustainability challenges is less clear. Pupils are clearly engaged and understand what biomimicry is, and that it can inspire more environmentally-friendly human innovation. Pupils are able to apply elements of the biovation (biology-to-challenge) process, however, their resultant innovations or inventions show mixed results in terms of applying the abstraction of strategies from Nature, and tend to be more orientated towards biomorphic design and bioutilization (see Annex 3 for examples).

Specific Objective 2: Provide STEM learning that develops the competences of pupils to be confident learners, creative thinkers and adept at solving problems.

The exemplars have proven very valuable in increasing the ability of pupils to link their science learning with everyday life. Teachers support this, and agree that the exemplars offer excellent interdisciplinary STEM learning resources. As a result, it is clear that pupils have increased creativity and confidence to understand how STEM learning can help them solve problems.

Specific Objective 3: Provide support for teachers to integrate STEM subjects with biomimicry.

A key success of the BLF learning resources is their interdisciplinary nature. Teachers have been able to link learning resources with a wide range of subjects that go beyond STEM to include the arts and language. Teachers report positively that the learning resources link with the needs of pupils, however the sustainability aspects could be better illustrated.

Specific Objective 4: Provide learning resources for teachers to deliver sustainability and biomimicry learning.

Teachers are clear that the BLF learning resources, together with the training they have received, do strengthen teacher confidence and competence. The learning resources, particularly the exemplars, are of high quality and show clear links with biomimicry. As noted above, the sustainability aspect which is integrated into the learning resources is less clearly identifiable for teachers. The partners have been successful in attracting new teachers to biomimicry due to the quality of the learning resources provided.

The summary above, supported by the detailed analysis below, evidences that the approach taken by the BLF partners is both innovative and engaging. There has been considerable success achieved in introducing biomimicry to a primary school audience. The foundations for biomimicry learning have been strongly established with the exemplars developed.

Building on those foundations is the role of the Biomimicry Days; here there is still work to be done in making a learning 'jump' from content based to competence-based learning, especially where

abstract thinking skills are essential. Looking into the future, the competence and confidence of the teacher to facilitate competence-based learning is key. The challenge for biomimicry is increased given much of the content is new for teachers. With that said, teacher and pupil feedback clearly evidence the benefits of this approach to learning.

Given the strong push across Europe to move towards competence-based curricula, and the urgent need to address environmental challenges, BLF has a great deal to offer teachers, learners, and society at large. If the challenges outlined in this report can be addressed, then biomimicry can become an integral part of not just learning for a sustainable future, but a key part of STEM learning.

1. Context, Background and Challenges

The implementation of BLF took place over several phases with pilot schools. In the initial phase the exemplars where piloted, and in later phases the entire biovation (biology-to-design) process was introduced. Analysis and review of this work is covered below. It is important to assess the impact of BLF on teachers and pupils within the context of schools within each of the partner countries.

Curriculum reforms adopted last year in Slovakia has positively influenced schools' interest in BLF as it offers a new educational approach. These reforms support projects such as BLF which have less boundaries in terms of content and pedagogical approaches, allowing much greater freedom for both teachers and pupils. The timing for BLF was very good.

The Czech situation is somewhat different. Here, the curriculum is complicated and teachers complain of it always being in the process of change. Some teachers, frustrated with constant change, even refuse the new competence-based curriculum. For more ‘modern’ teachers the changes are welcomed more positively. The Czech partners, SEVER, also have time-based restrictions in September – November and April – June as this is the core period when schools visit their centre and staff do not have free time to conduct outreach programmes such as BLF.

A common situation across all partners is the curriculum deliver difference between primary and secondary schools. Within primary, most schools operate the one teacher one class model, making it simpler for a teacher to decide to bring in an inter-disciplinary learning approach such as that advocated by BLF. The subject specialist approach employed in most secondary schools mitigates against such inter-disciplinary approaches, making it much more challenging to for teachers to cooperation in project-based learning.

For several of the partners, sustainability week (Hungary) and Earth Day (all countries) provided opportunities for partner to promote BLF as a new and innovative way to engage pupils, offering something different, especially as many schools are looking for activities for these special events.

Hungary faces particular challenges. The climate for NGOs working within state institutions such as schools is very difficult. Access into the school system it tightly regulated with high levels of bureaucracy to gain permissions to work with external organisations. This discourages many schools from taking this route to support learning.

2. How was the project evaluated?

BLF was evaluated through the key four project objectives. For each, specific outcomes and indicators were developed, and evaluation mechanisms agreed (see Annex 1). This was achieved at the first Transnational Partner Meeting. At the same time, partners assessed their own personal success criteria and ambitions. Finally, a set of recommended evaluation tools was compiled (see Annex 2). The main evaluation mechanisms were post-delivery questionnaires for pupils and teachers, examples of pupil work, interviews with teachers, and session observations by BLF partners. In total, evaluation data was received from 489 pupils and 25 teachers across the four delivery countries.

Evaluation data was collected by partners and submitted to the UK partner for analysis. Additionally, each partner met with the UK partner to discuss the contextual factors of delivery in their country and assess the lessons learnt.

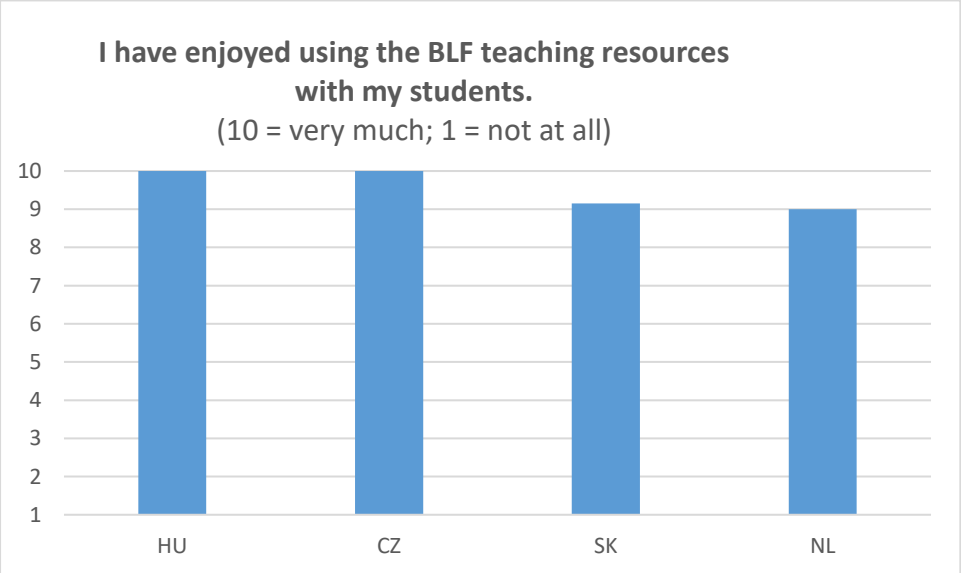
The final report was drafted and shared with partners to check factual accuracy, and allow for additional clarification and evidence to be presented, before finalising the report.

3. What is the impact on teachers?

Teachers are strongly supportive and value the BLF learning resources. They report good pupil engagement with learning and regard the quality of the learning resources as a key element in this. As with pupils, they struggled with the biovation activities, although those who has received training and support appeared to have managed better indicating a kye need to support teacher competence. It is difficult with a limited sample size to gain a clear picture of limiting factors, and a more longitudinal assessment of teacher competence in delivering biomimicry programmes will be extremely valuable in understanding, and over-coming, limiting factors.

3.1. Have teachers enjoyed using the BFL resources with their pupils?

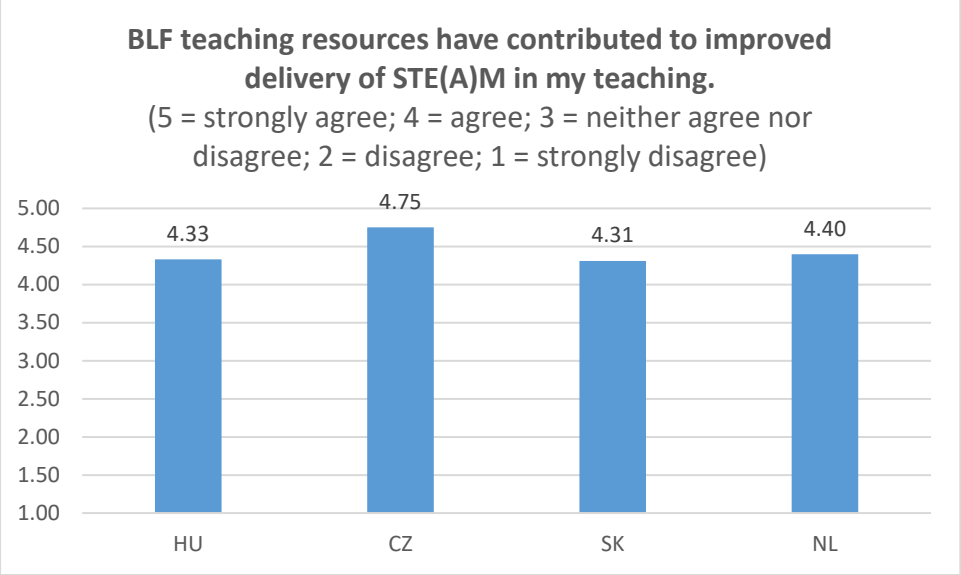
All teachers agree, they really enjoy using BLF resources.



(Average results by country based on 3 Hungarians 4 Czech, 13 Slovak and 5 Dutch teachers)

3.2. Have BLF resources contributed to the improved delivery of STE(A)M teaching?

Teachers are positive that BLF learning resources do improve the delivery of STE(A)M teaching.



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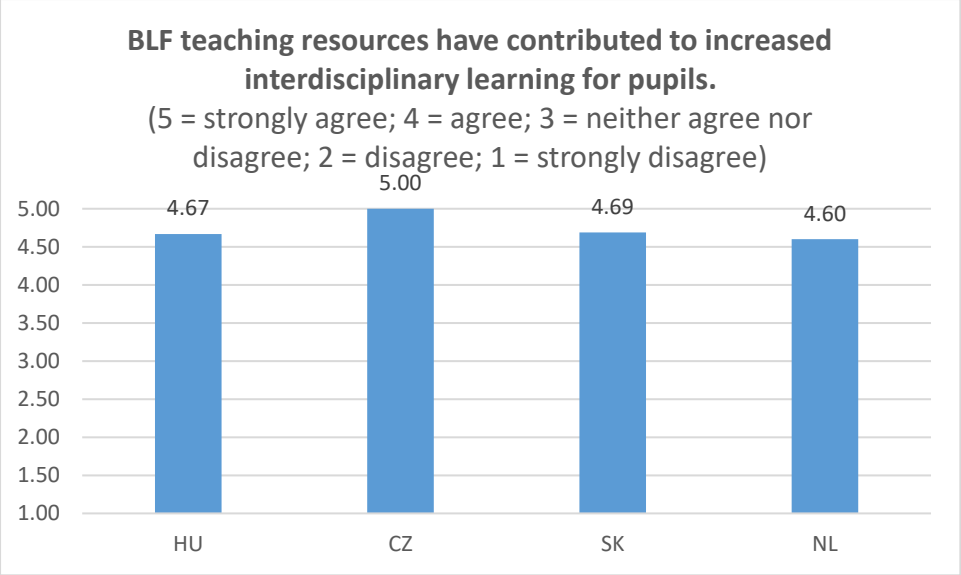
Teachers clearly felt that the materials made a positive contribution to their teaching, enabling them to bring in new perspectives to the STE(A)M teaching. They commented that:

- Although the STE(A)M cannot be interpreted in kindergarten, the BLF modules broaden children's relationship with Nature and the possibilities of environmental education. (Hungarian teacher)
- Children had possibility to see STEM subjects from different view. (Czech teacher)
- I liked that we could show the children the connection between Nature and human inventions. The children could try being a scientist themselves. To observe Nature with an eye that is not normally viewed. (Czech teacher)
- The materials highlight practical applications of theoretical topics in chemistry, especially biochemistry. The students are very interested in the practical application of what they are learning. (Slovak teacher)

3.3. Have BLF resources increased interdisciplinary teaching?

There is strong agreement that BLF resources increase interdisciplinary teaching. Teachers listed a range of subject areas supported by the BLF resources including: languages, maths, art, chemistry, physics, biology and technical education. They also listed interdisciplinary competences including presentation skills and higher-level thinking functions.



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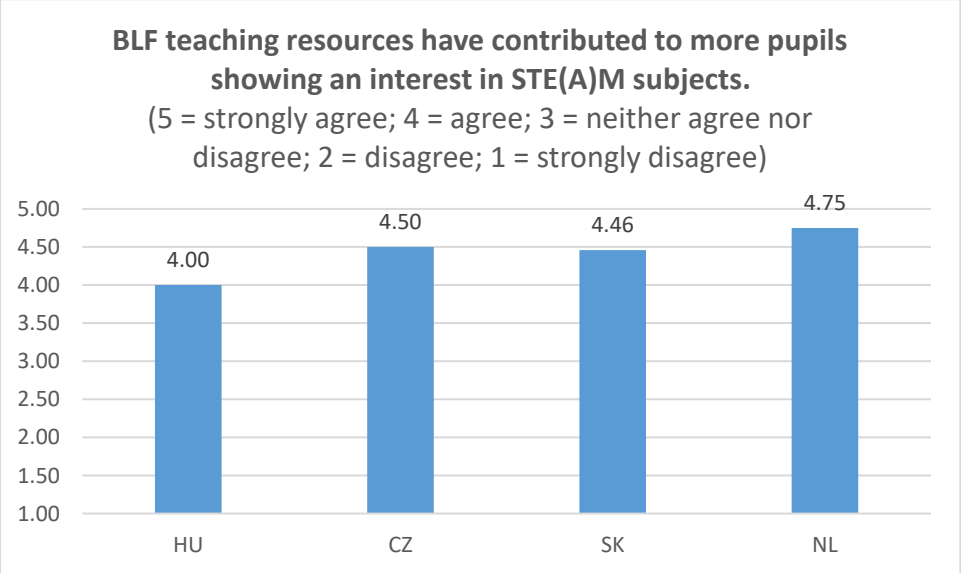
There is strong agreement that BLF resources increase interdisciplinary teaching, with teachers commenting that:

- "We connected primary education, mathematics, art education, Czech language, presentation skills and other skills. (Czech teacher)
- Children are challenged to use higher thinking functions. It's great that this is at the level of individual competences. (Dutch teacher)

3.4. Have BLF resources contributed to pupils showing a greater interest in STE(A)M subjects?

Here the results show a wider range of results, but all in the positive range. This is very encouraging given the wide-ranging factors that influence pupil subject preferences. Also worth noting, that the challenges discussed in 4.7 below did not appear to impact these results.



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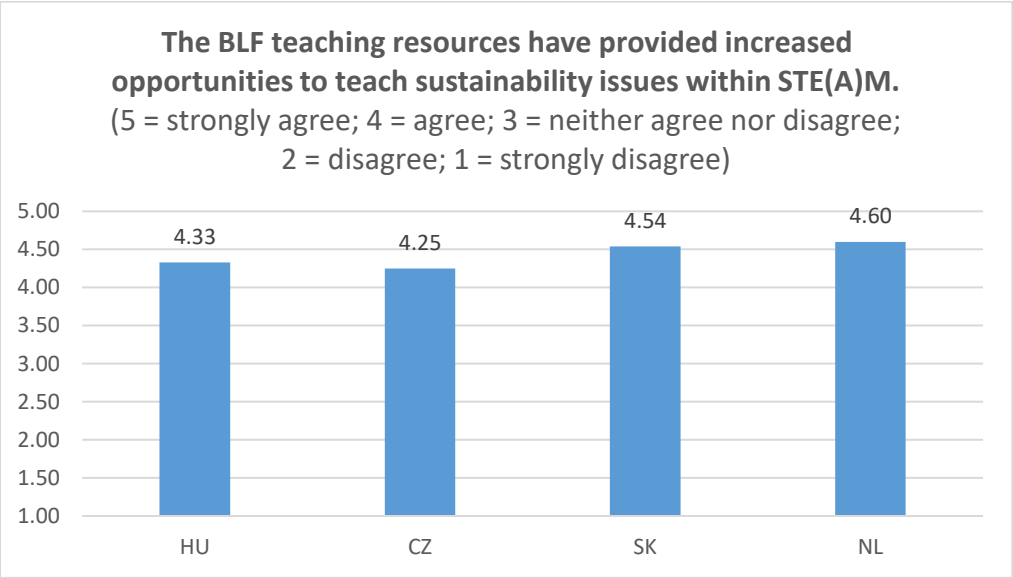
Teachers reported that:

- Pupils were very involved and enthusiastic. (Dutch teacher)
- I do not think children directly link this with STE(A)M. (Dutch teacher)
- Pupils are very excited about next year's biophilic design, which we are looking to run in collaboration with our art teacher. She is more than willing to do it. (Slovak teacher)
- My pupils were interested in science subjects before using BLF but it has encouraged the girls in particular. (Slovak teacher)

3.5. Have BLF resources provided increased opportunities to teach sustainability issues within STE(A)M?

These are positive results despite partners reporting that the links between biomimicry and sustainability were sometime not clear to many pupils (see 2.5 above), and that these needed more careful planning to ensure links were made.



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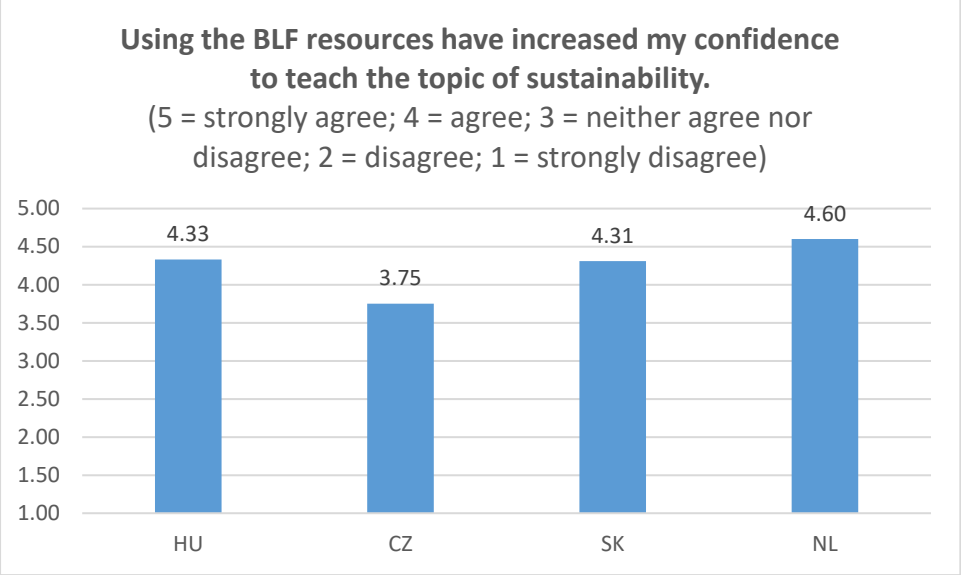
Teachers open responses to this question also indicated that the learning resources did not make clear links with sustainability in their view. That said, Slovak and Dutch teachers were more enthusiastic than the Hungarian and Czech teachers, commenting:

- Using biomimicry in the classroom is a great way to implement sustainability principles into the school environment. However, it is important to address this systematically, over a long period of time and across multiple subjects. (Slovak teacher)
- When studying and trying to apply biomimicry in the classroom, one starts to notice more the genius and at the same time the fragility of Nature, which makes me more concerned also in the classroom about the sustainability of our way of life and the search for possible and small solutions.
- Certainly, but then I would have to link it to a theme in the longer term. Wonderful starting point. (Dutch teacher)

3.6. Have using BLF resources increased teacher competence to teach sustainability?

With the positive comments on the learning resource, it is logical to expect an increase in teacher competency to teach sustainability, and the results bear this out.



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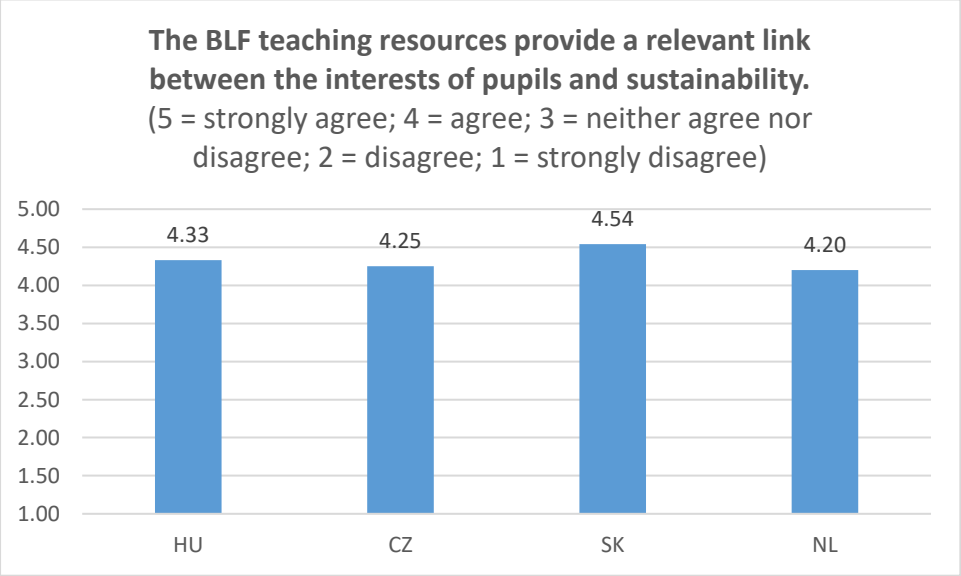
As a result of using BLF resources, teachers are more confident and competent to teach sustainability. That said, teachers are less able to explain why.

3.7. Do the BLF resources provide a relevant link between the interests of pupils and sustainability?

There is strong teacher support that the BLF learning resources link pupil interests with sustainability.



(Average results by country based on 3 Hungarians 4 Czech, 13 Slovak and 5 Dutch teachers)

Teachers commented that:

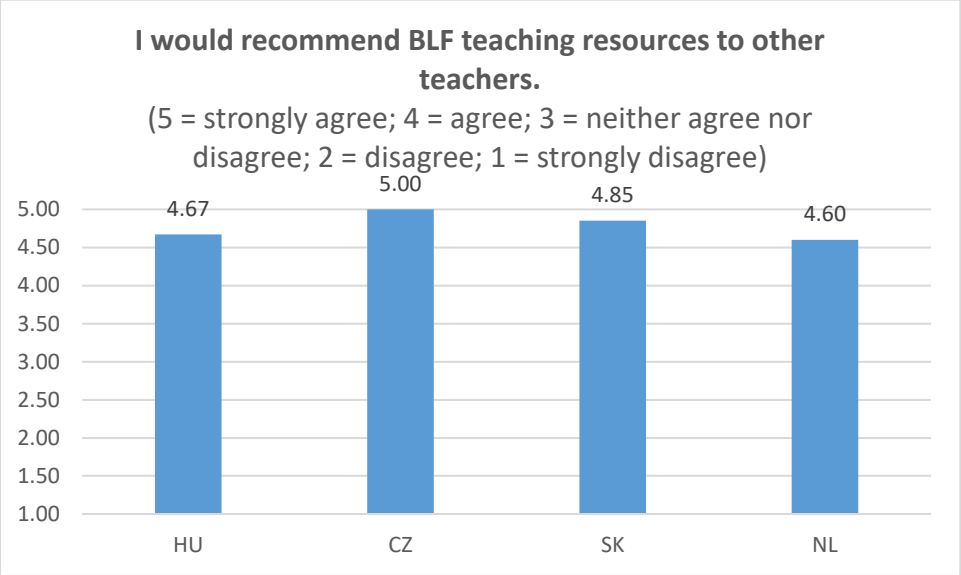
- The BLF modules require a different way of thinking, where children discover new possibilities for themselves, become more sensitive to environmental problems, which can

lead to good action. If the child realises that he or she can do something for a healthy, liveable environment, he or she may behave and act differently to maintain the status quo. (Hungarian teacher)

- Learning resources allow for a relatively high degree of flexibility of use and, to some extent, adaptation to the interests of the students. (Slovak teacher)
- Pupils become aware of the uniqueness and irreplaceability of each component of Nature, they can get to know it better, discover its many "wonders", get inspired, find solutions to problems that interest them - they become aware of the importance of protecting the environment. (Slovak teacher)

3.8. Would teachers recommend BLF resources to other teachers?

Teachers are very positive regarding the BLF resources and very confident to recommend them to other teachers.



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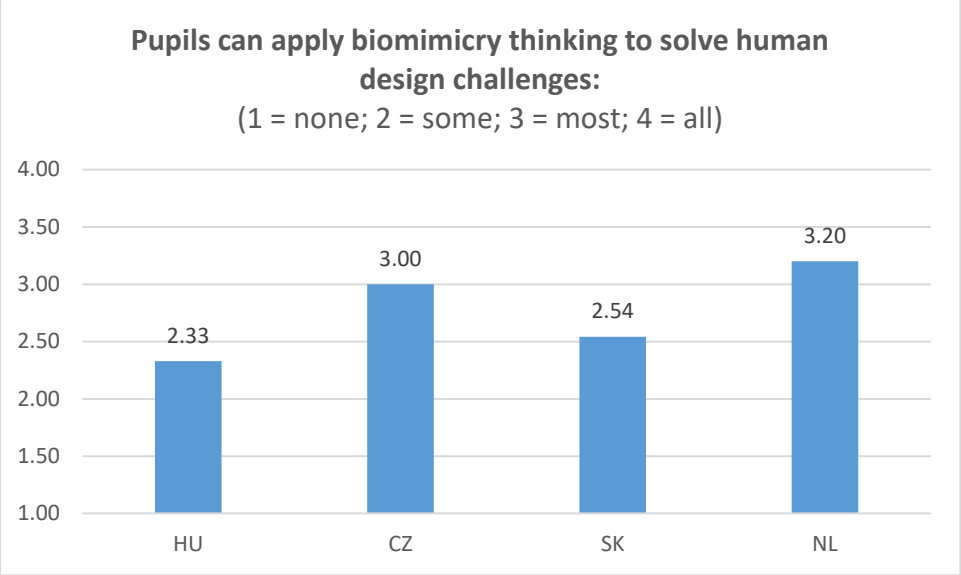
3.9. Do teachers think pupils can apply biomimicry thinking to solve human design challenges:

Teachers have mixed views on the competence of their pupils to apply biomimicry. Pupils clearly enjoy their learning and are engaged by the approach used in the BLF learning resources. That said, most pupil responses show good retention of knowledge taught to them but a rather poorer in terms of applying that learning to a new situation.



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Some reasons for this have already been discussed in 4.7 below. Teachers own experience of biomimicry will also influence these results. Partners observations indicate that teachers often fo und their experiences to be very positive, but it was less clear at times if teachers had sufficient understanding of biomimicry to evaluate how well pupils can apply biomimicry. As a consequence, there might be a tendency for teachers to over-evaluate the work of their pupils.

Teachers add that:

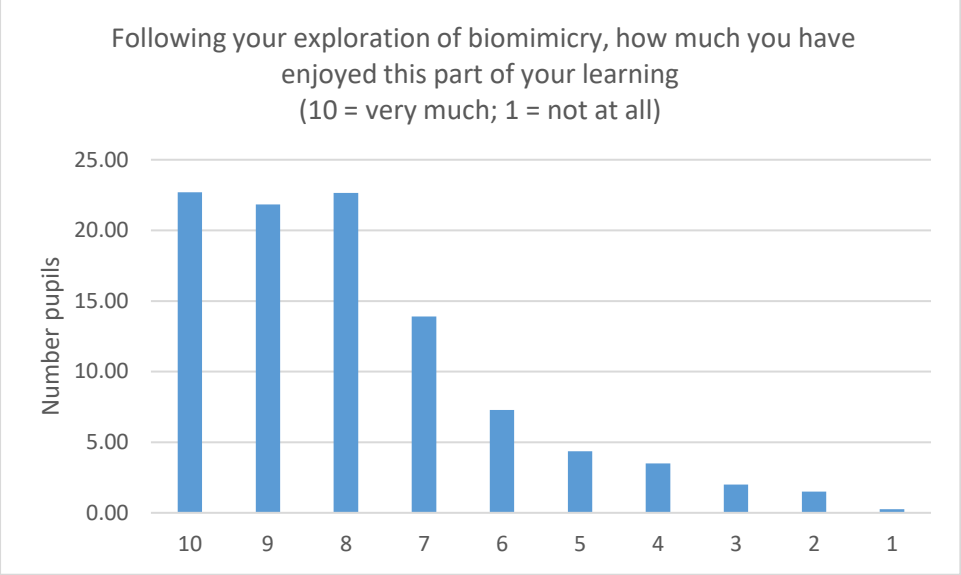
- It all depends on the extent to which it can be integrated either in teacher training or in curriculum development. How far we can make the modules and this kind of thinking broad. (Hungarian teacher)
- Not all pupils Such creative activities are challenging for pupils (and adults) and not just time consuming. But it was not a disaster the first time... If I include such activities more often, it will be better and better. (Slovak teacher)
- When designing innovations, a deeper interest, knowledge of different areas and especially creativity are needed, which I was not able to achieve with all pupils. (Slovak teacher)
- The children are young, but the vision is already fixed in their brains. (Dutch teacher)

4. What is the impact on students?

The overall impact on pupils is positive. They clearly enjoyed their biomimicry learning experiences and they are able to identify biomimicry examples which are of interest and relevance for them. As a result, there is a strongly positive influence on pupil interest in science subjects and in their ability to address sustainability challenges, although pupils are slightly less confident that biomimicry is providing ideas to become more sustainable. These very positive outcomes need to be compared with the portfolio of evidence presented by pupils in the forms of their biovation results. In this respect pupils generally struggled to generate 'new' biomimicry-based innovations or inventions, a point discussed in detail below.

4.1. Do pupils enjoy learning about biomimicry?

Pupils are clearly enjoying the lessons they participate in.



Evaluation data shows a high level of pupil enjoyment in their learning. This is mirrored across all the partner countries. In the Netherlands, 68% of pupils score their enjoyment as 8/10 or above, in Hungary it was 50%, in Czechia 89%, and in Slovakia 62%.

4.2. Can pupils identify examples of biomimicry and how they can help them?

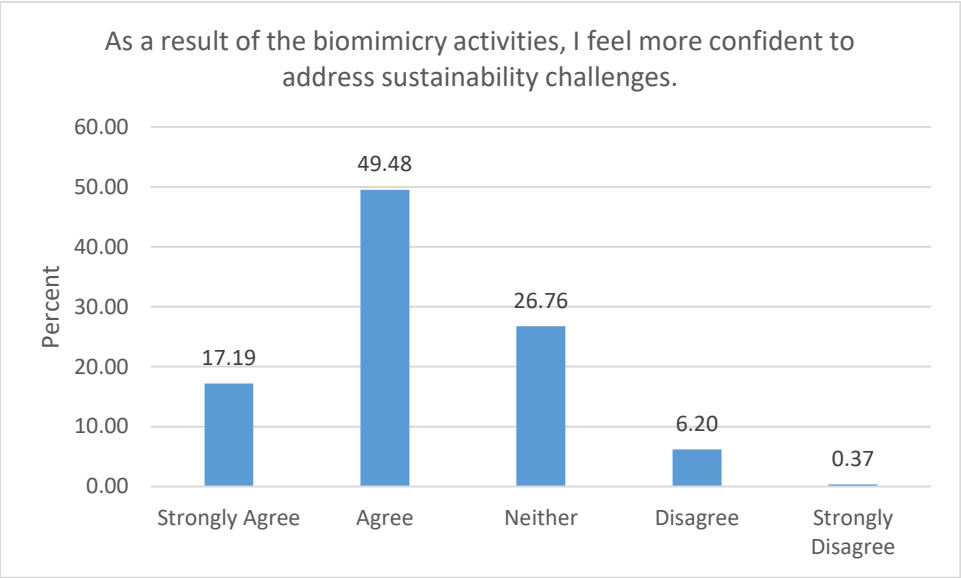
Pupils were asked to name one example of biomimicry they had learnt about. Almost without exception, all pupils were able to name one example. However, when asked how this example might be helpful for them pupils tended to struggle. For example, only 14% of Czech pupils could answer, 60% of Slovak pupils, 37% of Hungarian pupils and 24% of Dutch pupils. Some of the positive responses include:

- I was interested in animal fur, if you wrap your hand in bubble wrap (margarine, fat), the water will be warmer than without the wrap.
- I found out that the water striders can stay on the water level thanks to the molecules that are with each other. And it works like a pin.
- I learned what is hydrophobic and what is hydrophilic, I was interested in the flowing droplets.
- A water strider, for example, and a shoe we could use to walk on water.
- A pine cone - tilting automatic blinds according to the sun.
- The example of the egg surprised me the most. The example could help by making things or buildings that need strong protection.
- I am going to look how my waterproof things are made, and then look if the lotus plant is in it.

Hungarian pupils, however, struggled to answer this question and mostly could only repeat content from their lesson. This might be influenced by the younger age of some of the Hungarian pupils, however this was a common issue amongst all Hungarian pupils.

4.3. Do pupils feel more confidence to address sustainability challenges?

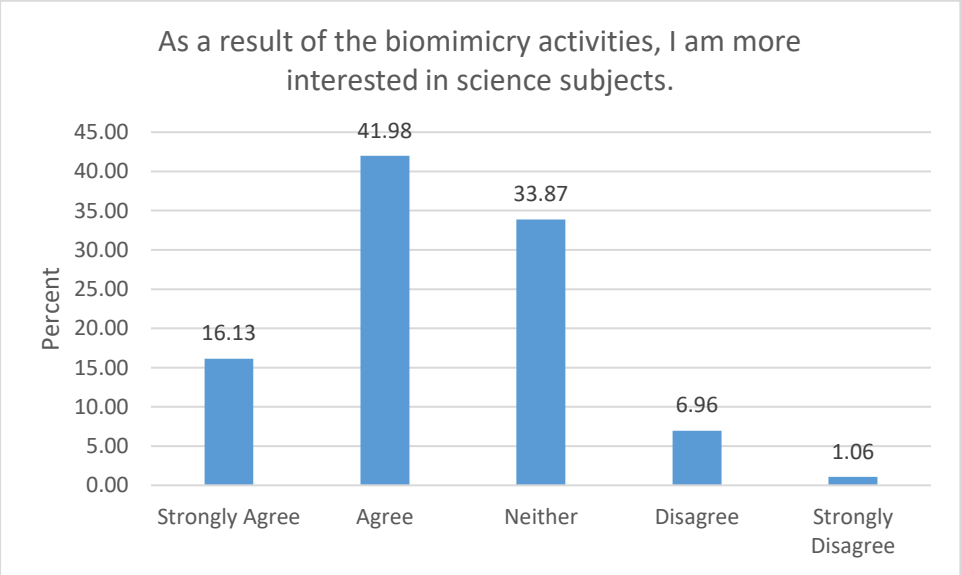
Over 2/3rd of the students felt confident about addressing sustainability challenges after the project.; an impressive result.



Again, the results are generally consistent across all the partners, with Dutch and Hungarian pupils showing the most positive results.

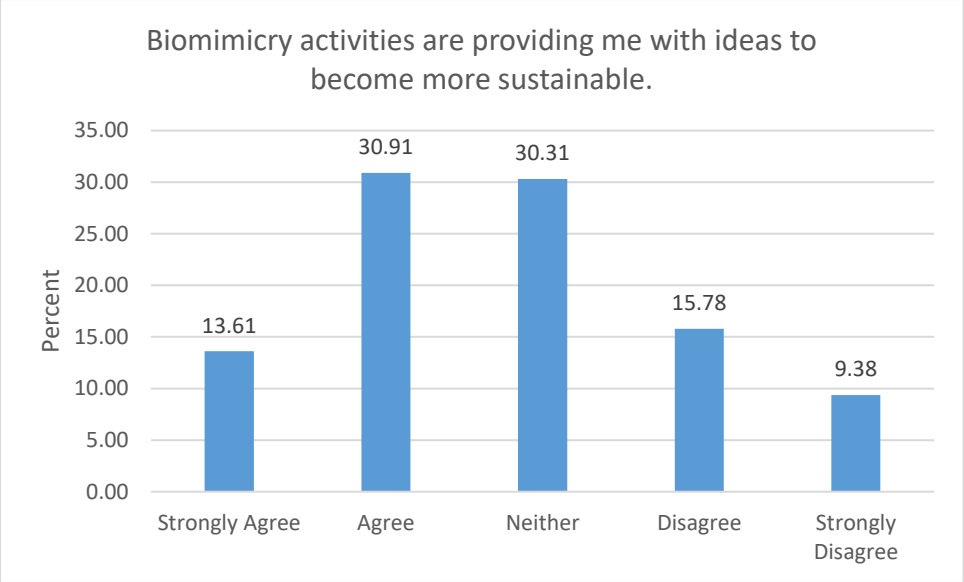
4.4. Are pupils more interested in science?

The BLF activities have a positive impact in interest in science, with over 65% expressing a positive impact. The results are consistent across all partner countries.



4.5. Biomimicry is providing ideas to become more sustainable?

Almost twice as many pupils (44%) agree that biomimicry helps them to have ideas to become more sustainable than disagree (24%).



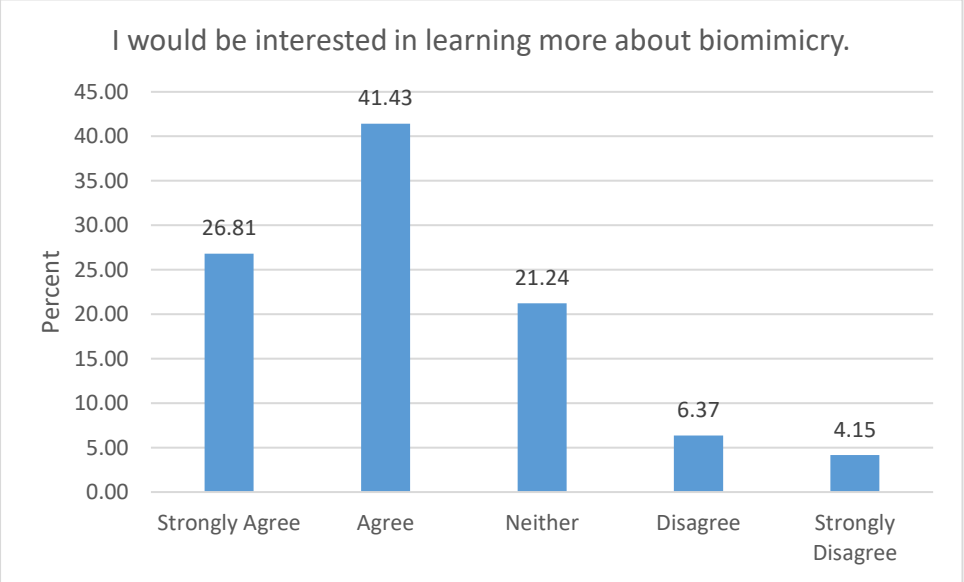
This question was followed by asking pupils to name an example of how biomimicry could help them become more sustainable. Here pupils struggled to provide biomimicry-based responses.

Slovak and Dutch pupils were able to provide examples, however, these mainly repeated ideas they were taught about within the lessons rather than applying their learning to a new idea. Hungarian pupils tended to provide 'traditional' responses including switching lights off, saving water and collecting rubbish. And Czech pupils generally struggled with this question.

Possible reasons for the pupils struggle to respond to this question are discussed in section 4.7 below.

4.6. Are pupils interested to learn more about biomimicry?

Not only did pupils enjoy their biomimicry lessons (see 2.1) but they also expressed a strong desire to engage in more biomimicry learning in the future; over 65% agreed.



4.7. Can pupils use a biomimicry design approach?

A key component of the BLF programme was a Biomimicry Day to be delivered at each school. The core element of the day was to complete a 'Biovation.' In essence, this was an invitation for pupils to explore a chosen natural artefact (plant, animal, or part thereof), and use that as inspiration to create a new innovation or product. In completing this task, pupils are guided through the stages of:

a) Finding a natural artefact of interest and producing a detailed drawing.
b) Identifying the different features of their natural artefact.
c) Understanding what each feature does for their natural artefact.
d) Asking how that feature might link with something we'd like to do in the human world.
e) Drawing a new product or innovation.

Detailed instructions, activities and lesson planner are provided via the BLF website.

Although pupils had little trouble understanding the different examples of biomimicry presented to them, and clearly enjoyed the style of hands-on learning, they generally struggled to turn their learning into new ideas based on biomimicry.

Reviewing a selection of the pupil biovations, generally none offered a clear example of a biology to design process. Either the biovations were very simple copies or it was not clear how the organism had inspired an innovation.

Observing this, teachers and delivery partners reviewed the biovation experience to identify potential causes and improvements which could be made.

Abstract thinking – the process of abstracting the way something works in Nature and applying it to a human product or innovation is challenging, and requires careful scaffolding for this age range. Reviewing the biovation ideas presented, it is unclear how well pupils were able to translate the features they identified on their natural artefact with something useful for the human world. A key reason for this might have been the clarity of instruction provided. Slovak partners, for example, noted that once teachers had received training and specific additional activities, they found teaching the biovation process far more effective.

Limited time and inadequate guidance materials – the lesson planner provided for the Biomimicry Day did not allocate sufficient time for the abstraction step. Given the importance of this step to the biovation process, more times needs to be allocated and additional guidance provided for teachers and pupils.

Choice of natural artefact – in most cases pupils were given freedom to select a natural artefact of interest to them. This did result in pupils choosing very challenging natural artefacts (in one case a stone). It would be useful to provide advice to teachers around choosing suitable artifacts. The freedom is good, but in the learning part less choice might be better. Some pupils changed artifact once they got started.

Teaching approaches – biovations require a teaching approach with a change in position of the teacher from someone who knows everything to someone who helps pupils along their learning journey. It is hard for some teachers to admit they do not know how to do the new style of teaching.

Teacher training – not all teachers leading the Biomimicry Day had received training beforehand. It will have been difficult, therefore, for them to understand the technical nuances of the biovation process.

Teacher feedback includes:

- Some kids were better at designing than others. Some had an idea right away, others couldn't even come up with something with a lot of help from me, or didn't like this part very much.
- Find a different way how to deliver the innovation part of the biomimicry day. This part, unfortunately, was a failure for us throughout the whole pilot testing and the biomimicry day.
- Fewer activities and more time to create innovations.

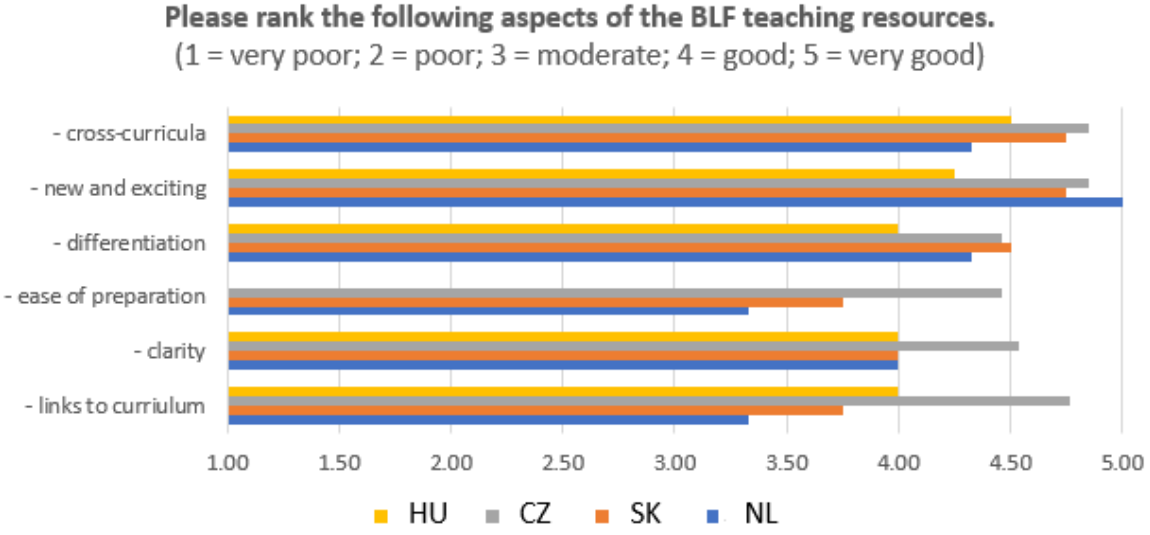
Despite these challenges, teachers were positive about the Biomimicry Days.

See Annex 3 for examples of pupil biovations.

5. Are learning resources of high quality?

Teachers were asked six questions relating to the structure and targeting of BLF learning resources. These were related to:

- Cross curricula – do the learning resources support interdisciplinary learning.
- New and exciting – do the learning resources provide an attractive and interesting package.
- Differentiation – can the learning resources be easily adapted for different age groups and learning needs.
- Ease of preparation – are the learning resources easy to prepare before teaching.
- Clarity – are the instructions provided easy to understand.
- Link to curriculum – are links with existing curricula subjects made clear.



(Average results by country based on 3 Hungarians 4 Czech, 13 Slovak and 5 Dutch teachers)

Cross curricula – most teachers agreed that the resources provided good cross-curricula learning opportunities. Teachers listed a wide range of subjects that the learning resources brought together including sciences, arts and language. For example, one Czech teacher commented that “We connected primary education, mathematics, art education, Czech language, presentation skills and other skills” and a Slovak teacher added that “Thanks to cross-curricular relationships, pupils understand more of the content of science subjects.”

New and exciting – all teachers agreed that the learning resources met this challenge. One Czech teacher commented that “It was something innovative, I didn´t met before”, a Slovak teacher said “I am extremely happy with the BLF resources. They help me a lot” and a Dutch teacher commented that “If it was up to me, biomimicry should be a permanent part of every school.”

Differentiation – all teachers strongly agreed that the resources were simple to differentiate for different learning needs. One Slovak teacher noted the benefits for girls in particular “My pupils were interested in science subjects before using BLF but it has encouraged the girls in particular.”

Ease of preparation – teachers did not encounter significant difficulties with preparation, although perhaps given the new nature of the activities and materials preparation was more time consuming than with more commonly used activities.

Clarity – teachers clearly agreed that the resources are well written and easy to understand. One Slovak teacher wrote “The activities are complemented by high-quality professional support material from various fields - especially natural sciences” and a Dutch teacher added that “The great thing is that it is also very concrete.”

Links to curriculum – teachers had no difficulty finding curriculum links to the learning resources, although it should be noted that most teachers delivered learning outside of specific curriculum specifications.

6. Lessons Learnt

Partners were asked to reflect on the lessons they had learnt from the project: how they improved implementation during the project and what priorities have emerged going forward.

Biomimicry Days / Biovation

Schools often combined the use of the exemplars with the biovations. Clearly the exemplars worked well. They were clear and well written learning activities, do much so that older pupils could be tasked with leading activities for younger pupils.

The biovation process was far more challenging. The time allocated to carry out the process was far too short and needed to be spread out over several lesson periods. Ideally, teacher support needs to check pupil progress at each stage, ensuring tasks are completed to a good standard before progressing to the next stage. Without these learning checks, it is relatively easy for pupils to lose the direction of the process and end up with challenges when they come to the innovation stages.

There is some evidence from the piloting that some pupils struggled with the biovation process as a result of the general didactic style of teaching they were used to. Biovation is a very hands-on and inquiry-based approach to learning, and best suited pupils who were used to a high degree of autonomy in their learning and less reliant on teacher answers.

To overcome these challenges, clearer guidance is needed on the biovation process, particularly highlighted where the challenges lie and where teachers need to intervene. This needs to be supported by more examples of 'good' and 'bad' biovations to clarify the tasks for both teachers and pupils.

Another tip that emerged from piloting was that when pupils worked with unfamiliar species, they were more likely to find valuable learning. This perhaps relates to avoiding pre-conceived ideas. Partners also noted that some species choices are really difficult to work with during the biovation process. It would be easier for teachers to work with a list of recommended species, at least when working with biovation for the first time. Partners could provide more detailed support for the recommended list, and teachers would be more confident that pupils will reach satisfying results.

Finally, teachers should be encouraged to access additional supporting resources. In the describing features stage, some schools used tablets to help pupils fill in knowledge gaps and this proved to be beneficial.

Teacher Training

Where teachers attended training days, and online support, offered by the partners, they generally found the biovation process easier and found better results. Biomimicry is a new way of teaching for many teachers and involves new and unfamiliar content. Teachers are also busy people. Specific time allocated together the experts to learn about biomimicry and the BLF learning resources appears critical. Further development of teacher training resources seems to be a critical step to embed high-quality biomimicry into school learning. Partners need to consider innovative ways to deliver this to busy teachers so they can try biomimicry for themselves before teaching their pupils.

Expanded Learning Resources

As highlighted above, the biovation process requires more detailed resources. The Slovak team created card sets illustrating six different examples of how biomimicry progresses from learning about a particular species, understanding how it provides different functions or services, and how these can be abstracted and used for human design solutions. Creating and using these card sets was a real 'aha' moment for the Slovak team, and they report the card sets being a valuable resource to aid teacher and pupil understanding as well. The card sets also made a link with sustainability, which was otherwise largely absent from the learning resources.

The Czech team made use of video resources which were successful in engaging teachers. With reference to some of the challenges noted above, more use could have been made of video resources to demonstrate good examples of biomimicry and biovation. It is noted that this was not a planned output of the project, and providing high quality video resources requires time and professional support.

External Experts

At least two partners used external experts to supplement teaching. This provides an additional support for teachers and perhaps excitement for the pupils. Teachers and pupils certainly appreciate the additional information external experts can provide. However, this needs to be tempered with the additional cost and time required to bring external experts into the classroom.

Sustainability

This is an area which could be stronger within the project and more clearly defined. Where pupils did offer sustainability ideas, they tended to be based on 'traditional' responses including switching lights off, saving water and collecting rubbish. It seems clear that pupils were no seeing biomimicry as a new and different approach to sustainability, and more work needs to be done to make this element visible within the learning resources.

Equipment

Partners created toolboxes to support delivery. Including basic fieldwork equipment such as hand-lenses and collection pots will help pupils explore the different organisms they find and examine them closely.

7. Conclusion and Recommendations

BLF has only completed restricted piloting to date, so the evidence of impact on teachers and pupils is limited. That said, feedback received to date suggests that biomimicry is an attractive subject for teachers and supports greater pupil engagement in sustainability and science topics.

It is clear from the results that teachers find this approach both exciting and relevant. There is almost universal agreement from teachers on this. There is also clear support amongst teachers that the BLF project strongly supports STE(A)M and interdisciplinary learning, within a particular focus of sustainability. Teachers strongly praise the quality of the BLF learning resources, and these are clearly a lasting legacy of the project.

For pupils, again they clearly enjoy the learning opportunities provided and feel more interested in science subjects as a result. There is good evidence to suggest that pupils recognise the relevance of biomimicry to creating a sustainable future, and the biomimicry design process as a way to achieve this.

Recommendations:

1. **Community of Practice:** Teachers are the foundation of success and developing strong communities of practice will take biomimicry more and more into mainstream education. Classroom practice offers both the best feedback for improving on the BLF learning resources, and the best route for teachers to be advocate to other teachers. If biomimicry is to make a more significant impact in mainstream education, then a clear focus on professional teacher competence and support networks will be critical. Finding innovative ways to support teachers in this endeavour is critical given the huge time pressures most teachers are under.

2. **Subject Links:** Develop closer links to subject specifications to support an increased use of biomimicry within core timetabled curriculum time. This will build increased confidence in biomimicry as an approach and content which enriches the core curriculum, not just as an 'exciting' one-off event.

3. **Pedagogy Development:** More testing of the biology-to-design process and additional resources to support teacher delivery and pupil implementation; this should include better examples of good biomimicry innovation based on age/ability, and clarity between biomimicry and other Nature-inspired design approaches.

4. **Involve More Subjects:** Do not limit biomimicry to STEM subjects; involve the arts to increase ability of pupils to visually represent their ideas.

5. **Value the Baby Steps:** Do not expect the project to deliver genius kids who do great biomimicry; focus on the baby steps that we can see rather than setting unrealistic expectations e.g. a little bit more seeing Nature as a source of inspiration; seeing that Nature can provide opportunities; etc. Focus on the competences developed along the way rather than the final output; focus on what the pupils have gained through the project rather than the end product.

If these recommendations can be delivered, then biomimicry might deliver the vision of one Slovak teacher:

"Using biomimicry in the classroom is a great way to implement sustainability principles into the school environment. However, it is important to address this systematically, over a long period of time and across multiple subjects."

Annex 1 – evaluation indicators

BLF Objective	Specific Outcomes	Indicators
Specific Objective 1: Develop the competence of pupils to learn from Nature and apply biomimicry to understand sustainability challenges.	1. Enhanced STEM content enriched with biomimicry, connected with real-world issues of concern to pupils. 2. Pupils connecting their core knowledge and skills with pathways to influence change. 3. Increased motivation and capability of pupils to take action to address sustainability challenges.	1. Increases in ability of pupils to relate STEM theory to practical applications. 2. Increases in competence of pupils to apply biomimicry to sustainability challenges. 3. Changes in student motivation and willingness to address sustainability issues.
Specific Objective 2: Provide STEM learning that develops the competences of pupils to be confident learners, creative thinkers and adept at solving problems.	1. Increased ability of pupils to link the principles of science to everyday life. 2. Better understanding of the role of science in supporting the development of a healthy environment.	1. Increases in ability of pupils to connect learning with real-world problem solving. 2. Increases in ability of pupils to apply observation skills and creativity towards problem-solving. 3. Number of pupils expressing increased confidence to think creatively and address sustainability challenges.
Specific Objective 3: Provide support for teachers to integrate STEM subjects with biomimicry.	1. Increased relevance of STEM teaching to sustainability challenges facing Europe. 2. More effective interdisciplinary teaching. 3. Teaching and learning linked with the real needs of pupils and a sustainable society.	1. Increased relevance of STEM teaching to sustainability challenges facing Europe. 2. More effective interdisciplinary teaching. 3. Teaching and learning linked with the real needs of pupils and a sustainable society.
Specific Objective 4: Provide learning resources for teachers to deliver sustainability and biomimicry learning.	1. Strengthened confidence of teachers to deliver inspiring STEM lessons that relate to the everyday lives of their pupils and to developing a healthy environment. 2. Open and flexible Open Education Resources enabling pupils tointeract with their local environment through inquiry-based learning.	1. Published learning resources integrating STEM and sustainability. 2. Number of new learning tools and uptake by teachers and pupils. 3. Number of teachers able to effectively use new learning resources within education.

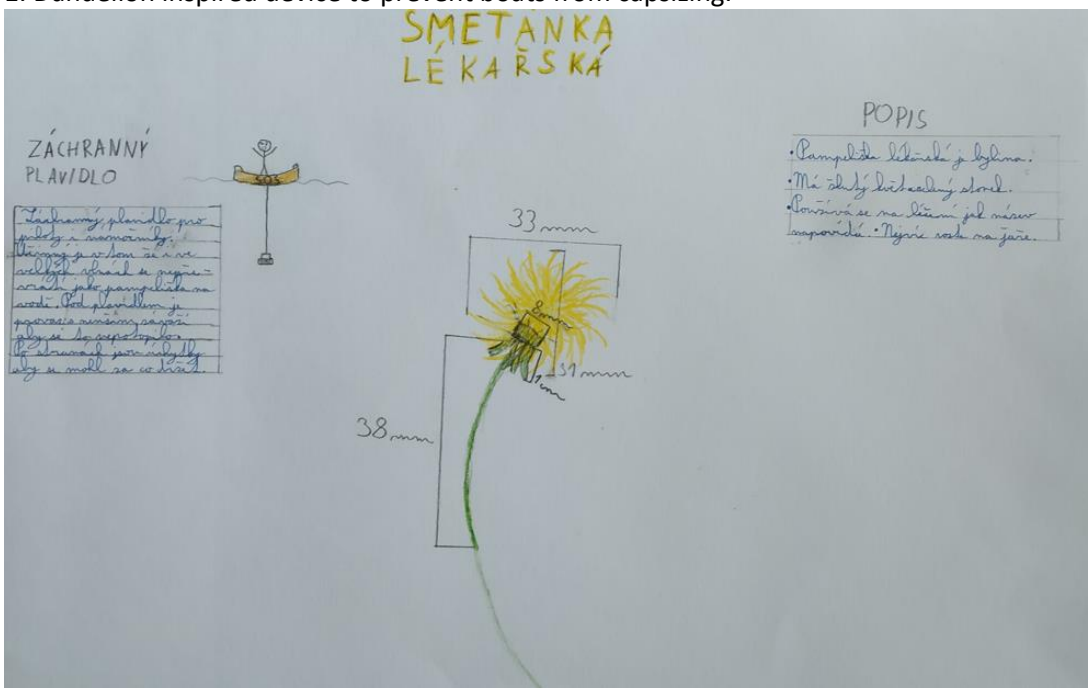
Annex 2 – recommended evaluation tools

Evaluative Mechanism / Evidence	Details
Likert Survey for Students (SO 1 & 2)	Surveys to include questions based on indicators above. Delivered using google forms/ survey monkey (or paper forms if more appropriate).
Likert Survey for Teachers (SO 3 & 4)	
Led School Assessment Visit	Interactive session with pupils based on set questions to elicit pupil feedback.
Website data (SO 4)	Extracting website metrics – downloads and visitor numbers, as well as number of online modules / resources.
Curriculum linkage table (SO 3 & 4)	Basic table cross referencing BLF resources with broad STEAM curriculum areas. The final table will demonstrate what connects with the curriculum and what acts as supplementary material/learning.
Student portfolio (SO 1 & 2)	Best-practice outcomes of use of resources.
Teacher Testimonials (All SO's)	Informal and formal testimonials from teachers.
Partner Questionnaire – assessing partner impact	Annual questionnaire focused on partner (personnel and organisation) development.
Partner Questionnaire – monitoring project delivery	Annual questionnaire focused on partner evaluation of project delivery, processes, challenges and teamwork.

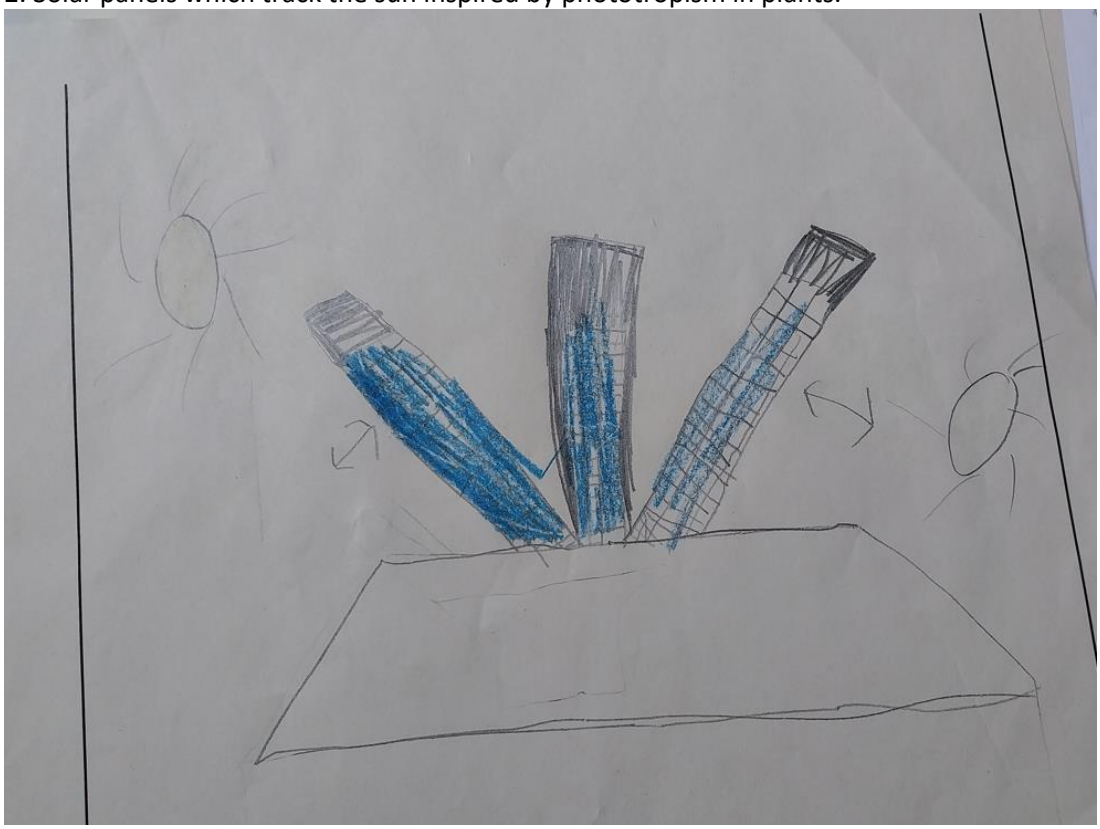
Annex 3 – examples of pupil biovations

<u>Biomimicry examples</u>

1. Dandelion inspired device to prevent boats from capsizing.

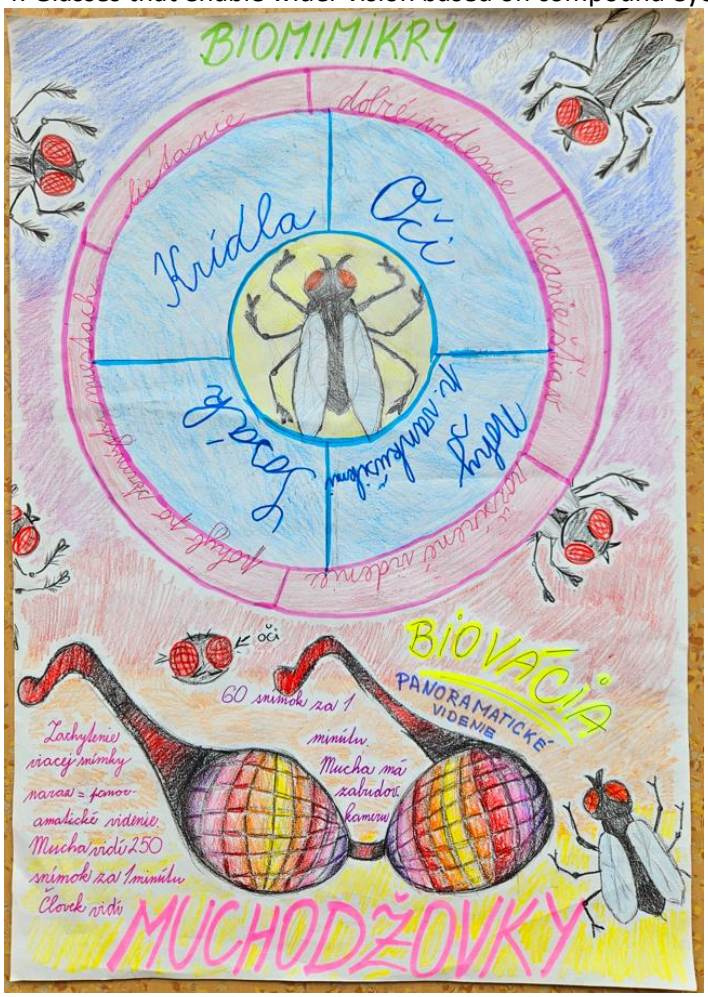


2. Solar panels which track the sun inspired by phototropism in plants.



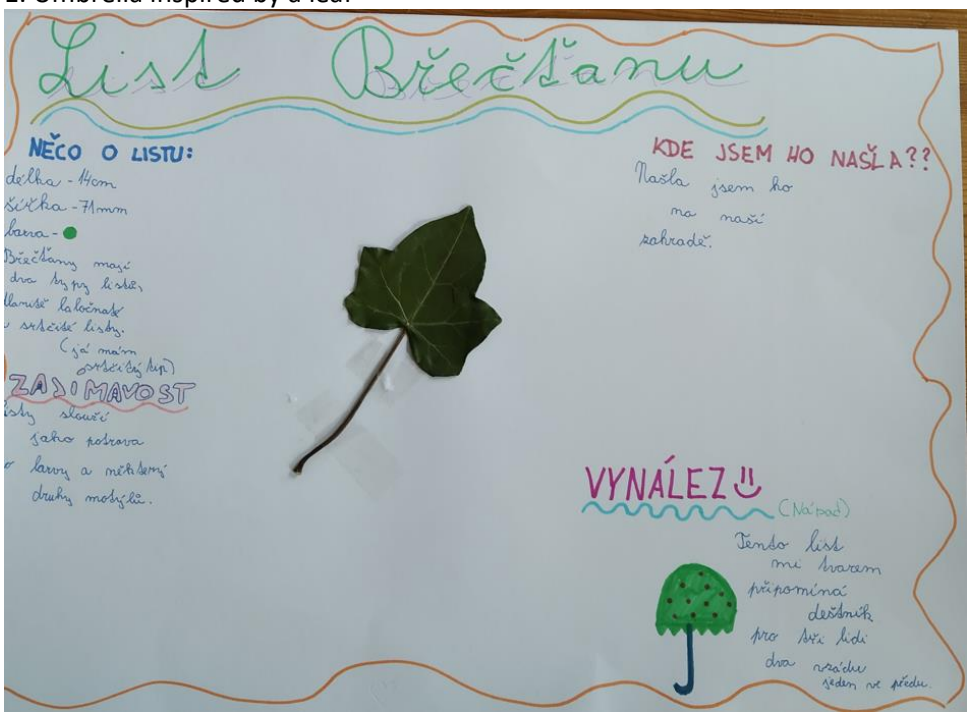
3. Tool for drilling holes in soil inspired by snails.

4. Glasses that enable wider vision based on compound eyes in insects.

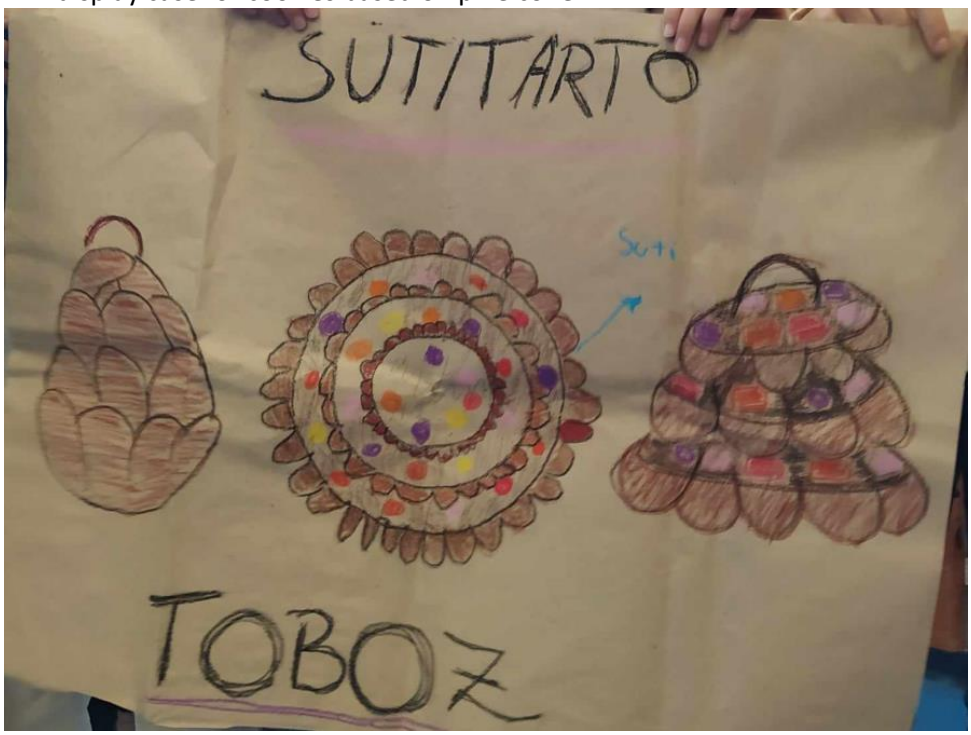


Biomorphism examples

1. Umbrella inspired by a leaf

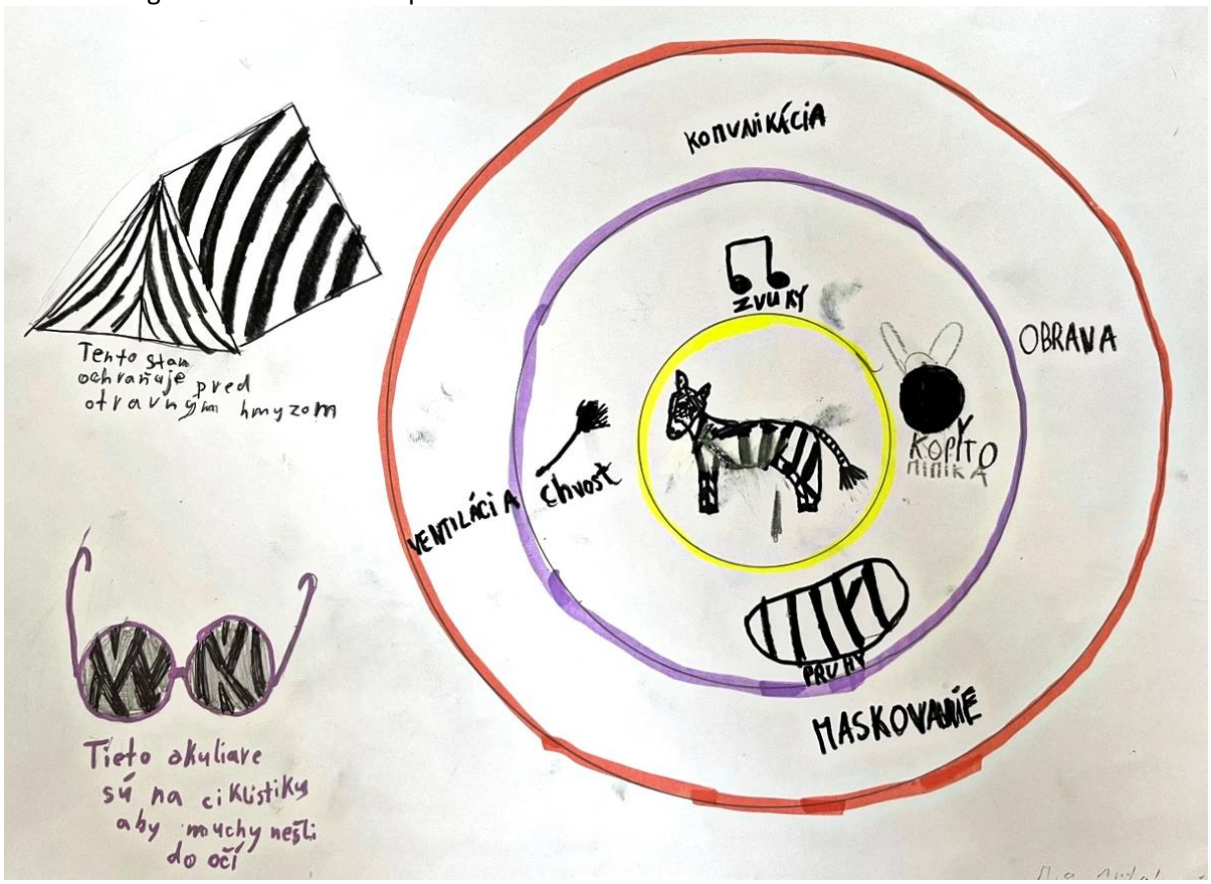


2. A display case for cookies based on pine cone.



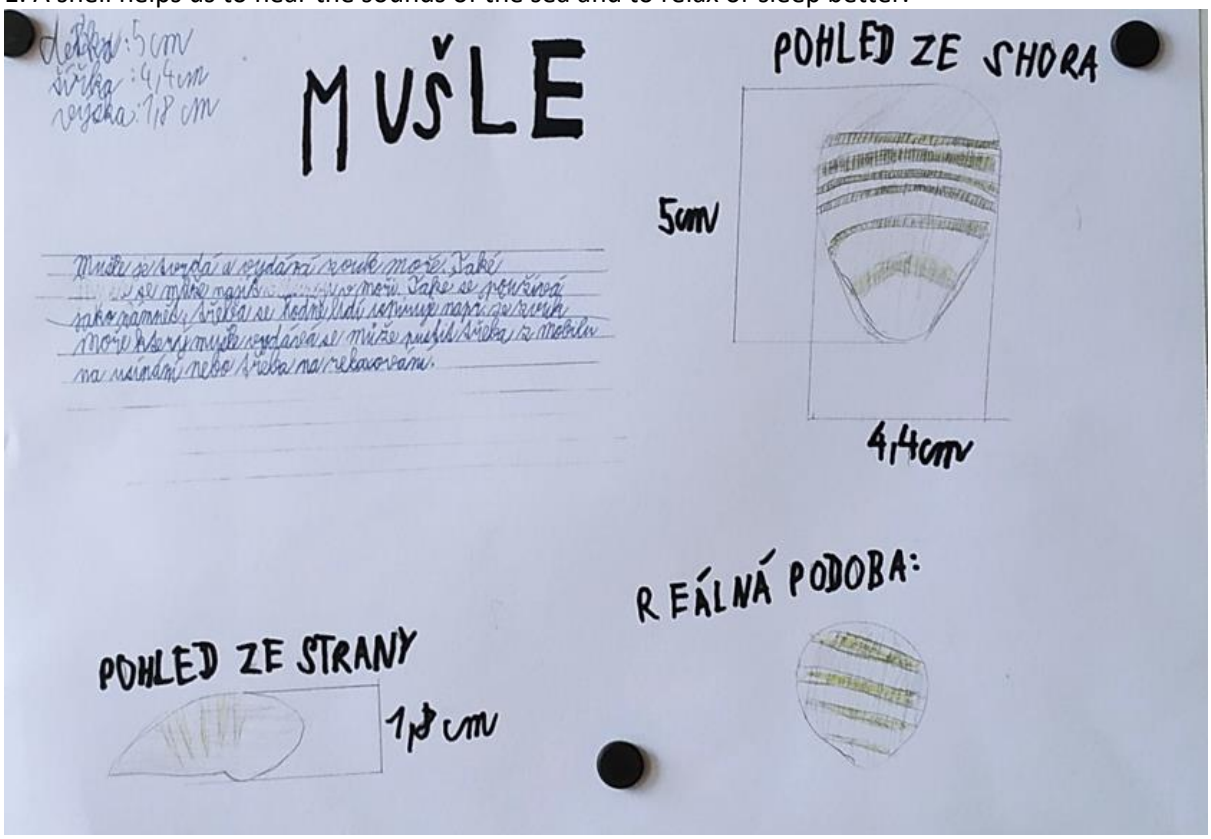
3. A crib based on a seed shell shape.

4. Camouflage based on zebra stripes.



Bioutilization examples

1. A shell helps us to hear the sounds of the sea and to relax or sleep better.



Annex 4 – BLF Learning Framework Reflections

Is a biomimicry thinking process clearly present?	
Key elements	*Are they present? (yes, no, maybe)*
Do activities connect learners with Nature?	Yes, both the exemplars and Biomimicry Days directly encourage pupils to learn from Nature through direct experience.
Do activities encourage close observation of Nature? (first-hand, images, video)	Yes, both the exemplars and Biomimicry Days directly encourage pupils to closely observe Nature and pay attention to details.
Do activities reveal Nature's talents and abilities? (function - strategy)	Yes, the exemplars are clearly successful in achieving this. It is less clear from evaluation evidence the depth to which pupils understand how organisms deliver function and strategy; there is little evidence that pupils can do this for themselves.
Do activities provide connection between biological models and human design?	Yes, the exemplars are successful in achieving this and pupils can easily recall information they have learnt from the exemplars.
Do activities provide opportunities to research or learn about natural examples?	Yes, the Biomimicry Day process clearly encourages these, however, it is less clear how much this has actually been taken up by teachers and pupil work shows limited research has taken place. There are notable exceptions where pupils have been specifically directed to carry out research.
Do learning activities provide opportunities to create human designs based on Nature?	Yes, the Biomimicry Day process offers this opportunity. The evidence presented from piloting, however, suggest the quality of human designs resulting is below expectations (see point 4.7 for a further discussion on this).
Do activities provide opportunity to reflect on and improve 'design' ideas?	Yes, these opportunities are present but again there is little evidence that this took place in practice.
Do activities stimulate awe, wonder and respect for/about/in Nature?	Yes, pupils are clearly excited by their learning.
Are biomimicry principles explored?	This is unclear as no set of agreed biomimicry principles was integrated across the project. Whereas there are biomimicry principles engrained with the learning resources, they are not clearly presented. The learning activities do offer a 'Biomimicry Connection' statement for each learning activity.

Does content support STEM and sustainability learning?	
Key elements	*Are they present? (yes, no, maybe)*
Does content encourage recognition that humans are a part of Nature?	Maybe, this is rather implicit than explicit in many of the resources and there is no evaluation evidence to support this.
Does content provide a relatable sustainability challenge?	Yes, the exemplars all contain relatable content relevant to the age-range of the learners.
Is content strongly connected with a range of STE(A)M subjects?	Yes, teachers strongly agree.

Can content be differentiated for pupil ability?	Yes, content can be differentiated and teachers agree.

Do teaching and learning approaches encourage engagement, exploration, explanation, elaboration and evaluation?	
Key elements	*Are they present? (yes, no, maybe)*
Engagement: ○ Is it hands-on? ○ Is the outdoors/natural world used for learning? ○ Is it inter-disciplinary? ○ Is it something pupils care about? ○ Are learners engaged in a topic of interest?	A strong yes to all elements. Teacher evaluation strongly support all statements.
Exploration: ○ Do learners elicit information and create ideas for themselves? ○ Are hands-on and minds-on learning used?	Maybe, results of pupil biovations are generally 'weak' and do not show clear links between exploring how Nature does things and applying this to creating human designs. Whereas pupils do elicit information for themselves, there is less evidence they can use this information effectively for biomimicry.
Explain: ○ Can learners share their findings with others? ○ Can learners demonstrate understanding? ○ Can learners discover relationships between content?	Maybe, most pupils are able to share their ideas through visual and verbal presentations, and in doing so demonstrate their understanding of content. There is limited evidence that pupils can discover relationships between content e.g. between the abilities or an organism and human design.
Elaboration: ○ Can learners put ideas into practice? ○ Can learners apply their learning?	No, this was not piloted within the project.
Evaluation: ○ Do learners reflect on their work? ○ Can they learn from 'mistakes'?	No, there is no classroom evidence that this took place as a part of learning.

Do learning outcomes address each element?	
Key elements	*Are they present? (yes, no, maybe)*
Observation – the ability to observe the natural (including humans) world closely and identify how it works.	Yes, this is clearly present in the BLF learning resources and in classroom evaluation of delivery.
Curiosity – the ability to ask questions about the natural world, and to describe and draw it accurately.	Yes, pupil drawing at times show a very high level of competence.
Problem solving – the ability to compare, explain, categorise and analyse in order to understand an issue and find solutions.	No, there is very limited evidence that pupils can use learning from their studies of different organisms to address problems and find solutions (see 4.7 for a wider discussion on this).

Questioning – the ability to decide, prioritise, justify.	No, this appears to have not been assessed.
Creativity – the ability to imagine, plan, design and relate (to something new).	Maybe, there are good examples of pupil creativity with regard to new ideas, however, they are limited in number.
Connecting – the ability to relate content matter to personal interest, and to wider sustainability of natural systems which include humans.	No, whereas common examples of actions for sustainability are easily elicited from pupils, there is very little evidence to suggest new thinking in terms of the sustainability of natural systems.