
AC 2012-3473: BIOMIMICRY INNOVATION AS A TOOL FOR DESIGN

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Biomimicry Innovation as a Tool for Design

Abstract

A modified form of Problem-Based Learning (PBL) was employed to apply the ideas of innovation and biomimicry to ergonomics problems. This Biomimicry Innovation Tool (BIT) begins with a focus on nature's laws as a starting point to design and allows students to uncover evidence that will enable the useful application of the laws of nature to solve a technical ergonomics design problem. The BIT blends aspects of problem based learning, innovation, biomimicry, and ergonomics into a single student experience.

The prototype BIT was applied and assessed in an undergraduate ergonomics course. The program the students were in requires alternating twelve-week terms of academics and cooperative education employment. The students began by individually identifying an ergonomics concern at their co-op workplace and providing a one-page written description of the concern. The concern was then passed along to another student to innovate a nature-based solution to the concern. Using a step-by-step approach, students formed an idea that evolved into a solution. A grading rubric allowed the professor to fairly and objectively evaluate the final presentations. The prototype BIT will be modified based on student assessment data and experiences in the classroom.

Purpose

Students can be empowered to learn by balancing academic and experiential educational processes with a goal of work-integrated learning. Integrating work experiences with the educational process can be facilitated by specific activities and intentional assessment. Intern, co-op and capstone experiences and preparation for professional certification provide learning experiences and relevance in technical programs.^{1, 2} Through engagement in problem-based learning and experiences in the innovation process in the classroom, students may come to appreciate the importance of developing their professional identity by integrating classroom resources and experiences with work/life applications. In addition, learning is enhanced through the preparation of a professional presentation. Critical thinking is encouraged through the assessment of peer presentations. The authors believe that students need to be strong not just at solving well defined technical problems, but should be able to identify problems worth solving, be able to generate a wide array of possible alternatives to a given design problem, and understand the commercialization considerations associated with a given design alternative. The prototype Biomimicry Innovation Tool (BIT) described herein is an attempt to integrate these other aspects into the academic design curriculum. Please note that the BIT was formerly referred to as Tool for Inspiring Innovation in the Classroom with an emphasis on Biomimicry or commonly referred to as TIIC-b.

The purpose of this paper is to provide background and details for the final innovation presentation required in an ergonomics class to introduce the principles of biomimicry. In contemporary engineering education, there is a need to incorporate activities showing relevance

to professional practice within the STEM classroom.³ An educational process tool is necessary to actively engage students in the design process by applying the contemporary topic of biomimicry to a real-life scenario.

Background

Problem Based Learning

The term “problem-based learning” (PBL) is used in medical education in the United Kingdom. This method of teaching and learning in small groups has had a positive impact on medical education and is also relevant to engineering education. In PBL, students are tasked with a problem scenario and must do independent, self-directed study before returning to the group to discuss and refine their acquired knowledge. Such group learning facilitates not only the acquisition of knowledge but also several other desirable attributes such as communication skills, teamwork, problem solving, independent responsibility for learning, sharing information and respect for others.⁴

PBL is a natural component for work-integrated learning institutions and follows the theory that students “learn best by doing.”

Innovation

The importance of innovative thinking is described by Curtis Carlson in his book *Innovation*. He describes the rationale for development and growth through the innovation process using the Five Disciplines of Innovation.⁵

- Important Needs: Work on important customer and market needs, not just what is interesting to you.
- Value Creation: Use the tools of value creation to create customer value fast.
- Innovation Champions: Be an innovation champion to drive the value-creation process.
- Innovation Teams: Use a multidisciplinary, team-based approach to innovation to create a collective, genius-level IQ
- Organizational Alignment: Get your team and enterprise aligned to systematically reproduce high-value innovations.

After the Five Disciplines of Innovation, the NABC approach is described by Carlson and others as a simple way of envisioning the process of innovation and is aligned with engineering education. The tool described in this paper was motivated by previous classroom tool attempts including the original Contemporary Issues that Impact Engineering Solutions (CITIES).⁶ The inspiration for redesign was a result of the need to integrate innovation into the classroom and an introduction to Biomimicry. Biomimicry, or seeking design inspiration from nature, is one of a variety of systematic techniques designed to facilitate generation of a wide array of concepts to address a given design problem. In the context of Carlson’s NABC, the proposed project has the following attributes:

- Needs: Faculty and students have a need to innovate and design using contemporary ideas and technology. Many faculty members teach a variety of different classes and need some common teaching tools that will enable them to inspire innovation in many different classes. Students need to see how classroom topics can be applied and create value through the design of an innovative product or service. Both faculty and students need topics in the classroom that are relevant and applicable in the modern world. Students seldom learn structured techniques (beyond brainstorming) that can aid in the concept generation technique.
- Approach: Provide a flexible procedure for students to work on a project related to syllabus topics and allow innovative design ideas to be researched and presented to the class. The students will use the NABC methodology along with biomimicry design principles to inspire innovation. A standard rubric will be provided for assessment.
- Benefits per cost: Students benefit by demonstrating their ability to “walk the entrepreneurial talk” by becoming innovators related to a course topic. In addition, the students will present their idea to peers. Instructors will have a tool that can be used in multiple classes and a rubric to enable fair grading. The rubric will enable students to know what is expected in the presentation. The only cost is time for students to prepare and present their ideas. Of course, the students can address financial aspects of their idea in their pitch.
- Competition: The competition to the BIT process is the informal process of telling students to “present your idea on how to use biomimicry applied to a course topic.” The resulting presentations will be highly variable, difficult to assess fairly and students feel frustrated with such an open-ended project without a process for completion.

Innovation is a necessary component to work-integrated learning institutions and should be fostered across the curriculum.

Biomimicry

Biomimicry begins with a focus on Nature's Laws as a starting point to design. DaVinci used biomimicry as he studied birds in his attempt to enable human flight. While he was unsuccessful in attempt, he was an inspiration for this new and important field of innovative study. The possibilities of design through the natural world are limitless and the applications for human benefit are many.

The term “Biomimicry” refers to design that is inspired by nature. The Biomimicry Institute⁷ was founded in 2005 by science writer and consultant Janine Benyus, in response to overwhelming interest in the subject following the publication of her book, *Biomimicry: Innovation Inspired by Nature*.⁸ In the book, Benyus presents seven biomimicry principles that describe nature's laws, strategies, and principles:

- Nature runs on sunlight
- Nature uses only the energy it needs
- Nature fits form to function
- Nature recycles everything

- Nature rewards cooperation
- Nature banks on diversity
- Nature demands local expertise
- Nature curbs excesses from within
- Nature taps the power of limits

Biomimicry can enable an engineer to generate fresh, new designs.

Ergonomics

Ergonomics is the study of the role of human beings relative to their surroundings with a goal of a safe, healthy and productive working environment. The International Ergonomics Association defines ergonomics as:

Ergonomics (or human factors) is the scientific discipline concerned with the understanding of interactions among humans and other elements of a system, and the profession that applies theory, principles, data and methods to design in order to optimize human well-being and overall system performance.⁹

Specifically, physical ergonomics is concerned with human anatomical, anthropometric, physiological and biomechanical characteristics as they relate to physical activity. The relevant topics include working postures, materials handling, repetitive movements, work-related musculoskeletal disorders, workplace layout, safety and health.

The Industrial Engineering student typically takes at least one introductory course in ergonomics as part of their undergraduate curriculum. Thus, work integrated learning is a natural fit due to the presence of workplace features and discussions that necessarily happen in this type of class. Innovation is necessary as new workplaces and equipment are brought into the workplace with increasing speed and complexity. Biomimicry seemed like an interesting application for physical ergonomics problems since nature faces and adapts to numerous environmental conditions and potential hazards.

Bringing it All Together

These four fragmented topics – PBL, Innovation, Biomimicry and Ergonomics – are brought together in the engineering educational process through an educational design tool called the Biomimicry Innovation Tool (BIT). The tool includes not only the step-by-step design process, but also adds a grading rubric to enable fair assessment of the student design. This tool is being used in an undergraduate engineering classroom with learning assessment measures forthcoming. Figure 1 is a simplified illustration of the student thought process for redesigning a work scenario using nature to provide inspiration for potential solutions. A traditional lecture introduces the ergonomics problem of back-breaking work and is discussed from a textbook theory approach within the ergonomics classroom. The possible design solutions are varied and the problem-based learning technique enabled through the BIT directs the students to follow a clear process including nature-inspired solutions. The BIT process is motivational, educational and clearly defined with a grading rubric that is provided to the students ahead of time.

Problem: Awkward postures required for working



What can we learn from an elephant's trunk?



Figure 1: Innovative Design Scenario

Learning Objectives

Using the BIT educational process students will have the opportunity to refine innovation skills through biomimicry design, engage with the course content in a different way, and present a compelling argument to student classmates. The purpose can be expressed with four learning objectives:

- *connect* innovation methodology with biomimicry design principles and apply to classroom topics;
- *demonstrate* the ability to innovate using the NABC philosophy; N=Needs, A=Approach, B=Benefits per cost, C=Competition
- *describe* an ergonomic design idea inspired by nature using the NABC approach, and
- *assess* communication skills through peer evaluation.

The entire task is broken down in a step-by-step process to insure consistent delivery and assessment. The process was developed using the biomimicry design process and can be applied to any situation that demands similar learning and communication skills.

The Plan

There are four basic steps to the overall plan for completion. The scenario described in the first two steps can be modified for any problem-solving or design course and may even be archived for later use. The first usage of this tool was in an Ergonomics class for Industrial Engineering students and the field of Ergonomics lends itself to biomimicry applications.

1. Create a scenario of an (ergonomic) issue ideally from co-op work experience, but potentially from some life experience. This scenario will become the basis for a design inspired by nature for analysis by a classmate. The scenario should be one-page and include four elements:
 - (1) Course topic from syllabus
 - (2) Function needed by innovation
 - (3) Text description of problem (1-3 paragraphs)
 - (4) Picture or sketch of scenario
2. Share your scenario with a classmate (next student alphabetically on roster) and receive scenario from another classmate (prior student alphabetically on roster.)
3. Follow “The Steps” provided in Figure 2 and prepare a 10 minute presentation.

4. After presenting and submitting the presentation, peer- and self-assessment will enable a reflective summary of the entire activity.

The peer assessment portion of the plan engages the audience and provides other students the opportunity to contribute to the learning experience. The presenter will receive more than just a grade as feedback. They will receive both comments from the instructor as well as comments from peers on their approach.

The Steps

As a professional in a technical field, engineering graduates are expected to integrate design solutions from theory, personal experience, discovery, and the larger body of professional literature. The product of this integration is often a conference presentation, business proposal delivered in person, or a presentation to colleagues. This synthesis of knowledge often takes place at high levels of performance in professional situations.

In the classroom, however, the process will utilize knowledge from personal and/or published cases of application. The student will need to know the topic well enough to see the connections between the theory and practice in relevant applications. In addition, the professionally-aligned values of accuracy and precision, clarity, and practicality are essential to achieve a quality presentation as a result of this process.

The commonality between professional presentations and classroom presentations are two broad goals. The first goal is a good design that integrates the needs of the customer with innovative technical expertise. The second goal is to communicate the design in a manner that is logical, interesting and compelling. The Steps outlined in Figure 2 attempt to formalize the design and communication process for an innovative technical design based on the principles of biomimicry.

The first step directs the student to begin by gathering information. A summary of the topics addressed in the course will provide the opportunity to reflect on the topics from the syllabus and how those topics might be applied to a real design problem as defined by a peer. Brainstorming bio-applications and customer needs will allow the student to consider a fresh perspective before jumping into a solution.

The second step, analysis, attempts to challenge the student to think differently about analysis by looking critically at pairs of bio-applications with functional needs. Optimistic and pessimistic views provide an opportunity to weigh the pros and cons and stretch beyond the obvious to the unique. This analysis step leads into the third step, design a plan, where many students are tempted to begin without the reflection and critical thinking necessary for innovative biomimicry solutions.

The fourth and final step is the communication piece of designing slides and practicing delivery. If the first three steps are taken seriously, the slides will practically write themselves. Observational data has shown that students who follow each step in detail will deliver a good design that integrates the needs of the customer with innovative technical expertise that is communicated in a logical, interesting and compelling manner.

<i>Biomimicry Innovation Tool (BIT)</i>	
Step 1: Information Gathering	
1. Summarize course topic.	Review the course topic from classroom materials, and summarize key ideas.
2. Problem/Function definition	Review scenario provided by classmate. Make a list of what you know about the problem and define the key functions needed
3. Bio-applications	Make a list of bio-applications that may perform a similar function, even if only remotely related.
4. Define customer needs (N)	Brainstorm (Painstorm) important functional needs related to the scenario and course topic.
Step 2: Analysis	
5. Pair	For every function, pair up bio-applications that may perform the function. Refer to the biomimicry functional taxonomy at aksnature.org when looking for nature's solutions to the critical functions. Pick the most promising matches.
6. Optimism	List what could be possible if one or more function/bio-application pairs performed the intended function
7. Pessimism	List reasons why a function/bio-application pair is unlikely to work.
8. Synthesis	Use the lists to re-evaluate each pair and/or re-consider other pairs
Step 3: Design Plan	
9. Identify approach. (A)	Describe an approach that will provide an innovative product or service inspired by nature to meet the customer need.
10. Identify benefits per cost. (B)	Describe the benefits to the customer's use of the proposed product or service. Provide a realistic estimate for any costs involved with the innovation.
11. Identify competitors. (C)	Provide insights on the competition found. Are there other options to meeting the functional needs?
Step 4: Communicate Idea	
12. Create slides and notes.	Begin the presentation with a 90 second elevator pitch. Prepare a logical outline. Add notes to each slide to guide the speaker. Be sure to cite sources.
13. Practice delivery.	Use the slides and notes to deliver the presentation to a test audience. Keep track of the time (<10 minutes) and ask for constructive feedback from the listeners. Refine the presentation prior to delivery.

Figure 2: The Steps

Assessment

Self and Peer Assessment

After the student has delivered the presentation and gathered feedback from the audience, it's time to reflect upon the entire activity. It is inherently relevant to engineers to understand and analyze how the world works and the learner becomes actively engaged in the learning process. In addition, this activity allows the student to review their biomimicry innovation with feedback from the "customer" and build upon the principles discussed in the classroom. The experience can tie together classroom concepts with innovative ideas.

Think about the purpose of the activity and review the Performance Criteria. Then, use the SII assessment process to formally assess the experience.

Strengths *(and why they are relevant and important)*

Areas for Improvement *(with an action plan to implement each)*

Insights *(include the impact of the new perspective)* What surprised you during the BIT preparation? What trend do you predict for the future based on your topic?

This SII Assessment is performed as a peer assessment between students as well as a self-assessment upon completion of the presentation

Instructor Assessment

The instructors goal should be to insightfully apply course topics by integrating them into an innovative design using biomimicry as an inspiration for design. The design should be assessed by a professional presentation to peers. From the students perspective, the goal is typically to optimize their grade. A strong and fair rubric will allow both the instructor and the student the chance to meet their individual goals. The instructor may use the following grading rubric for performance evaluation.

	5	4	3	2	1	0	Points Possible	Points Earned
	Exemplary	Adequate	Need minor revisions	Need major revisions	Off target	Not done		
Performance criteria								
Factor 1: 90-Second elevator pitch to summarize the presentation	20	17	15	10	5	0	20	
Factor 2: Clear and concise description of problem and functional requirements	20	17	15	10	5	0	20	
Factor 3: Meaningful application of Biomimicry using NABC innovation approach	20	17	15	10	5	0	20	
Factor 4: Quality presentation materials – post to BB	20	17	15	10	5	0	20	
Factor 5: Thorough documentation of references	10	7	5	3	2	0	10	
Evidence that scenario was developed, BIT methodology was followed and SII thoughtfully completed	10	7	5	3	2	0	10	
							TOTAL	_____

Example

This section will summarize the work of one student¹⁰ from the winter 2011 term following the order of the slide presentation. Additional student work will be presented at the conference.

The student began by summarizing ergonomic course topics of heat stress and high humidity in the work environment. The scenario that was given to him by a student peer was that of workers in an engine assembly plant in Guangdong, China where employees are required to wear full cover clothing during normal work hours. The temperature of Guangdong is hot and humid and the workers are affected by heat stress. The student then discussed bioapplications of a termite mound for building efficiency, a black mangroves roots for distribution of heat and a Toco Toucan's bill for thermoregulation by modifying blood flow. Due to an increasing number of manufacturing facilities in China, there is more awareness to workers' health and safety and more demand for a more comfortable and safer workplace. Thus, there is a customer need for an inexpensive solution to heat stress.

Pairs of bioapplications and customer needs were discussed and the favored design paired the skinlike walls of a termite mound with the nature of human skin's ability to release excess heat and sweat. The student went on to study the Eastgate Centre in Harare, Zimbabwe, that was shown to be a successful Termite Mound structure. The combinations of materials that perform similar functions was not discussed in great detail in this ergonomics class but alluded to as future research for critical design criteria.

Reflection from this student listed his strengths as having researched the backgrounds of each option and the bioapplications that resulted in a proposed solution. His areas for improvement were based on his agreement with his peers assessment that his speech was sometimes unclear and he should have been more prepared. He added the insight that his topic was more open-ended than others and that his classmates felt he did a good job.

Future Directions

The BIT format was the starting point for integrating biomimicry into an ergonomics classroom. It spawned additional collaborations and ideas for integrating biomimicry into the general design process. Project extensions and assessment data will be ongoing to determine the limits of its application. The BIT process will continue to be used in the Work Design II: Ergonomics course and tweaked for continuous improvement.

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