Biomimicry: A Transdisciplinary Approach for Human Computer Interaction

Catharina van den Driesche[1][0000-0003-0759-7973], Åsa Cajander[2][0000-0001-7472-2215] and Shweta Premanandan [2][0000-0003-0732-7009]

[1] University of Amsterdam: Amsterdam, NL and Independent Researcher
[2] Department of Information Technology, Uppsala University, Uppsala, Sweden
c.j.h.m.vandendriesche@uva.nl

Abstract. Biomimicry, the method of emulating nature's functions, strategies, and systems, offers a transformative perspective for designing intuitive, sustainable, and regenerative Human-Computer Interaction (HCI) systems. The complexity of human-computer interactions, particularly within domains such as augmented reality (AR), virtual reality (VR), and wearable technology, demands interfaces and interactions that are not only intuitive but also transparently integrated into users' environments. Beyond this, when HCI is situated within the context of global challenges, like climate change and biodiversity loss, design approaches need to engage understanding of nonhuman needs and perspectives to ensure that solutions are not only human-centered but also aligned with ecological sustainability. Biomimicry, as a transdisciplinary methodology, offers an approach for knowledge transfer by blending human and nonhuman perspectives. The mimicry of functions, strategies, and systems found in nature enables to integrate theoretical knowledge with practical, actionable applications for interaction design. Furthermore, by co-developing theoretical perspectives on design methodologies with industry partners, it becomes possible to align the biomimicry process with design strategies and company roadmaps, leading to the creation of responsible designs that mitigate unintended consequences on ecosystems. This paper synthesises insights from two workshops held at Uppsala University in 2023 and 2024, which explored biomimicry's potential to address emerging challenges in HCI by examining the shift from screen-based to immersive scene-based interaction, integrating human and nonhuman perspectives to inspire new collaborative approaches and partnerships for more-than-human participatory design.

Keywords: Biomimicry, More-Than-Human Design, Transdisciplinary Approach, Human-Computer Interaction, Collaborative Design, Analogical Thinking

1 Introduction

Biomimicry, or biometrics, is the imitation of functions, strategies, and systems, found in nature for solving complex problems [20,3] The problem-driven approach in biomimetic development (i.e., a design 'pull process') focuses on addressing a specific practical human problem, using the identified issue as the starting point for the design process [16]. It involves finding biological models that perform a particular function or strategies, extracting their underlying principles, and applying them to technological solutions [20,16]. This approach aligns closely with the iterative design process, which consists of the stages: discover, explore, ideate, develop, and evaluate.

While biomimicry aims to replicate the natural world's life principles [14] to create more intuitive, regenerative, and sustainable technologies, interaction design focuses on how people interact with technology. By drawing inspiration from nature, considering how nature interacts with its environment, designers can create more natural (i.e., short learning curve) and intuitive (i.e., learned or familiar behaviour) experiences that can help us to connect with the technology transparently. For instance, biomimetic principles can lead to systems that are both responsive to user needs and capable of evolving in response to changing contexts, much like the dynamic systems found in nature.

To explore how biomimicry can inform interaction design, it is essential to understand the concept of scenes, as part of designing experiences with multiple technologies in the user's environment. Scenes refer to the many ways that people interact with their environment, offering an alternative to screen-based interactions [11]. In this context, users engage directly with their environment more naturally and intuitively, rather than relying on screen interfaces. For instance, instead of providing feedback through visual displays, designers might utilize tactile feedback, such as vibrations to create a more immersive user experience. As interaction designers aim to create engaging, intuitive experiences, biomimicry offers an approach that allows designers to craft more seamless interactions and find new ways to interact with large amounts of data while reducing dependence on screens.

This paper discusses workshops conducted in 2023 and 2024 at Uppsala University, focusing on a problem-driven biomimicry approach, emphasizing the alignment of natural principles with the challenges of contemporary human computer interaction design. It addresses practical design process challenges by identifying underlying principles of 'shape change' as biological systems by abstracting them and applying them to technological solutions [13] during workshop activities. Participants were independent designers and researchers at the Department of Information Technology at Uppsala University that explore different themes related to humans and technology, e.g., robotics, artificial intelligence, digitalization, gender, work engagement, and educational development. Hence, the organisation of the workshops was a so-called 'Design exploration' [6] to hands-on experiment with alternatives for existing design methodologies towards inclusion of different human and natural nonhuman perspectives [19]. The nonhuman perspective considers the role of animals, biotic and

abiotic ecosystems, aiming to understand how they interact with their environment and how changes might affect them. Focusing on nonhuman needs and perspectives shifts the human-centric paradigm to a more ecocentric or systemic viewpoint [19]. The overall goal of the workshops was an initiatory step towards collaborative activities that promote the co-production of a framework that considers the integration of transdisciplinary knowledge (i.e., human knowledge and other knowledge) across science, industries and nature at large [15]. Hence, this paper reflects a unique collaboration between industry practitioners and academic researchers, leveraging their combined expertise to explore biomimicry as a transformative approach for interaction design. By bridging academic theory and practical application, this work demonstrates the potential of interdisciplinary efforts to address emerging challenges in the field.

2 Background

2.1 Biomimicry and Technology

As technology evolves, so do the ways people interact with it. From wearable devices and voice-based interactions to virtual reality (VR), and augmented reality (AR), human-computer interactions have undergone a transformation towards immersive experiences for users. Designers create immersive experiences that transport users into "digital worlds" combining multi-sensory technologies. These imaginative scenes provide realistic, interactive environments that allow users to explore virtual spaces as if they were physically present. These developments have expanded the boundaries of HCI, demanding the integration of diverse interaction conditions to accommodate the complexities of scene-based technological systems.

The ongoing development of AR and VR is particularly noteworthy, as these technologies enable the exploration of new interaction methods beyond traditional screen-based models. They allow users to engage with data, technology, and environments more intuitively and immersively. However, this shift also presents challenges, such as the need to design interfaces and interaction that support users to make sense of large datasets and make informed decisions efficiently through cues in the environment, like colour changes, smells, vibrations and through touch.

Simultaneously, global challenges like climate change and biodiversity loss necessitate sustainable approaches to interaction design. The method of biomimicry is an innovative and creative approach to problem-solving that uses nature's strategies and systems as an inspiration. It seeks to understand and emulate the strategies and systems used by nature's ecosystems to create sustainable and regenerative solutions [20]. By observing how natural systems optimise energy use, promote resilience, and create balance within their ecosystems, biomimicry allows HCI designers to develop user experiences while actively contributing to environmental restoration. For example, interaction designs inspired by regenerative principles [9] can integrate adaptive feedback loops, resource efficiency, and waste-minimizing processes, mimicking how ecosystems regenerate and sustain themselves over time.

Biomimicry has been applied across diverse fields, such as engineering, aviation, urban design, product design, architecture, and art. In the context of HCI, it offers a pathway to designs that not only accommodate the complexities of scene-based

interactions but also promote balance between human centred technology and the natural world.

2.2 Biomimicry as a Problem Driven Approach

Biomimicry, unlike human-centred design approaches, reframes nature as a model for mimicking biological principles to inform solutions. Following Fayemi's model (figure 1), once a relevant biological model is identified, the designer abstracts the principle (e.g., distributed regulation of activity to avoid overload) and begins translating it into potential design solutions.

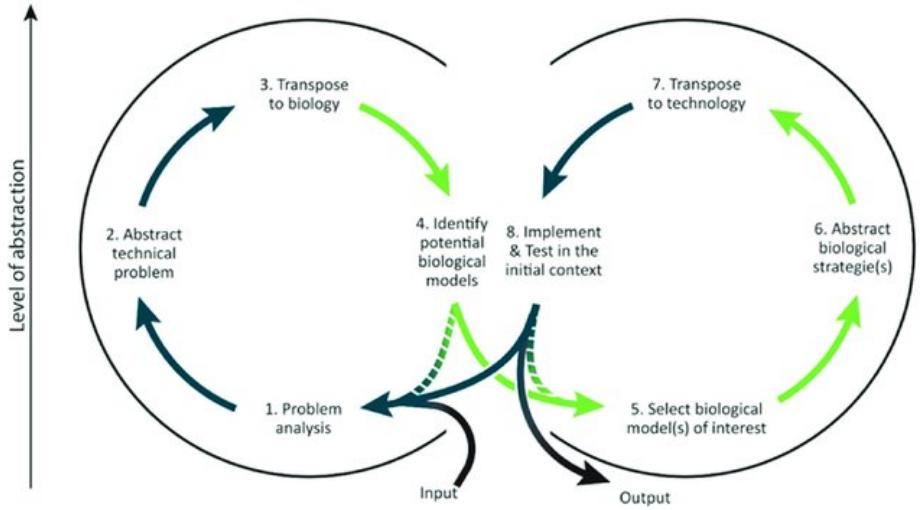

Fig. 1. The unified problem driven biomimetic process from Fayemi [7].

Biological models can be identified through literature reviews, online searches, database exploration, field observations and collaboration with biologists, ecologists, and experience experts [7]. This biomimetic process, rooted in analogical thinking, identifies and applies biological principles to develop sustainable and regenerative solutions [17,18,12] by creating multiple scenarios, each leading to distinct, relevant ideas, concepts, and prototypes.

Take, for instance, a design challenge on how we might design a remote work interface that helps users manage cognitive load throughout the workday? While a human-centred approach might focus on user feedback, interface simplicity, or productivity metrics, the biomimetic process encourages us to explore how nature regulates energy flows under high-pressure or fluctuating environments. From there, the search for biological analogues might include how certain tree species manage energy, or how octopuses distribute control across semi-autonomous limbs, reducing central processing demands, strategies that might inspire decentralised interface features, or gentle environmental feedback mechanisms that support flow.

Throughout the biomimicry process, analogical thinking plays a central role in translating principles from nature into human-centred solutions. It requires not only understanding and extracting key concepts from biological systems but also adapting

them to align with technological and cultural constraints and possibilities. Given the interconnected and simultaneous functioning of natural systems, an analogical way of thinking is essential to enable exploration of natural phenomena and events [18,1].

Analogical reasoning entails the process of accessing elements from prior knowledge to design new solutions or "the ability to notice and draw similarities across contexts" [18]. Analogical reasoning involves several steps, including focusing on relevant knowledge identifying relationships within and across items, and mapping these relationships across domains to generate insights or uncover shared principles [10]. General biomimetic design phases support this identification to facilitate transitions between broader knowledge domains by exploring potential scenarios guided by specific strategies found in nature [2]. The goal is to transcend apparent differences between a strategy found in nature and to identify the shared relational structures that link diverse knowledge domains. The core of this process lies in recognizing structural relationships between domains, beyond superficial similarities [8]. Encouraging analogical thinking can help designers avoid misinterpreting or oversimplifying biological models [1]. Another important element of using biomimicry is understanding how interaction designs can affect the environment (i.e., the environmental impact of interaction designs) by mimicking interconnectedness between ecosystems.

2.3 Biomimicry as a Transdisciplinary Approach

Collaborative and participatory design processes generally focus on the needs of humans and human-made technological systems, without the integration of the natural nonhuman world as a stakeholder, either indirectly or in design time [19]. By studying how different species interact with one another and their environment, provides valuable insights into balancing the needs of humans, technology, and nature. These interactions reveal complex ecosystems where mutual dependence and synergy that support adaptability. Moving beyond the concept of 'survival of the fittest,' and instead embracing a philosophy of collaboration and interdependence within a diversity of perspectives.

The challenges of making nature a partner in the domain of interface and interaction design, for both academia and industries, aligns with the principles of regenerative design, which advocate for shaping human activities in harmony with nature. Regenerative design seeks to address the disconnection between humans and nature by supporting a co-creative partnership, treating natural nonhumans as partners in a shared design process [5].

The possibility of incorporating natural strategies and systems into the domain of human interaction development provides an abundance of resources. However, this abundance poses a challenge, as finding an example in nature that can solve design, or technological problems can be difficult. Moreover, the connections between biology and human computer interactions are often non-obvious. Identifying these connections requires a systems-thinking approach of exploration across multiple system levels. This approach relies on analogical thinking, which involves identifying similarities and differences between objects or recognizing patterns within groups of objects or the "shared relational structure between domains" [18].

In the next section insights from two workshops held at Uppsala University in 2023 and 2024 which explored the potential of biomimicry to address emerging challenges in HCI are presented. These workshops focused on transitioning from screen-based to immersive scene-based interaction paradigms, aiming to offer alternative perspectives on interaction design.

3 Method of research-based workshops

Central to both workshops in 2023 and 2024 was underscoring the importance of analogical thinking in transferring knowledge across contexts. In total, 14 participants, including researchers, assistant professors, PhD students, and lecturers, from the Department of Information Technology at Uppsala University and one designer from both industry and academia, identified connections between biological and technological systems. Two participants took part in both workshops. The workshops facilitated the exploration of multiple scenarios, allowing participants to pinpoint examples and transition between broader domains through structured phases guided by the biomimetic process [7].

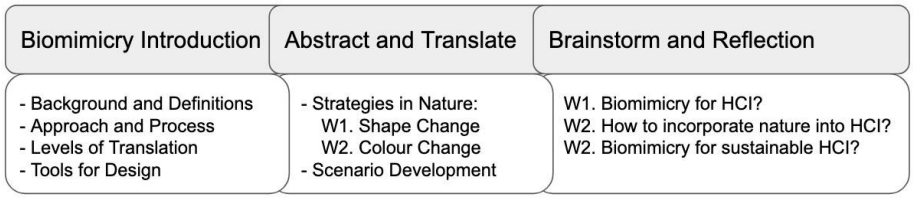

Fig. 2. Global overview for each of the two workshops.

3.1 Workshop 1: Brainstorming Interactions using Nature's Shape Changes

On January 26th, 2023, the first of two workshops was held at Uppsala University on the possibilities of the method biomimicry for Human Computer Interaction. The growing complexity of human interactions dealing with large amounts of data and the shift away from screen-based interactions is pushing the boundaries of Human Computer Interaction. By indirectly embedding knowledge of how nature operates into design processes, the workshops explored how biomimetic principles can reshape individual and collective perspectives, avoid unsustainable systems, and embed adaptive and intuitive nature-inspired solutions into HCI design.

3.1.1 Outline and Activities of Workshop 1

Through a series of reflective activities, the participants explored how biomimicry can be applied to the design of interactive products, services, and environments. Nine participants from the department of Information Technology engaged in a reflection process that consisted of three interactive activities. The activities began with an individual part and then transitioned into a reflective part in pairs or trio, followed by discussions.

The overall setup consisted of:
1. An introduction to the method of biomimicry.
2. Activity 1: 'Researcher Identity Memo' about biomimicry.
3. Activity 2: Biomimicry brainstorming using shape changes in nature.
4. Activity 3: Brainwriting on options and ideas for 'Biomimicry and HCI'.
5. Wrap-up and follow-up.

Activity 1: Researcher Identity Memo' about biomimicry.
After being introduced to biomimicry, the participants created a Researcher Identity Memo in the form of a mind map. This mind map helps to identify questions, biases, assumptions, and other elements of their thinking. It also allows them to visualise any changes in their thinking over time. Creating a Researcher Identity Memo was a useful tool to help the participants better understand their own thoughts on biomimicry.

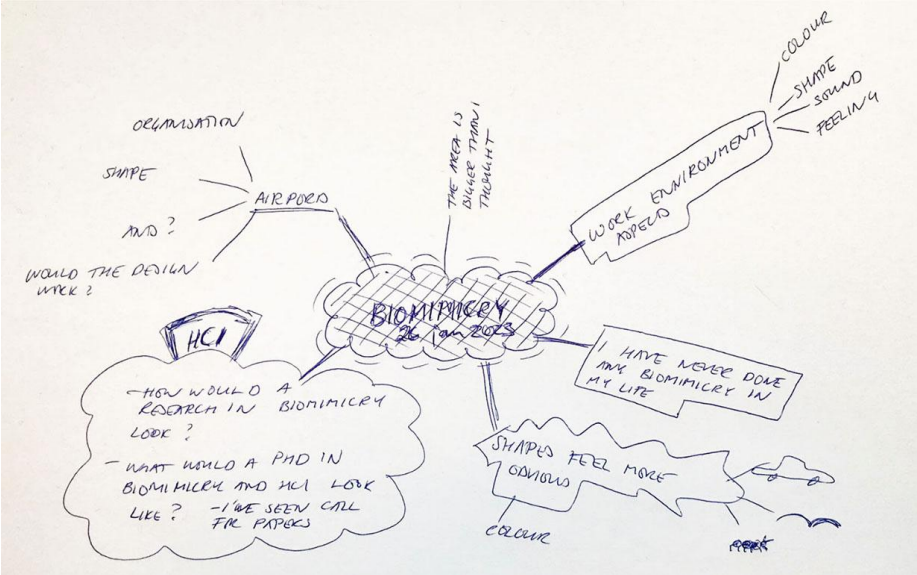

Fig. 3. Example of a Research Identity Memo: mind map on current thoughts and ideas about biomimicry.

Activity 2: Biomimicry brainstorming using shape changes in nature.
During the next activity, participants experienced biomimicry by 'thinking like nature operates' when designing a new interactive experience, discussing alternative possibilities for existing screen interactions (e.g., instructing, conversing, manipulating, and exploring) and translating systems found in nature into new ways of interaction in public space.

The design challenge of this activity was to integrate 'shape change' to create future scenarios for new ways of interacting as if having a conversation. The shape changes in nature are Elastomers, Auxetics, Rollable, Foldable, Inflatable, Anisotropic, Multi-stable, and Shape memory [13].

The context of a real-world setting was the environment of a train station where the person waiting for the train to arrive has a conversation explaining that they are late to someone who is not present at the station. Every participant could choose the shape change they wanted to integrate into the design of an intuitive and natural conversation using any kind of (imagined) technology (figure 4).

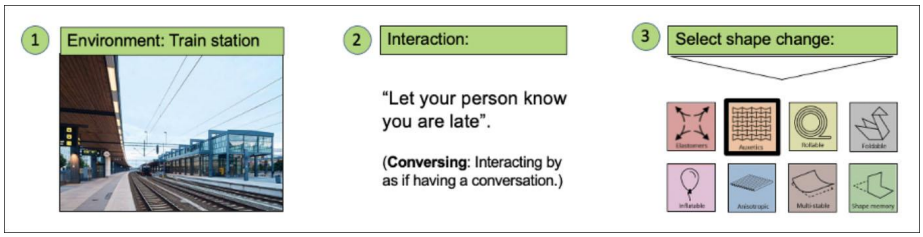

Fig. 4. The design challenge using shape change [13].

The first step in this activity was an individual brainstorm using the technique of the 'Crazy Four' for 4 ideas in 4 minutes (Figure 5). While the standard 'Crazy Eight' encourages fast-paced ideation with eight ideas in eight minutes, this activity was reduced to four ideas to ensure participants had enough time for reflection and discussion to choose an idea for the creation of a 'Future Scenario'.

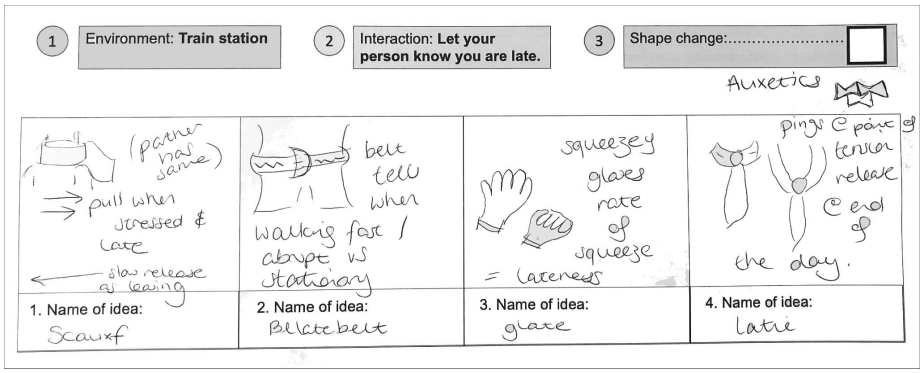

Fig. 5. Example of the 'Crazy Four' brainstorm.

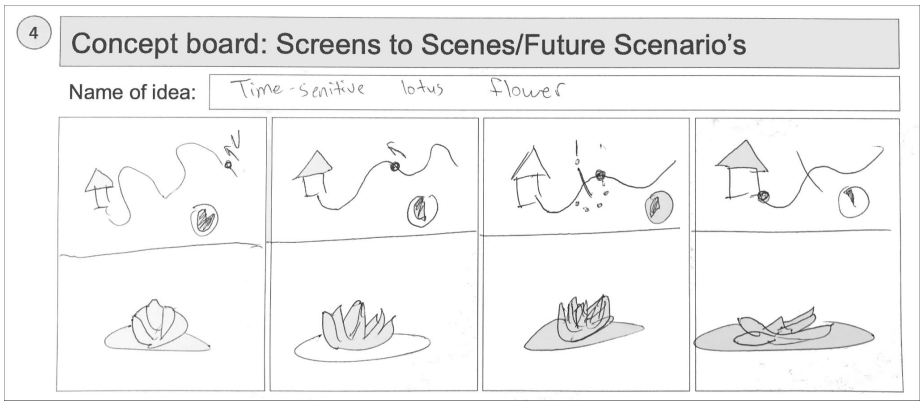

Fig. 6. Example of a Future Scenario moving from screens to scenes.

The second step was to discuss the ideas in pairs or trio to get inspired and pick the best idea to create a future scenario together (figure 6).

Activity 3: Biomimicry for HCI?
The last activity consisted of a brainstorm session and a discussion on what components of HCI could benefit from the method of biomimicry. The brainstorm technique consisted of two parts: individual creation of three How Might We' s, followed by the Round Robin or Brainwriting technique. Round Robin or Brainwriting is a brainstorming technique that encourages people to reflect on each other's ideas and generate new ideas collaboratively. By discussing various components of HCI and exploring the potential for utilizing biomimicry, the participants could identify potential pitfalls and risks associated with a proposed HMW.

The HMW activity was supported by two options for integrating the biomimicry method for HCI; 'preparing human interaction for biomimicry' and 'what components of human interaction would be an interesting start for using the biomimicry method'? During the Round Robin or Brainwriting activity participants reflected on possible ethical implications.

3.2 Workshop 2: An Interface Like a Beetle

On October 24th, 2024, the second of two workshops was held at Uppsala University on the possibilities of the method biomimicry for Human Computer Interaction. This workshop aimed to:

- Explore the convergence of biomimicry and HCI by brainstorming and designing organic, "living" interfaces.
- Conceptualise interfaces beyond traditional screen-based designs, inspired by nature's methods of sensing and disseminating information.
- Develop a deeper understanding of information dissemination and design new, intuitive human-information interfaces that reflect natural processes and functions.

The decision to focus on a beetle-inspired interface emerged from the beetle's unique physical adaptations of layering fluids to inform its environment of its emotional state and therefore its potential for rich metaphorical and functional translation into interface and interaction design.

3.2.1 Outline and Activities of Workshop 2

The overall setup consisted of:
1. An introduction to the method of biomimicry
2. Introduction to Processing Information as Nature's 'Interface'.
The workshop provided an in-depth look into how natural systems process information as interfaces, offering insights into potential applications in HCI. Nature's strategies for navigating, sending, processing, and sensing signals were presented as an alternative perspective on interface and interaction design.
3. Activity 1: Designing a Beetle-Inspired Interface
4. Activity 2: How might we: incorporate nature into HCI
5. Wrap-up and follow-up.

Activity 1: Designing a Beetle-Inspired Interface
Participants explored the unique properties of the golden tortoise beetle, focusing on its "chirped" multilayer structure, which enables it to toggle between two distinct colours depending on moisture levels. This beetle's adaptation serves as a model for designing interfaces that reveal information dynamically through environmental interaction.

The processes of Functional Abstraction and Translation aligned with Phase 6: Abstract Biological Strategies and Phase 7: Transpose to Technology in the Biomimicry Process framework by Fayemi [7]. Worksheets provided for these phases guided participants in abstracting and translating three key functionalities of the beetle's adaptations:

1. **Toggle Between Layers**: Mimicking the beetle's ability to reveal different layers to access varied information, the interface could allow users to switch views or data levels by manipulating the "layers" of the system.
2. **Displacement of Fluid in Grooves**: Similar to the beetle's moisture-displacing grooves, an interface could display new information by user interaction, revealing hidden data in a structured, layered manner.
3. **Porous Patches for Moisture Displacement**: Patches that respond to environmental changes could add an organic element to HCI, revealing new patterns or information based on user engagement.

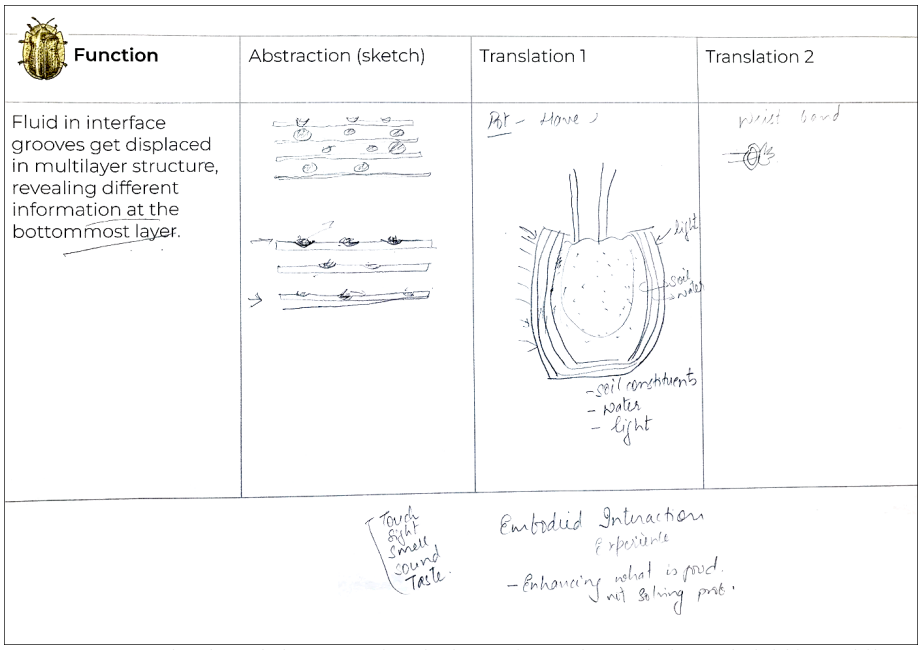

Fig. 7. Example of Worksheet Functional Abstraction and Translations of Fluid in Multilayer Structure

During these two phases, participants analysed how the beetle's colour-changing mechanism can be abstracted into functional design principles, such as responsiveness, material efficiency, and environmental adaptability. They then explored ways to translate these principles into interface features, including humidity-sensitive displays and dynamic visual cues that provide context-aware feedback.

Activity 2: How Might We Incorporate Nature into HCI?
Participants individually tackled two questions, and the answers were shared and discussed within the group.

1. **How might we incorporate nature into HCI?**
   Participants brainstormed design solutions for incorporating biomimicry principles, aligning with the biomimicry taxonomy [4] group Process Information consisting of functionalities:
   - Navigate
   - Send Signals
   - Process Signals
   - Sense Signals/Environmental Cues
2. **How might biomimicry support sustainable HCI?**
   Participants explored how biomimicry could promote sustainable practices in HCI, emphasizing the reuse and adaptation principles observed in natural systems.

The outcomes would serve as a foundation for further exploration, prototyping, for academic research and industries on integrating nature's strategies and sustainable design into the domain of human-computer interaction.

4 Results

The results of Researcher Identity Memo offer a glimpse into how the participants perceive biomimicry in relation to HCI, as well as potential ways of implementing biomimicry for HCI in a practical way. Before presenting the outcomes of the thematic inventory, it is important to note that out of a total of 14 researchers, 13 had no prior experience applying biomimicry in previous projects, highlighting both the novelty of the topic within HCI and the openness of participants to explore unfamiliar territory. Inductive coding was performed on the responses, allowing key themes to emerge in a bottom-up way from the data. This approach helped capture both the diversity of ideas and the underlying conceptual patterns that informed participants' thinking about biomimicry as a speculative, ethical, and interdisciplinary design lens.

4.1 Outcome of Workshop 1, Activity 1: Researcher Identity Memo on Biomimicry

The Researcher Identity Memos provided a diverse range of reflections on biomimicry in the context of Human-Computer Interaction (HCI). These insights were categorised into nine key themes, in alphabetic order:

Applicability: Questions arose about when and how biomimicry is appropriate in design, its practical feasibility, and whether it is taken seriously as a scientific approach rather than a novelty. Participants wondered: "When is biomimicry considered rigorous research versus a hobby?"
Ecosystems: Some participants explored biomimicry beyond individual organisms, asking how entire ecosystems could inform sustainable HCI solutions. "To save our planet, we must become part of it, saving ourselves is not separate from saving the planet."
Evolution: Many emphasised biomimicry's foundation in evolution, noting that nature's designs have been tested over millennia. Some reflected on abstract evolutionary principles, such as "spirals as a fundamental abstraction at higher levels."
Feeling & Inspiration: Participants expressed excitement and curiosity, describing biomimicry as "thought-provoking" and a source of "new inspiration." Others highlighted its aesthetic appeal, asking if beauty itself could be a guiding design principle.
Human and Nature: A recurring theme was the blurred boundary between humans and nature. Some questioned whether humans themselves could be mimicked, while others explored biomimicry as a way to reconnect with natural systems. "Mind = body = environment. The means is the ends."

Specific Ideas from Nature: Participants brainstormed tangible biomimetic concepts, including color-changing tattoos, hive intelligence, and airport layouts inspired by biological organisation.
Sustainability & Conservation: Some responses focused on biomimicry's potential to support ecological balance, while others warned of risks, such as exploitation. "So much potential vs. exploitation—when is it truly beneficial?"
Working with Nature: Many framed biomimicry as a collaboration with nature rather than mere imitation. This included questions about nonhuman agency and interaction: "How does nature communicate, and can this improve human pedagogy?

A key insight was the participants' shared lack of prior experience with biomimicry, underscoring the novelty of this approach within the field. Despite this unfamiliarity, the method sparked genuine interest, particularly for its interdisciplinary potential offering an innovation space where biology and interaction design could intersect. At the same time, the enthusiasm was tempered by thoughtful questions around ethics, feasibility, and the risk of superficial or inappropriate applications. These reflections highlight the importance of building frameworks that not only support the creative potential of biomimicry but also ensure its responsible and context-sensitive use.

4.2 Outcome of Workshop 1, Activity 2: Moving from screens to scenes using biomimicry.

The outcome of this activity was an engaging and analogical-thinking provoking experience within the biomimicry process. After a short time (30 min.) of creative exploration, the participants experienced the potential for applying natural systems to develop new ways of interacting in public space. Using the shape changes in nature as a starting point, participants discussed new possibilities for existing screen interactions, such as smart clothes, time sensitive materials, colour as information, tree and clouds communication, changing of shared objects (e.g., balls), and shape memory. It was inspiring to witness how, through the lens of biomimicry, participants were able to create and discuss alternative possibilities for existing screen interactions. This activity was a success in the sense that participants expanded possibilities for advancing and innovating technologies and the ways people interact with it using nature as inspiration.

4.3 Outcome of Workshop 1, Activity 3: How Biomimicry for HCI?

During the Round Robin/Brainwriting activity, participants generated a wide range of ideas exploring how biomimicry could inform Human-Computer Interaction. The responses revealed imaginative and critical engagements with natural systems as inspiration for new technological solutions. Through inductive analysis, five overarching research themes emerged, in alphabetic order:

Alternative Solutions: Participants envisioned non-conventional HCI designs inspired by natural behaviors or phenomena. Examples included nature-responsive clothing, intuitive classroom feedback systems, and brain-computer interfaces

replacing traditional input devices. These concepts aimed to create more seamless, sensory-rich interactions.
Ethical Issues: Several contributions highlighted the ethical complexities of bio-inspired design, such as privacy concerns in health monitoring, the risk of misinformation in assistive technologies (e.g., for people who are blind), and the emotional implications of human-like lifecycle (e.g., birth, youth, old age, death) design in machines. Participants stressed the importance of considering unintended consequences.
Improvement of Existing Solutions: Ideas under this theme sought to refine current systems by learning from nature. This included intuitive information delivery (e.g., beyond email), enhancing human-machine collaboration, or using biomimicry in education to improve programming exercises and in public transport.
Nature as Partner: Proposals involved incorporating natural feedback systems (e.g., trees or ants informing environmental or transport apps), integrating biomimicry in games, and exploring e-health and wellbeing applications. These ideas promoted mutual benefit and sensitivity to ecological rhythms.
Symbioses between Human and Machine: Participants explored designs where humans and machines work in a mutually supportive relationship, such as devices powered by the human body or interfaces that adapt to environmental conditions. This theme underscored a shift toward more integrated, reciprocal systems

Although almost none of the participants had prior experience applying biomimicry in HCI, their contributions reveal that they did not treat biomimicry as a ready-made toolkit but as a speculative and exploratory space that invites critical reflection. Their ideas highlighted tensions between innovation and responsibility, the possibilities of alternative futures, and the practical challenges of implementation. The discussion also surfaced the need for new interdisciplinary collaborations, as well as educational strategies to support the integration of biomimicry into HCI research and practice.

4.4 Outcome of Workshop 2, Activity 1: Designing a Beetle Interface

Participants began to rethink static interface elements, shifting toward dynamic, responsive systems that adapt to environmental or user inputs, taking inspiration from the beetle's multilayer structure. The strategy of toggling between data layers, prompted by the workshop task, sparked ideas for interface designs in which users could seamlessly transition between complex data views without losing contextual relevance.

In total, 11 distinct ideas were generated during this activity, each exploring how information could emerge or shift in response to environmental triggers or user actions, such as changes in temperature, humidity, or touch. Many of these concepts were inspired by the beetle's structural coloration and responsive surface properties. Inspired by the beetle's multilayer structure, participants envisioned systems that allow users to "toggle" between data or interface states by manipulating virtual or physical layers. While this activity enabled exploration of a specific biological strategy, it may have limited the diversity of conceptual directions.

4.5 Outcome of Workshop 2, Activity 2: Brainstorm on HCI and Nature

As part of this activity participants were asked to brainstorm and discuss how nature could be integrated into Human-Computer Interaction towards sustainable solutions and approaches. The outcome of this activity generated a wide array of ideas, focusing on the application of natural principles to enhance HCI. These ideas spanned various aspects of design, from learning through forest ecosystems and evolutionary processes to sensory integration and sustainability practices:

- Learning Through Forest Ecosystems: Exploring how trees teach and support young saplings to translate intergenerational knowledge sharing in HCI.
- Evolutionary Processes in Nature: Investigating nature's adaptive evolution to design resilient interfaces.
- HCI Community and User Understanding: Examining how natural principles could enhance user understanding within the HCI community.
- Nature's Approach to Sustainability: Looking at natural cycles as a model for sustainable HCI practices.
- Sensory Integration in Interfaces: Incorporating multi-sensory cues in HCI, inspired by how organisms use all five senses.
- Nature's Warning Signals: Adapting natural warning systems to develop more effective alerts and notifications.
- Enhancing Existing Systems: Leveraging nature's ability to enhance current resources to improve existing HCI systems.

These ideas collectively show how nature's principles can offer valuable insights for designing HCI systems that are more adaptive, sustainable, and nature-centred, reinforcing the importance of biomimicry in future HCI practices. In the next section the synthesised insights from the workshops are presented, and potential directions for future research and practice are outlined.

5. Conclusion and Discussion

As a result of the workshops, participants gained a first glance of how biomimicry can be used to explore how nature can be seen as a source of inspiration for interaction design. Additionally, they learned to use biomimicry to transition from screens to scenes approaches to create future scenarios based on nature's principle of shape change. This allows them to further explore the idea of working with nature, directly (i.e., as a partner or design time) or indirectly, to create solutions that could be beneficial to both humans and the nonhuman environment.

Reflection at the end of each workshop revealed that translating nature's principles into human-centred solutions relies heavily on analogical reasoning as a foundational cognitive process. Participants found abstraction and translation challenging but acknowledged that focusing on structural relationships helped bridge biological systems and technological applications. However, applying this approach also ensures the integrity and accuracy of biomimetic design, underlining the importance

of analogical thinking in unlocking the full potential of nature-inspired strategies for developing adaptive solutions across knowledge domains.

5.1 Biomimicry as a transformative approach for HCI

The insights derived from the workshops at Uppsala University demonstrate that biomimicry not only supports the transition from screen-based to immersive scene-based interaction paradigms but also supports an understanding of the parallels between biological and technological systems. The outcome of Activity 2 of the first workshop, "Moving from Screens to Scenes Using Biomimicry", demonstrated the potential of natural systems as a source to envision alternative, nature-inspired interactions that challenge traditional screen-based technologies. The participants were challenged to create ideas beyond predictable and known interfaces and interactions. The diverse ideas generated illustrate that nature inspires for generative solutions for human technology interaction. This activity not only expanded the participants' understanding of biomimicry but also gave insights on how nature can inform the development of more intuitive, responsive technologies in public spaces.

Workshop 2, Activity 1, further emphasised biomimicry's practical value. Participants reimagined interface design through the lens of the beetle's adaptive, multilayered structure. The exploration of dynamic, responsive systems such as environmental sensors and colour-changing interfaces, demonstrated the value of incorporating nature's strategies into HCI. Through scenario-based exploration and structured phases in the biomimicry process, they identified actionable pathways for integrating adaptive and sustainable interfaces for interaction design. Moreover, the iterative and scenario-driven approach supported them to recognise the potential of analogical thinking for knowledge transfer across disciplines. By the end of both workshops, participants also gained practical tools for applying biomimetic strategies to complex challenges.

5. 2 Biomimicry as a transdisciplinary collaborative approach

Collaboration between industry and academia is critical in generating innovation [15]) as such partnerships ensure that academic research remains relevant to practical applications. Biomimicry exemplifies this synergy by integrating diverse disciplines—biology, technology, computer science, ecology, and design—to address complex design challenges. The findings from the workshops underscore biomimicry's capacity to bridge theoretical biological knowledge with practical applications, providing a valuable framework for designing solutions that advocates for a shift that aligns human technologies with natural systems.

The workshops also underscored the potential for biomimicry to dissolve traditional disciplinary silos, encouraging inter- and transdisciplinary problem-solving. By engaging nature as a partner, biomimicry enables the development of alternative interactions grounded in the symbiosis between humans, nature, and technology. The outcomes of the workshops emphasise the transdisciplinary nature of biomimicry. The integration of ecological, philosophical and technological dimensions that support shared relational structures between disciplines is essential for effective collaboration between academia and industries.

With the main author's expertise from an industry perspective, the workshops bridged the gap between academic exploration and practical application, illustrating how biomimicry can seamlessly integrate into professional design processes. This collaboration offers actionable insights for industry practitioners, demonstrating how sustainable, nature-inspired methodologies can be applied to innovate within existing design workflows.

Furthermore, the method of biomimicry has demonstrated its potential for broader application in a range of industries, including architecture, product design, systems engineering, and even organizational development. Hence, its emphasis on systems thinking, contextual awareness, and multi-species relationships aligns well with current industry needs for sustainable, regenerative, and adaptive innovation (co-) creating long-term visions.

5.3 Applications and Future Directions

The Researcher Identity Memos have revealed nine key themes Applicability, Ecosystems, Evolution, Feeling, Human and Nature, Idea from nature, Inspiration, Sustainability - Conservation, and Working with Nature, research and industries should focus on deepening the integration of these themes to encapsulate the multifaceted relationship between biomimicry and its application in the domain of HCI. These nine key themes were enhanced by the identification of five core research concepts on biomimicry for HCI: Alternative Solutions, Ethical Issues, Improvement of Existing Solutions, Nature as Partner, and Symbiosis between Human and Machine. These research concepts reflect the diverse ways in which biomimicry can inspire innovative approaches to HCI, from ethical considerations to new design possibilities.

The outcome of Workshop 2, Activity 2, generated a wide array of ideas for incorporating nature into HCI. These ideas spanned various aspects of design, from learning through forest ecosystems and evolutionary processes to sensory integration and sustainability practices. Participants explored how nature's adaptive evolution, intergenerational knowledge sharing, and multi-sensory cues could inspire more resilient, intuitive, and sustainable interfaces. The potential to apply nature's warning systems and enhance existing technologies was also recognised as a key avenue for improving user interactions. These ideas collectively highlight how nature's principles can offer valuable insights for designing HCI systems that are more adaptive and nature-centred. The workshops highlighted several viable and relevant applications of biomimicry in HCI:

- **Caregiving and E-Health**: Nature-inspired interfaces for patient monitoring and wellbeing.
- **Education**: Using biomimicry to design immersive learning environments.
- **Public Spaces**: Shape-changing installations for enhancing community interactions.

Future research could refine biomimicry methodologies for HCI, promote inter- and transdisciplinary collaboration with practical processes for industries, and address ethical considerations for sustainable and regenerative innovations.

Moreover, future collaborations between academia and industry could explore structured frameworks to guide the biomimicry process and expand dialogue across disciplines by bringing together HCI researchers, design theorists, biologists, ecologists, and industry practitioners. While the content of the workshops was primarily inspired by natural forms and processes, they did not demonstrate ecological responsibility. This raises the important question: how can we assess whether a system is truly ecologically responsible, within the biomimetic approach? Ecological responsibility requires criteria such as lifecycle impact, resource use, long-term effects on ecosystems, and engagement with sustainability metrics which were not addressed during the workshops. By embedding these considerations into human-technology interaction practices, designers could work toward systems that are not only user-centred but also aligned with ecological systems, setting a grounded precedent for sustainable and regenerative innovation in interaction design.

5.4 Discussion

The findings suggest that biomimicry complements and extends current HCI approaches by offering a structured but flexible method to engage with biological principles. While bio-design, speculative design, and more-than-human perspectives advocate similar values, biomimicry offers a repeatable process for analogical transfer from biology to technology. This opens up pathways for practice-based inquiry, material prototyping, and regenerative interaction design that remain grounded in empirical biological insight.

However, challenges remain. The process of analogical reasoning is cognitively demanding and can be prone to misinterpretation or oversimplification of biological models. In addition, current design workflows are often not structured to accommodate long-term engagement with ecological systems or to involve biological experts in early ideation phases. Overcoming these hurdles will require changes in design education, interdisciplinary collaboration models, and funding structures that recognise the value of nature-inclusive innovation.

Although biomimicry presents promising pathways for reimagining interaction design, participants identified several critical challenges such as:

- Balancing inspiration with practicality.
- Avoiding the idealization of nature's solutions.
- Navigating ethical implications, such as unintended consequences of bio-inspired designs.

To address these complexities, the integration of biomimicry into HCI must go beyond treating nature as a repository of solutions—it must recognise natural nonhuman entities as co-creators in the design process. This shift entails cultivating a mindset that values nonhuman perspectives and ecological systems as equal participants in shaping interaction paradigms. To move toward this paradigm, design processes must involve practices that account for nonhuman needs, roles, and impacts by engaging ecological

expertise, long-term observation, and methods for embedding reciprocity. It calls for rethinking fundamental design principles, fostering inter- and transdisciplinary collaboration, and developing new tools and frameworks to move beyond anthropocentric models.

Early engagement with stakeholders, ranging from local communities to policy makers and industry, can help define ethical boundaries, practical constraints, and long-term visions. Designers, engineers, ecologists, philosophers, and ethicists must work alongside one another, with input from all types of knowledge (e.g., experiences, observations, photographs, sketches, stories and songs passed on from generations, raw data, insights) in biomimicry. Such distributed collaboration ensures that both the functional and ecological implications of biomimetic design are taken into account from the outset.

Another challenge in translating nature-inspired concepts into scalable, user-friendly interaction design often involves technical and financial constraints. Researchers and designers must find ways to implement these concepts without sacrificing accessibility or affordability to avoid mismatches in expectations and outcomes. This is particularly important given that nature operates on scales (e.g., time, space, system) that require long-term organisations and commitment.

As such, the decision to adopt biomimicry as a method should be carefully considered within inclusive, cross-sector collaborations between academia, industry, and other relevant actors. The value of biomimicry lies in its potential to inform the broad field of human technology interactions toward solutions that support both functionality and nature's principles, mirroring the interconnectedness of ecosystems. Collaborative efforts between academia and industry can strengthen nature-centred approaches' impact, and vice versa, towards intuitive, sustainable, and regenerative innovations in interaction design.

Acknowledgments. We are most grateful for the invitation to host the two workshops 'Biomimicry for HCI' at the Human Technology Organisations Research Group at Uppsala University in 2023 and 2024. Many thanks to all the participants for an open attitude and the many ideas they shared. Finally, special thanks for the 'Visiting Researchers to promote equal opportunities' funding from the host department of Information Technology initiated by Prof. Åsa Cajander as Visiting Sponsor.

Disclosure of Interests. The authors have no competing interests to declare relevant to this article's content.

References

1. Ahmed-Kristensen, S., Christensen, B.T., Lenau, T., et al.: Naturally original: Stimulating creative design through biological analogies and random images. In: DS 77: Proceedings of the DESIGN 2014 13th International Design Conference. pp. 427–436 (2014)
2. Badarnah, L., Kadri, U.: A methodology for the generation of biomimetic design concepts. Architectural Science Review 58(2), 120–133 (2015)
3. Benyus, J.M., et al.: Biomimicry: Innovation inspired by nature (1997)
4. The Biomimicry Institute (2015.) The Biomimicry Global Design Challenge Toolbox. http://toolbox.biomimicry.org. Accessed 26 Jan 2025
5. Du Plessis, C.: Towards a regenerative paradigm for the built environment. Building Research & Information 40(1), 7–22 (2012)
6. Fallman, D.: The interaction design research triangle of design practice, design studies, and design exploration. Design issues 24(3), 4–18 (2008)
7. Fayemi, P.E., Wanieck, K., Zollfrank, C., Maranzana, N., Aoussat, A.: Biomimetics: Process, tools and practice. Bioinspiration & biomimetics 12(1), 011002 (2017)
8. Gentner, D.: Bootstrapping the mind: Analogical processes and symbol systems. Cognitive science 34(5), 752–775 (2010)
9. Gibbons, L.V.: Regenerative—the new sustainable? Sustainability 12(13), 5483 (2020)
10. Holyoak, K.J.: Analogy and relational reasoning. The Oxford handbook of thinking and reasoning pp. 234–259 (2012)
11. Huang, M., Zhang, Z.: Research on multi-modal scene design under the development of digital ecological culture industry. International Journal of Education and Humanities 9(1), 220–225 (2023)
12. Nagel, J.K., Pidaparti, R.M.: Significance, prevalence and implications for bio-inspired design courses in the undergraduate engineering curriculum. In: International Design Engineering Technical Conferences and Computers and Information in Engineering Conference. vol. 50138, p. V003T04A009. American Society of Mechanical Engineers (2016)
13. Qamar, I.P., Stawarz, K., Robinson, S., Goguey, A., Coutrix, C., Roudaut, A.: Morphino: a nature-inspired tool for the design of shape-changing interfaces. In: Proceedings of the 2020 ACM Designing Interactive Systems Conference. pp. 1943–1958 (2020)
14. Rowland, R.: Biomimicry step-by-step. Bioinspired, Biomimetic and Nanobiomaterials 6(2), 102–112 (2017)
15. Sjöö, K., Hellström, T.: University–industry collaboration: A literature review and synthesis. Industry and higher education 33(4), 275–285 (2019)

16. Speck, O., Speck, T.: An overview of bioinspired and biomimetic self-repairing materials. Biomimetics 4(1), 26 (2019)
17. Stevens, L., Kopnina, H., Mulder, K., De Vries, M.: Biomimicry design thinking education: A base-line exercise in preconceptions of biological analogies. International Journal of Technology and Design Education 31, 797–814 (2021)
18. Vendetti, M.S., Matlen, B.J., Richland, L.E., Bunge, S.A.: Analogical reasoning in the classroom: Insights from cognitive science. Mind, Brain, and Education 9(2), 100–106 (2015)
19. Veselova, E., Gaziulusoy, İ.: Bioinclusive collaborative and participatory design: A conceptual framework and a research agenda. Design and Culture 14(2), 149–183 (2022)
20. Vincent, J.F., Bogatyreva, O.A., Bogatyrev, N.R., Bowyer, A., Pahl, A.K.: Biomimetics: its practice and theory. Journal of the Royal Society Interface 3(9), 471–482 (2006)