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SHARE: Building Bioinspired Prototypes using LEGO SERIOUS PLAY

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Motivation or Challenge

Students often are taught a single health-technology design process, such as the Biodesign Innovation Process, over multiple semesters. However, many academic programs expose students to additional health-technology design processes through technical electives. When teaching students a *completely new* design ecosystem and process within the confines of a *single* semester-long course, there is generally no prerequisite foundation laid to support assigning a single, semester-long final design project. Students do not have previous foundational course experience with the other unique design frameworks. An inquiry-based learning (IBL) experience using LEGO® SERIOUS PLAY® (LSP) is one of three scaffolded assignments allowing students to practice nature-inspired design concepts and skills in low-stakes assignments before implementing them in a final design project in the course entitled "Biomimicry, Biomimetic, and Bioinspired Approaches to Medical Device and Technology Design" [1]. All students in two offerings of the course have been familiar with LEGO. LSP permits students to use something familiar to creatively learn the translation of bioinspired structure and function to an engineering prototype prior to students learning about nature-inspired concept-knowledge (C-K) design maps and being assigned the final design assignment.

Learning Objectives

The assignment occurs within the context of a technical elective within the curriculum's medical device track. The five learning objectives for building a nature-inspired prototype using LSP are: (1) Enhance design thinking in biomedical engineering, (2) Apply design thinking to nature-inspired design spanning biomimicry, biomimetic, and bioinspired approaches to medical device and technology design, (3) Synthesize biology, physics, engineering, and robotics, (4) Create a nature-inspired prototype to meet a functional goal, and (5) Develop teaming and communication skills. The learning objectives align with the department's undergraduate program outcomes [2] and Bloom's revised taxonomy required by the university's College of Engineering.

Implementation

This assignment is introduced during week 3 of the course and is delivered to students in one or two 80-minute class sessions. The initial two weeks of the course focus on nature-inspired design thinking and analysis of contemporary nature-inspired medical devices and technologies. This expands the students' awareness of the wealth of medical devices and technology that have been developed using nature-inspired design principles. Before class in week 3, students are required to pre-read four manuscripts discussing nature-inspired needles and their applications [3-6] deployed on the Canvas learning management system to prepare students for how to translate nature into engineering design. Self-assembled student teams (4-5 students per team) are asked to select a specific flora or fauna from a curated list deployed on Canvas and then spend 10-30 minutes performing a deep dive on the biological organism selected (assignment presented in Appendix 2). The instructor curated the list by selecting flora and fauna known to demonstrate grasping aspects, thereby facilitating the assignment not being too open-ended. Then, the teams are asked to spend 10-30 minutes ideating to translate an aspect of the biological organism into a plan to grasp a yellow sphere, without *a priori* knowledge of what LEGO kits they will have. Teams are each then given two LEGO kits (484-piece Classic kit 10696; 564-piece BricQ

Motion Prime kit 45400) and asked to develop a nature-inspired prototype using LEGO bricks and specialized pieces with the end functional goal of grasping and holding a 2-inch plastic sphere. Teams are given 30 minutes to develop working prototypes. Students are free to use any ideation or brainstorming method they would like to employ. These methods are taught in earlier engineering design classes in the curriculum. Next, the five teams are collectively given 15 minutes to orally share their ideation and prototype with the class (Appendix 3). This is a "just in time" presentation without the creation and use of presentation slides. Finally, the entire class participates in open discussion to answer two sequential prompts: (1) What is needed to take their prototypes to the next level? (2) What are the advantages of nature-inspired grasping over traditional robotic grasping methods? The instructor facilitates response to the structured questions using the Socratic method to have students reflect and refine their responses. Students are previously exposed to robotic grasping in freshman physics, other core courses in the junior year of the biomedical engineering curriculum, and initial weeks of lecture content of this course, but this knowledge content could be added to the assignment as another layer of the teaching scaffold. The assessment rubric for the assignment is in Appendix 4.

Situational Factors and Replication

The initial two weeks of the course focus on bioinspired design thinking and analysis of contemporary bioinspired medical devices and technologies, providing students with the necessary knowledge and context for the assignment. The assignment described herein allows the instructor to be a "guide on the side" while the students actively discover bioinspired design principles and translation through discovery and teaming. Specifically, the instructor roams the room and acts as coach to the teams to foster student-centered learning, autonomy, and active engagement. This learning activity has been conduct using 5 or 10 teams and can be scaled to a larger number of teams. Student teams consisted of 4-5 students, but they could be made smaller, with the number of LEGO kits being the limiting factor. The assignment has been delivered to students in either one or two 80-minute class sessions, with one session working well for a small number of teams and extra time for a larger number of teams. This is largely to account for the extra time required for oral presentations. Both a lecture-style and active learning classrooms (i.e., room with teaming tables) have been used and work equally well if students can spread out in the lecture-style room. The timed tasks of the assignment maintain student focus and engagement. A description of all activities in this course has been recently published [1].

The assignment presented is not restricted for use as a scaffolding assignment to teach nature-inspired design. The assignment may be applied to a variety of design and engineering-based courses that require students to translate a concept into a prototype using engineering first principles. LEGO may be used to teach structural, mechanical, and software principles through hands-on, iterative design challenges. The familiarity of students with LEGO facilitates students focusing on the translation of knowledge and ideas rather than being distracted by developing prototype parts.

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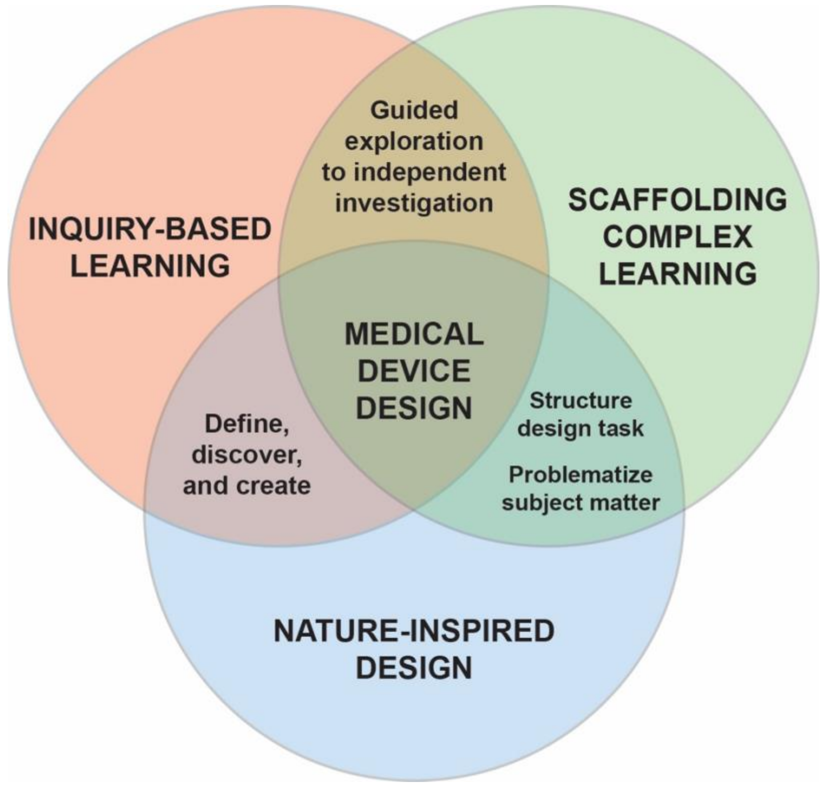
APPENDIX 1 – Theoretical Framework.

This novel initiative lies at the intersection of three engineering education frameworks (Appendix 1-Figure 1). Inquiry-based learning (IBL) is a well-recognized pedagogical approach for Science, Technology, Engineering, and Math (STEM) education [7, 8]. Students are placed in authentic learning environments and allowed to explore, communicating with one another and working collaboratively to construct their own knowledge as they interact with the material [9, 10]. That is, IBL emphasizes student-centered, active, and constructivist approaches to knowledge acquisition through exploration and problem-solving rather than direct instruction [11]. The IBL framework has been used by others to successfully teach mechanobiology [12], tissue engineering [13], structural engineering [14], electronics engineering [15, 16], and engineering design [17].

Scaffolding is a pedagogical tool that assists students in improving essential skills and competencies by engaging them through a series of authentic experiences and open-ended problems [18-20]. Scaffolding was first defined by Wood et al. [21] and expanded through Vygotsky's theory of zone of proximal development [22]. Scaffolding learning is a proven pedagogical technique that improves student engagement [20, 23]. Mallibhat describes thirteen different scaffolding models that suit design-based courses, spanning five categories: teachers, peers, activities, projects, and multimodal resources [20]. The scaffolding in this paper employs activities to upskill students with the knowledge and skills required for the final design project. Others have successfully employed scaffolding in design learning [20, 23-26] and for scaffolding complex learning [27, 28].

Nature-inspired design is a design framework that copies nature directly (biomimicry); emulates structure-function relationships, systems, or elements of nature (biomimetics); or takes an idea from nature, learns from it, and improves upon it to develop something novel (bioinspired) [29-31]. This design process is known to be distinct from the Biodesign Innovation Process [32, 33]. The Biodesign Innovation Process is needs-driven with a human or clinical starting point and a identify (needs) → invent (ideate, prototype) → implement (business and regulatory) pathway, whereas nature-inspired design employs biological observation as a starting point and a define (problem) → biologize (bio-translation) → discover (strategies) → abstract (emulate) pathway. Nature-inspired design is viewed by some as a subset of design-by-analogy [34, 35]. The nature-inspired ecosystem employs C-K design theory for engineering design ideation [36-43]. C-K theory was introduced by Hatchuel and Weil [36, 37]. This theory posits that design is modelled at the interplay between two interdependent spaces that possess differing structures and logics, namely a concept (C) space and a knowledge (K) space. As stated by Nagel et al., C-K theory does not rely on a particular engineering design approach; rather, the design theory relies on the process of discovery [40]. Hence, this design theory is a natural fit with an IBL framework. C-K theory has been employed in various engineering design contexts, including nature-inspired design [38, 40-43].

This activity utilizes LSP. Since its launch in 2002, LSP has been used in higher education learning communities [44, 45] and in engineering design [46-50].



Appendix 1-Figure 1: The intersection of three frameworks supporting the novel initiative for teaching medical device design.

APPENDIX 2 – LEGO assignment presented to the students.

PROJECT: NATURE-INSPIRED GRASPING

LEARNING OBJECTIVES

The learning objectives of this project are to:

- Enhance design thinking in biomedical engineering.
- Apply design thinking to nature-inspired design.
- Synthesize biology, physics, engineering, and robotics.
- Create a nature-inspired prototype to meet a functional goal.
- Develop teaming and communication skills.

Nature-inspired refers collectively to biomimicry, biomimetics, and bioinspiration. In this project you will focus on creating a nature-inspired grasping prototype using Lego bricks. Grasping devices can be translated into numerous applications, such as robotic surgery, assistive devices, etc.

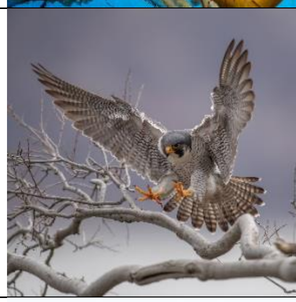
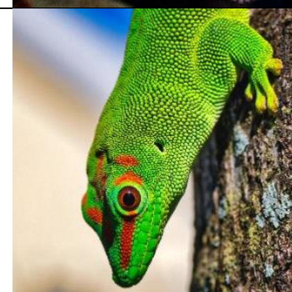
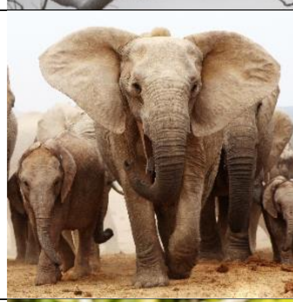
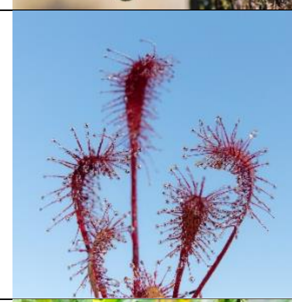
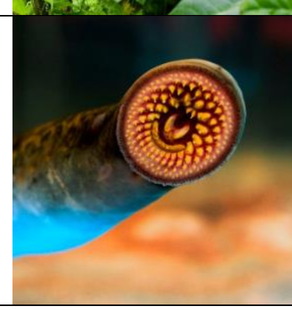
TASKS

- 10 minutes: Team members select <u>one</u> nature focus from Table 1 to garner inspiration. Do a deep dive into the organism.
- 10 minutes: Translate nature into a plan (ideation).
- 30 minutes: Develop a nature-inspired prototype using Lego bricks with the end goal of grasping/holding a sphere.
- 15 minutes (class): Share the inspiration and the prototype with the class.
- 15 minutes (class): Answer the prompts:
    - What is needed to take the prototype to the next level – to demonstrate functionality?
    - What are the advantages of nature-inspired grasping over traditional robotic grasping methods?

DELIVERABLES

- Prototype (team)
- Oral presentation (team)

Table 1. Nature foci

Critter	Photo	Critter	Photo
Jelly Fish		Octopus	
Falcon		Gecko	
Elephant		Drosera	
Chameleon		Pole Beans	
Snake		Lamprey	

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- Falcon-inspired aerial grasper: https://www.dailymail.co.uk/sciencetech/article-10263591/Engineers-create-robotic-bird-grasp-branches.html; https://www.science.org/doi/full/10.1126/scirobotics.abj7562
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- Rose-inspired gripper: https://techxplore.com/news/2023-07-rose-revolutionary-nature-inspired-soft-embracing.html#google_vignette; https://techxplore.com/news/2024-09-rose-gentle-versatile-robotic-gripper.html
- Pole bean-inspired gripper: https://opg.optica.org/oe/fulltext.cfm?uri=oe-28-23-35158&id=442320; https://www.therobotreport.com/how-pole-beans-inspired-this-soft-robotic-gripper/
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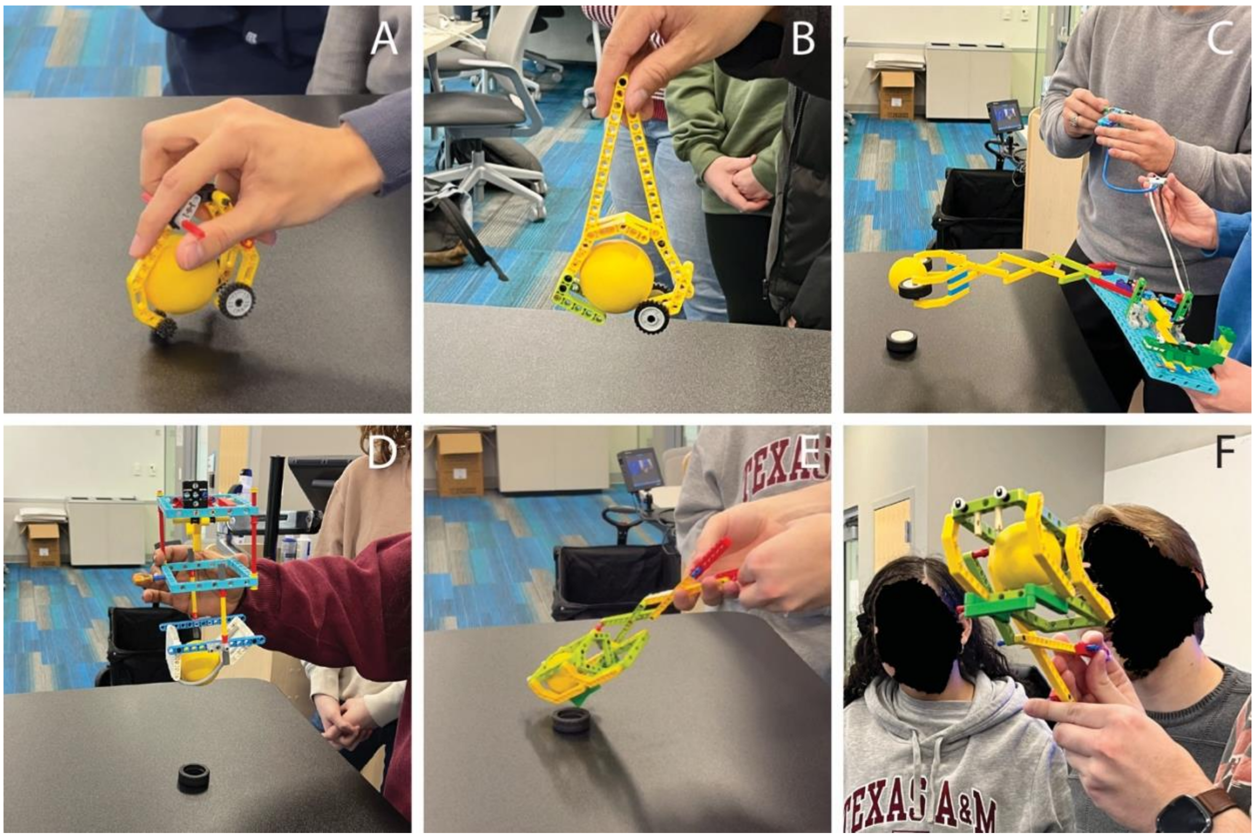
APPENDIX 3 – Examples of nature-inspired prototypes resulting from the assignment

(A, B) Prototypes inspired by a hawk's claw. (C) A prototype inspired by a chameleon's tongue. Pneumatics are used to extend and close the grasping end. (D) A dual-mode prototype. The bottom is inspired by a hawk's claw and the soft aspects of a jelly fish. A claw-like structure and pressure plate capture the ball and jelly fish-like structures retain the ball. The top is inspired by a hawk's claw and lamprey teeth. A claw-like structure and pressure plate capture the ball and lamprey-like teeth retain the ball. (E, F) A snake-inspired prototype. Independent jaws open and extend to capture the ball and python teeth retain the ball.



APPENDIX 4 – Assignment Grading Rubric

(maximum total 15 points)

Criteria	Exceeds Expectations (3)	Meets Expectations (2)	Below Expectations (1)
Prototype Function	Prototype fully meets (or exceeds) core performance goals reliably and repeatably; elegant, robust solution	Prototype meets main functional requirements consistently under normal conditions	Prototype does not function or barely functions for intended purpose
Translation of Nature	Sophisticated translation of the nature inspiration into an engineering design	Some translation of the nature inspiration into an engineering design, but inconsistent or superficial application	Little to no translation of the nature inspiration into an engineering design
Use of Resources	Highly original use of Lego parts; goes significantly beyond standard/expected designs	Some original thinking, but mostly conventional approaches	Poor use of Lego parts without meaningful adaptation
Teaming	Excellent evidence of shared leadership, iteration, equitable contribution, constructive feedback, and systematic design process	Good teamwork; most members contribute meaningfully; some iteration visible	Very little teamwork evident; one person dominates or chaotic process
Oral Presentation	Effective communication	Satisfactory communication but some elements are missing	Poor communication of prototype's motivating inspiration, translation to engineering, and mechanics of the prototype