Designing Biologically Inspired Movements into the Esthetics of Interactive Artifacts

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http://dx.doi.org/10.5772/intechopen.71117

Abstract

Biological creatures have a variety of qualities that inspire design esthetics such as form, color, texture, structure, mechanics, and dynamics. This paper presents a biology-to-design approach as a design research method for adapting biological movements into the design of the kinetic and interactive esthetics of jewelry artifacts. It describes a preliminary study in which prototypes were developed by identifying and classifying the biophilic movements of small creatures, in consultation and collaboration with a biologist. It details how the biological insights were adapted into ideation concepts: beginning with a brainstorming workshop followed by further iterative sketching and prototyping. It adds to the literature on methods for taking design inspiration from nature, in particular, in the area of kinetic product esthetics.

Keywords: kinetic interaction esthetics, biology-to-design, kinetic design, biophilic movements, wearable computing

1. Introduction

Product esthetics are important in product design, where designers have traditionally paid considerable attention to the visual appearance of products. Although visual esthetics are important in design, designers are also becoming more aware of other aspects of product esthetics that contribute to pleasure such as interactions that engage multi-sensory modalities [1–5].

Incorporating physical movements into product esthetics can also enhance the emotional value of the objects [6]. Nam et al. noted, "One of the ways to enhance emotional interaction is to use dynamic attributes as a way of expressing functional or emotional states of products" ([7], p. 1). Nevertheless, incorporating the element of movement into the design of products has been somewhat overlooked in the realm of industrial design. According to kinetic designer Ben Hopson (oral communication, December 2013), "Movement has not historically been the designer's territory. It's really been the engineer's territory". He believes there is a need for tools and guidelines for designers working in this area [8].

Moreover, interdisciplinary approaches to the design of kinetic and interactive devices may involve various disciplines including science, design, fashion, computer, and technology [9–11]. This interdisciplinary study draws from the disciplines of biology and kinetic design to explore the esthetics of movement in the design of interactive artifacts. It adds to the literature on methods for taking design inspiration from nature, in particular, in the area of kinetic product esthetics.

1.1. Interactive wearable artifacts and kinetic design

Today, wearable objects are becoming increasingly interactive by engaging a range of sensory experiences through various types of sensory inputs and outputs. Garments with embedded sensors are employed for interactive entertainment, sport, military, medicine, exercising, connecting people to others, and to other networked activities [9–11]. The technology inputs and outputs may depend on embedded sensors that could result in dynamically lighting up, moving, and/or changing shape. Shape changing interfaces may be functional, exploratory, or hedonic. Hedonic interfaces that evoke human emotion may be used to stimulate, to identify, to esthetically enhance, or to increase the experience of fun [12]. The examples that follow demonstrate different kinetic dynamics that may evoke hedonic responses in the design of wearable artifacts.

In Joanna Berzowska's behavioral dresses, named "Kukkia and Vilkas", kinetic components frame the wearer's face, opening and closing slowly over time [13] and Fusakul's work, "Aliform", responds to the wearer's heartbeat by changing shape [14]. Wallace's neckpiece, "Journeys Between Ourselves" provides kinetic tactile feedback when a mother interacts remotely with her daughter through it [15]. Ross and Wensveen note, "designing such products and systems requires an aesthetic that goes beyond traditional aspects of static forms. It requires a new language of form that incorporates the dynamics of behaviour" [16]. Young et al. recommend that in designing movement for a product, the form of the object, and the capabilities of performing its designed movements should be considered first [17]. Furthermore, Hopson emphasizes the importance of choreographing product movements as follows:

Designers are not just form-givers, they are whole object creators and experience designers. By incorporating the creative and experiential notions of kinetic design into their vocabulary, designers will produce more exciting, more unified products, which will, in turn, lead to greater commercial success [8].

This study explores the kinds of biologically inspired movement that could contribute to different interactive outputs and kinetic product esthetics for wearables. It builds on other studies that indicate that shape-changing interfaces and organic, life-like movements can contribute to emotional or hedonic responses to the product [12–17].

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In addition, the literature describes the qualities of movement: such as direction, volume (change in size), path (the line the object movement creates), speed, rhythm, continuity, and beat (cited by [18, 19]). For expediency, this research concentrates only on the kinetic qualities of direction, volume, and path. Other qualities of speed, rhythm, continuity, and beat are considered as stable variables in this study.

1.2. Intersection of biology and design: bio-inspired movements

Humans have a historical and emotional attachment to nature. Contact with nature can provide positive impacts for human beings [20–22]. Even a minimum amount of interaction with nature: in the form of representations and reminders such as images, statues, and jewelry with a nature focus: can act as a medium for satisfying people's biophilic desire for nature [23]. It improves the physical, emotional, and intellectual well-being of humans [24]. As a result, natural biological elements-referred to in this paper as biophilic elements- can provide a familiar and even comforting source of inspiration for design.

Natural features have long-inspired science and engineering as well as art and design disciplines [20, 24, 25]. In the design literature, discussions about biology and design may refer to copying, adapting, or deriving from nature, or in some way integrating nature or natural elements into everyday objects, and environments. These discussions cross disciplines, but are related thematically, with names such as, 'biologically inspired design', 'biomimicry', 'bionics', 'biomimetics', 'biophilic design', and other similar terminologies [24, 26]. There are also numerous examples of biologically inspired kinetic approaches in the literature, however, few are focused on the hedonic aspects of kinetic esthetics as this study is. For example, Oxman's 2013 sophisticated robotic arm that uses figure-eight movements, similar to those of a silkworm, to create cocoonlike structures [27] and Festo's robotic octopus gripper, based on the octopus' tentacles, provide functional alternatives for the design of mechanical products, but not for addressing emotional experiences [28].

This study takes a biologically inspired design and 'biophilic design' approach. The latter is derived from Wilson's concept of the 'biophilia hypothesis'; that people have "an innate human urge to have contact with other species, to spend time in natural environments, surrounded by animals and other living things"(cited by [25], p. 34). Kellert further adds to the meaning of biophilic design as having a positive environmental impact, due to the bonding between people and nature within the built environment [24]. It would seem that biophilic design creates environments and products that incorporate naturally agreeable and appealingly positive emotional experiences [20, 29]. For that reason, bios forms are often applied in design to improve the value of the products for the consumer market [30].

Benyus and Baumeister, co-founders of the Biomimicry Institute, proposed two approaches for developing nature-based things: they are biology-to-design and challenge-to-biology [31]. Volstad and Boks refer to these as biology-to-design and design-to-biology. In the biology-to-design approach, the design could be inspired by form (what it looks like), material (what it is made out of), structure (how it is made), mechanics (how it works), or function (what it is able to do) [32]. Challenge-to-biology and design-to-biology are outside the scope of this study.

Therefore, this paper presents part of a biology-to-design preliminary study in which a step-by-step approach for adapting biological movements was developed and applied to prototype design of kinetic jewelry. This is a process for generating bio-inspired designs for wearable products with kinetic esthetics. It presents an approach for designing movements that were inspired by natural creatures, especially those that people seem to experience positively. While positive impacts may enhance the value of a design, impacts from dangers in the natural environment, like snakes or height could create fears, stress, and "biophobic" responses [33]. Given that jewelry is typically an accessory to fashionable clothing, this study is part of a larger project to explore positive emotional responses to biophilic design elements. Its main contribution is a design approach for taking inspiration from biological movements and generating new ideation concepts in the design development stages of practice. It adds to the literature on methods for biology-to-design inspirations for ideation and early design development stages [32, 34, 35].

It describes the steps taken to identify, classify, and adapt biological movements into the design concept development process in order to create esthetically pleasant interactive products. This paper proposes a set of steps for applying biophilic movements in the ideation stage of designing interactive/kinetic esthetics for artifacts that may also convey emotion and elicit biophilic responses. The methods may be useful for artists, fashion designers, and form creators who aim to evoke various emotions in users through biophilic movements.

2. Methods

This biology-to-design study includes the stages of: identifying, classifying, and adapting biological movements [**Figure 1**].

2.1. Stage 1: identifying

The first Identifying stage started with investigating and gathering information from the field of biology. Different methods were employed to collect the information about movements found in biological systems. While movements could have a positive or negative impact on viewers, this study attempted to identify the type of movements in nature that could possibly bring about a positive emotional impact on human beings. They were considered to be 'biophilic movements'. It was important to have a biologist to consult with when designing and taking inspiration from nature in order to benefit from his knowledge and expertise [36]. This interdisciplinary study included on-going consultations with a biologist, Dr. Jeff Dawson, as a method for gaining more insight about the movements of living creatures. Dr. Jeff Dawson is a biologist and professor at Carleton University who is an expert in the biomechanics of insect flight and animal locomotion.

2.1.1. Internet survey of videos and exhibition visits

The study also included observation of plants and animals in natural settings, videos, museums, and exhibitions. Regarding the importance of observation in research, Martin and Hanington note, "A fundamental research skill, observation requires attentive looking and systematic recording of phenomena-including people, artifacts, environments, events,

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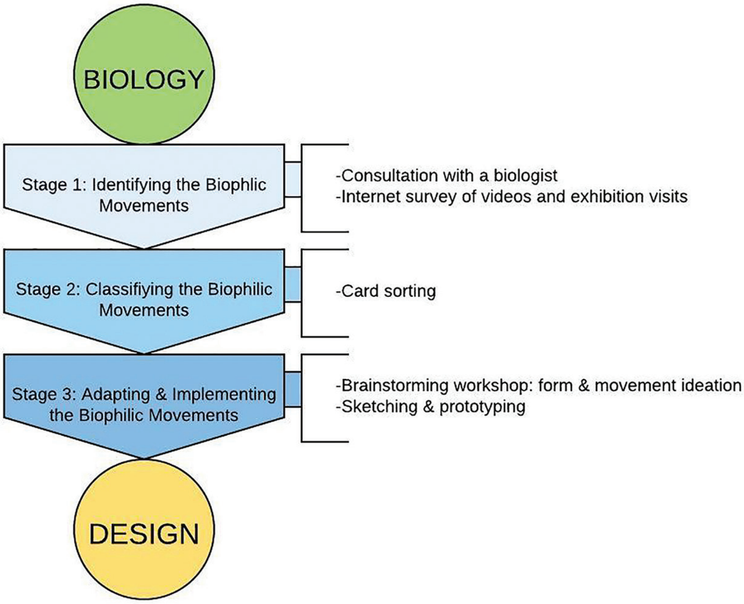


Figure 1. Biology-to-design process.

behaviours and interactions" ([37], p. 120). Initially, butterflies were observed at Carleton University's weeklong 'Annual Butterfly Show' in the department of biology. In addition, the behaviors of insects were carefully observed while attending the Insectarium, a Botanical Garden in Montreal. Lastly, a visit to the American Museum of Natural History and a special exhibition on marine animals provided more observation opportunities to study the life of sea creatures and different types of marine creature movements. This step involved careful observation as well as gathering visual materials such as videos and images (Appendix A). The visual materials collected were samples of the movements that might create a positive emotional impact on viewers. The choice of visual materials was based on ease of access to videos depicting motion details, as well as direction from the biologist.

2.2. Stage 2: classifying

The aim of this step was to categorize similar types of movements and explore if the concepts could be related to one another. Classification of the creature's movements began after observing different types of movements and participating in on-going consultations with the biologist. This phase of the research was accomplished by using a card sorting technique.

2.2.1. Card sorting

Card sorting is a design technique for meaningful categorization [37]. In this phase of the research, card sorting was conducted to generate options for structuring the information collected. The participants in this session were the biologist and design researchers. The crucial aspect at this stage was the interdisciplinary collaboration between the biologist with a background in biomechanics and locomotion and the design researchers with kinetic design interests. The biologist's knowledge assisted in better analyzing the patterns of movements in this step. Images of each of the creatures and their movements were printed onto a specific card for each one. During the session videos related to each image were also viewed to better clarify the movement pattern. The goal in this stage was to group the similar patterns of movements based on the formal qualities of direction, volume, and path.

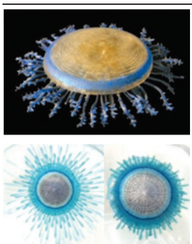
In the card sorting session, 12 cards were used with the following creatures' images: Blue-button, Feather Duster Worm, Anemone, Orange Cup Coral, Long-spined Sea Urchin, Fire Urchin, Green-and-orange Nudibranch, Christmas Tree Worms, Dragonfly, Morpho Butterfly, Sun Coral, and Ladybird. These were the creatures whose movements were identified in the previous step. They were chosen because their movements were different enough from each other and still basic enough to observe and reinterpret, and were perceived as pleasant, as opposed to dangerous. They were also simple enough to consider that the movements might contribute to generating a wider range of bio-inspired kinetic product esthetics combinations from simple to complex.

For each card, plenty of time was dedicated to watching the video, discussing, and analyzing each creature's movement. At the end of the session, biophilic movements, based on the direction and shape they formed in space, were classified into four different types: open-close, flapping, translational, and tentacle-like [**Table 1**]. At this point the classifications were primarily esthetic and not based on the kinds of mechanisms enabling the movements, however the organ that moves is indicated (e.g. Butterfly-wings).

The different categories are explained below:

In the *Change of size* category:

- **Open-close** movement occurs when an object moves outwards from a center and goes back to the center again, like the movement of strands in *Porpita porpita* (blue button).
- **Translational** movement refers to the movement of the object from one point to the other point in a direct path like the direct movement of the tentacles in feather duster worm from one point inside the tube to the other point in the same path outside the tube.

Change in size (variable volume)		**Not change in size (fixed volume)**	
Open-close	**Translational**	**Flapping**	**Tentacular (tentacle-like)**
			
Porpita porpita **(Blue-button)-strands**	**Sabellidae (Feather Duster Worm)-tentacles**	**Dragonfly-wings**	**Sea Anemone-tentacles**

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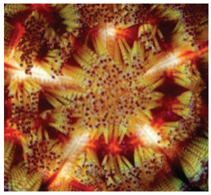
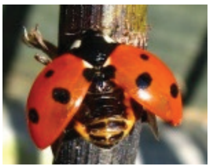
Change in size (variable volume)		Not change in size (fixed volume)	
Open-close	**Translational**	**Flapping**	**Tentacular (tentacle-like)**
 **Sabellidae (Feather Duster Worm)-tentacles**	 ***Spirobranchus giganteus*** **(Christmas Tree Worm)-tentacles**	 **Butterfly-wings**	 **Tubastraea (Orange Cup Coral)-tentacles**
			 **Long-spined Sea Urchin-tentacles**
			 **Fire Urchin-tentacles**
 **Ladybirds-elytra**			 **Feather Duster Worm-tentacles**
 **Tubastraea (Sun Coral)-tentacles**			 **Green-and-Orange Nudibranch-tentacles**

Table 1. Classification of biophilic movements.

In the *No* change *in size* category:

- **Flapping** movement refers to symmetrical wing shapes that come together and apart in unison as in a flying butterfly's wings.
- **Tentacle-like** movement is the wavy movement of an object, which does not have the same continuity or rhythm such as the movement of Sea Anemone's tentacles in the water.

Overall, while translational and open-close movements result in a change of size, flapping, and tentacle-like movements do not.

2.3. Stage 3: adapting from classification to inspiration for ideation concepts

In this stage of the study, the research aimed to translate the knowledge and insight gathered through collaborating with the science of biology into the design of interactive kinetic wearable objects. This phase of the study employed: a Brainstorming workshop, Sketching, and Rough Prototyping.

2.3.1. Brainstorming workshop: form and movement ideation

The objective of the workshop was to understand how participants might create three-dimensional kinetic models using simple materials such as paper, beads, wire, colored paper, cardboard, and foam to model their ideas. These materials were chosen since they were familiar, easy to work with and did not require sophisticated technical knowledge. This was important because the workshop participants were drawn from a convenience sample of one professor and five university students from different fields, since the participants' backgrounds were not a controlling factor. The six individuals provided their consent according to the approved ethics protocol. Four participants had design backgrounds and the others had IT backgrounds.

This workshop lasted for 2 h: it had three sections: an introduction (15 min), a working session (1:15 h), and a sharing session (30 min). In the introduction, participants were asked to design different movements with the materials provided. They were not aware of the natural movements classified in the previous stage and were not constrained to specific movements or forms. In the working section, all six participants created different forms incorporating a range of movements. In the final section, participants discussed their model/models, how it/they moved, and the source of inspiration for that type of movement [**Figure 2**].

Even though the participants were sitting beside each other, they did not copy each other's ideas. Each participant explored different forms and three-dimensional kinetic models. Some workshop participants developed similar movements through various forms. **Figure 3A** shows two different models from the workshop. Both have the same pattern of movement, but the movement is represented through different formal compositions. The final rough concepts show that, based on the models' direction of movement, some participants represented the movement through a circular or a direct path while others showed movement through a change in shape [**Figure 3**, Panels A–C]. In short, the workshop results indicated that similar movements could inspire a wide range of formal esthetics, even without inspiration from nature. Some of these movements were similar to those observed in the natural creatures in the previous stages.

Figure 2. Models developed in the brainstorming workshop.

2.3.2. Sketching and prototyping

This phase synthesized the kinetic outcomes of the two previous stages: the classification of biophilic movements (different types of movements) and the insights from the brainstorming workshop (form and movement ideation). The researcher undertook sketching and "looks-like" prototyping explorations to select and translate insights into rough, but tangible "works-like" prototypes.

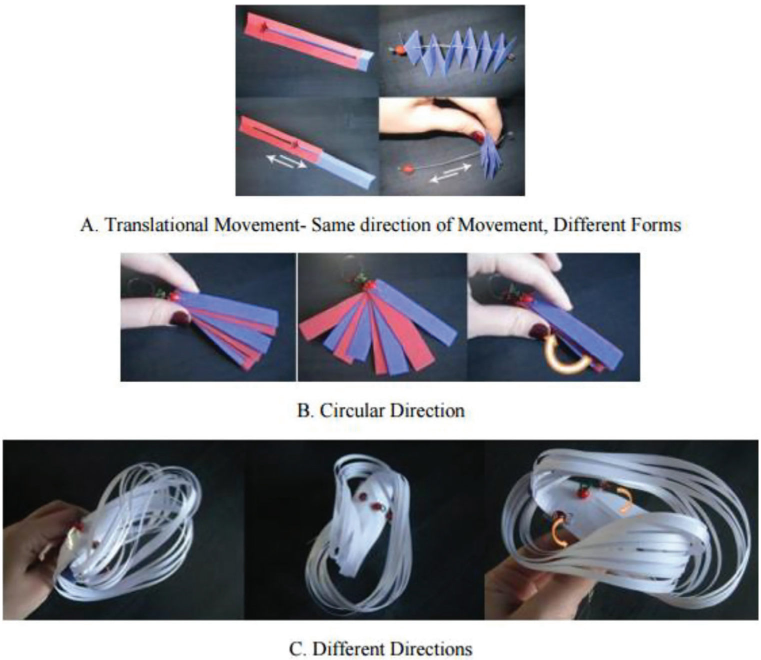


Figure 3. Different directions of movement presented through various forms.

The results of the previous phase of this research revealed the importance of form in representing movement. For example, **Figure 4** compares the same movement pattern with non-organic forms and organic forms [**Figure 4**]. Both of them have a translational type of movement. This means that the object moves in a direct path from one point to the other point. In the three-dimensional model shown on the left side, the arrows show the direction of the movement. In the image of the feather duster worm on the right side, the same type of movement occurs when it moves from one point inside the tube to the other point in the same path outside of the tube.

Based on this comparison, it seems that the form of the object has a significant impact on how the same type of movement is perceived in different objects.

Thus, concepts from the brainstorming session with an organic esthetic were selected and combined with the related types of biophilic movements taken from **Table 1**: classification of biophilic movements. The different forms and movements that were generated through two-dimensional and three-dimensional sketches are illustrated in **Figure 5**. At this point only the design researcher generated the sketches.

After the phase of sketching and initial rough model making, four different kinetic forms were selected in order to reflect the biophilic movements of **Table 1**. Each form was selected because it would best mimic its inspirational biological creature and better reveal the type of movement that specific creature embraced. This study then applied prototyping as a creative method for translating research and ideation into slightly more esthetically pleasing tangible and "works-like" physical forms for the development and testing of ideas [37]. In the more refined prototyping phase, this study aimed to integrate all four types of biophilic movements resulting from stage 2 (classification) into the design of wearable artifacts. The four types of movements are: open-close, flapping, translational, and tentacle-like.

Four different prototypes (wearable objects-brooches), with a range of different movements, were developed as testing prototypes. The creatures—butterfly, feather duster worm, anemone, and blue button—were the main inspiration for the forms and movements of the prototypes. Provisional and simple mechanisms were designed and added to the objects to make each one move in a certain direction, mimicking its inspirational biological creature. For these early experimental prototypes, the movements were activated by a hand-controlled mechanism. This is often the case in early prototypes to minimize the cost, effort, and time involved in creating working models before finalizing the design concept [38]. Mechanisms were designed and built in the biology lab, at Carleton University with the assistance of the biology professor Dr. Jeff Dawson. The prototypes were all in the form of brooches. The brooch

Figure 4. Similar movement in non-organic and organic forms.

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Figure 5. Two-dimensional and three-dimensional sketches.

format was selected because it has the least formal human factors' limitations; for example, it does not have to conform to a wrist, a finger or a neck. The premise was that it would be much easier to experiment with size and shape as well as represent different types of movements. Moreover, it could be gender neutral—an important consideration for future testing.

As shown in **Table 1**, each of these creatures exhibited specific types of movements. These four prototypes also have the same distinct movement types as described below:

2.3.2.1. Prototype A

The movement and form of this brooch were primarily inspired by the feather duster worm [**Figure 6**, Panel 2]. This brooch includes 'translational', 'open-close', and 'changing size'

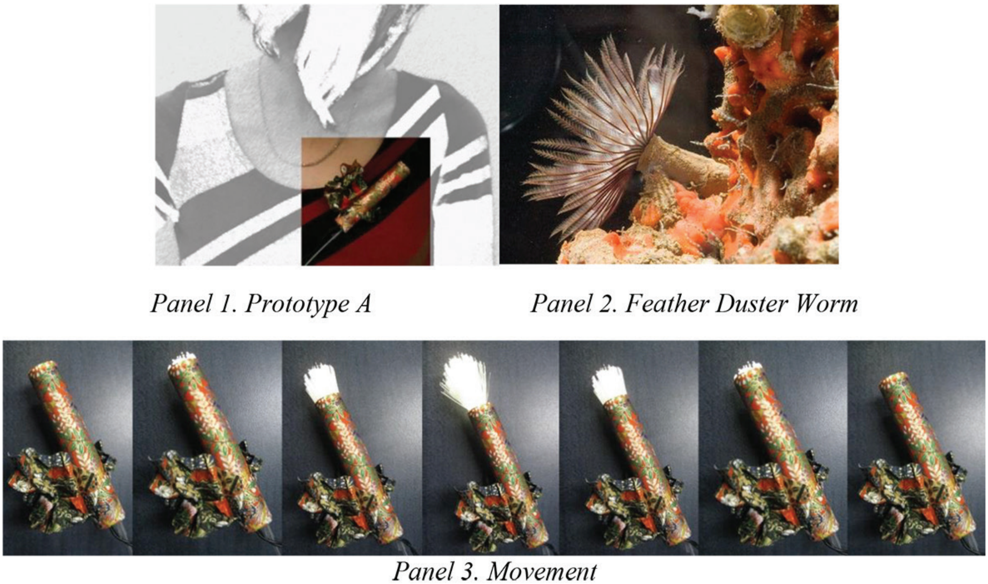


Figure 6. Prototype A.

types of movements [**Table 1**]. In this brooch, the fibers come out of the tube along one plane (translational movement), open in another direction and then close (open-close movement), and go back inside the tube again (translational movement) [**Figure 6**, Panels 1 and 3].

2.3.2.2. Prototype B

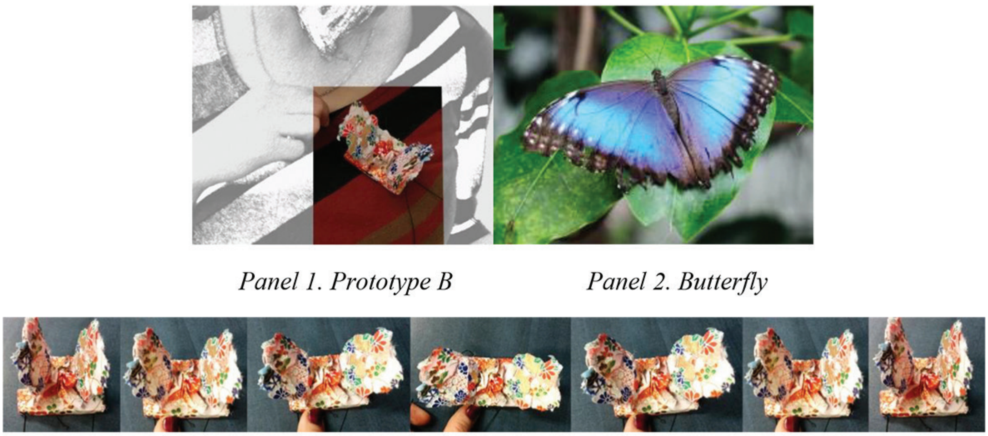
The movement and form of this brooch were primarily inspired by the movement and the form of a butterfly [**Figure 7**, Panel 2]. In this brooch, the wings have a bi-lateral symmetrical up and down movement (flapping motion) [**Figure 7**, Panels 1 and 3].

2.3.2.3. Prototype C

The movements and form of this brooch were inspired by a blue button [**Figure 8**, Panel 2]. The movements of this creature are open-close and tentacular [**Table 1**]. This marine animal has many strands, each having multiple branchlets that radiate outwards and go back inward to their previous position. In this brooch, the five attachments come out of the blue dome shape, move outward (which enlarges the overall size), and return inward again. Therefore, this brooch includes 'tentacular', 'open-close', and 'changing size' types of movements [**Figure 8**, Panels 1 and 3].

2.3.2.4. Prototype D

The form and tentacle-like movements of this brooch were primarily inspired by an anemone [**Figure 9**, Panel 2]. The organic form of the brooch consists of curvilinear strips that curl to make its shape. The prototype includes three strands filled with red beads that can be seen from inside the shape. These strands come out of the whole shape and go inside again (open-close movement). When the strands move outward, they also vibrate in a tentacle-like movement form. This prototype includes an 'open-close' and a 'tentacular' movement which also results in a change in size [**Figure 9**, Panels 1 and 3].



Panel 1. Prototype B *Panel 2. Butterfly*

Panel 3. Movement

Figure 7. Prototype B.

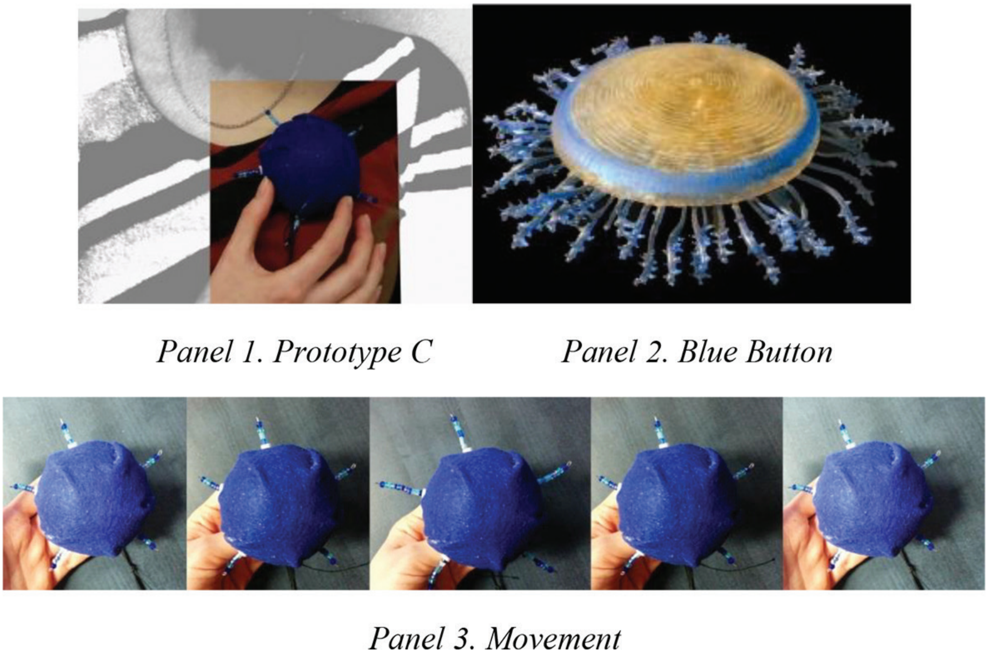


Figure 8. Prototype C.

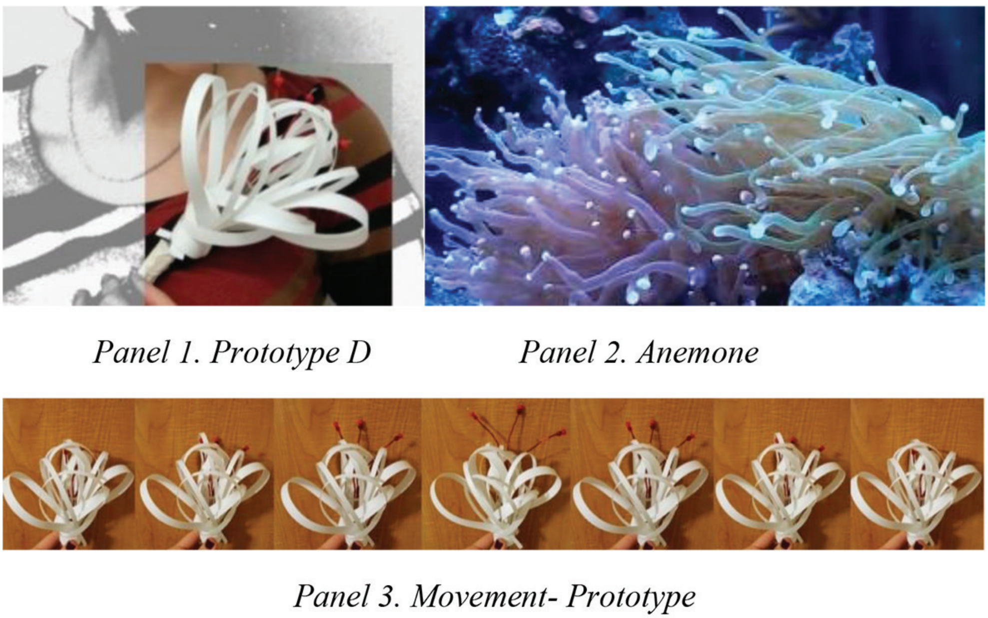


Figure 9. Prototype D.

3. Discussion

This exploratory study introduced a step-by-step process for applying a biology-to-design approach to early stages of ideation and concept generation.

3.1. Step-by-step biology-to-design approach for kinetic ideation

Each stage of this exploratory study provided useful outcomes for developing the next stage [**Table 2**]. The steps taken for adapting inspiration from biology and applying it to design esthetics followed this path:

- **Observing and identifying** natural movements with a biologist and designers/design researchers.
- **Classifying** the kinds of movements based on direction, volume, and path [**Table 1**]. These classifications were based on observations of nature and conducted in consultation with a biologist.
- **Sketching and iterative prototyping**. This stage involves synthesizing the ideas inspired from observation of movements in nature (creatures, in this case) and ideas generated by considering movement on its own.

3.2. Biophilic form and movement

This study contributes the term "biophilic movement" to the area of biophilic design. In this research, the initial focus was to take inspiration from the 'biophilic movements' found in nature. However, the findings that emerged from the brainstorming workshop indicated the importance of creating 'bio-inspired forms' as well while designing 'movement'. Therefore, it was not possible to define 'biophilic movements' without related 'forms' that represent their behaviors and movements. Ben Hopson and Young et al. indicated that form and movement are tightly correlated [8, 17]. In addition, Ross and Wensveen refer to this as a "new language of form that incorporates the dynamics of behaviour" [16].

3.3. Collaborating with a biologist

This interdisciplinary study benefitted from collaboration with a biologist at different research stages. As illustrated in **Figure 1** and described in **Table 2**, working with and consulting the biologist throughout stages one and two was important for generating innovative and creative outcomes. In stage one, the biologist provided expert insights related to the science of biology as well as more exposure to this discipline. In stage two, the collaborative card sorting provided a scientific approach to categorizing the types of biological movements. This indicates that biologists who study the movements of specific species may be able to recommend suitable sources of inspiration and provide designers with examples of organisms that may be of interest as design inspiration.

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	Stages	Method	Explanation	People involved	Purpose	Result
Biology	Stage 1. Observing and identifying the biophilic movements	Internet survey of videos and exhibition visits	On-going consultation with a biologist Observation of: plants and animals (marine animals, butterflies, and other insects) in natural settings, videos, and exhibitions	Design Researchers and a biologist	Gathering visual materials and information on samples of movements in nature that might create a positive impact and emotional responses on viewers	Identifying examples of creatures' movements that might create positive emotional responses in people
	Stage 2. Classification of biophilic movements	Card sorting	Grouping the similar patterns of movements based on the formal qualities of direction, volume, and path	Design Researchers and a biologist	Categorizing similar types of biophilic movements gathered from previous stage	Classification table (types of biophilic movements: open-close, translational, tentacular, and flapping)
Design	Stage 3. Ideation	Brainstorming workshop: form and movement ideation	Practicing creating three-dimensional kinetic models (this step was conducted apart from the previous section)	Convenience sample of one professor and five university students from different fields	This workshop was conducted to understand types of movements participants create without paying attention to the biological inspiration	Describing the importance of form in representing movement. It is not possible to define 'biophilic movements' without related 'forms' that represent their behaviors and movements
		Sketching and prototyping (adapting the biophilic movements)	Sketching organic forms and synthesizing the forms with the biophilic movements derived from classification table	Sketching: researcher only Prototyping: researcher and a biologist	Creating ideation and initial "looks-like" prototypes that represent biophilic movements	Creating "works-like" design prototypes of interactive brooches with kinetic esthetics

Table 2. Step-by-step biology-to-design approach for kinetic ideation.

3.4. Observation

In stage one, the Internet survey of videos and exhibition visits, and the deep observation in the science of biology was an exciting technique for a researcher with a design background. This kind of observation is valuable in 'bio-inspiration' for becoming familiar with the behaviors and interactions of creatures in their natural environments (a sort of animal ethnography). Part of this observation was done with real creatures in museums and exhibits, and part was done virtually through videos and images. Closely observing the behaviors of creatures helped in better analyzing the patterns of movements. While observing different species and creatures, it was important to keep a record of the creature movements that seemed to evoke positive feelings in viewers since the focus of the study was on 'biophilic movements'.

3.5. Limitations and further research

This study was part of a larger qualitative research project focused on identifying terms for and emotional responses to biophilic inspirations. As a result, the prototypes from this study were later evaluated by another set of participants. Testing different prototypes with various biophilic movements could provide more complete knowledge about this topic.

Given that the study focused on a narrow set of sea animals and insects due to time constraints, there is potential for studying a wider range of animal and plant movements and expand the **Table 1**. The initial step of identifying and observing biophilic movements could also be applied to different kinds of biological sources of inspiration and used as a guideline for kinetic designers in the area of biology-to-design.

This preliminary study focuses on biologically based movements and the qualities of direction, volume, and path, not on the mechanisms that generated the movements. Further study would benefit from investigation into the mechanisms of the movement in order to develop the technical requirements for implementing the concept.

In addition, the Brainstorming workshop participants were not exposed to the results of the earlier creature studies. If future participants could be exposed to the natural movements previously classified, the participants might generate more bio-inspired concepts. Moreover, the materials for the workshop were primarily two-dimensional. A more advanced workshop could use more sophisticated materials and/or parts with Arduino programming of kinetic movements.

In this study, biophilic movements were designed for "looks-like" and "works-like" prototypes of jewelry pieces and activated by the researcher manually. In further studies, prototypes could be made using Arduino and sensor technologies to replicate nature more accurately. This would also provide the opportunity for different movement variables, such as speed, time or beat, continuity, direction, volume, and rhythm.

4. Conclusion

This study is preliminary research into inspiring idea generation for biophilic movements for kinetic and interactive artifacts. It contributes a step-by-step biology-to-design approach for

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kinetic ideation. In particular, it highlights the importance of collaborating with a biologist when collecting, observing, and classifying natural movements.

Appendix A: Internet survey of videos and exhibition visits

Exhibition: Carleton University's 'Annual Butterfly Show', Ottawa, Canada.

Museums: Canadian Museum of Nature, Ottawa, Canada | American Museum of Natural History, New York, USA | Insectarium, Botanical Garden, Montreal, Canada.

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