Reverse Engineering to Teach Scientific Concepts: Biomimetic Robot Systems

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Abstract: This mentor presentation displays how Team Genius mentors teach concepts through the process of reverse engineering. It examines the current applications of reverse engineering to teach both a scientific concept, in this case, biomimetics, and engineering concepts. To begin, we will describe existing robots and prototypes—from research labs of Stanford University and the Massachusetts Institute of Technology—with visual aids/models. Later, we will take apart (reverse engineer) working biomimetic LEGO robot prototypes. This structural and functional analysis will convey the biomimetic concepts integrated within the robots. In the process of examining and reverse engineering biomimetic robots, the presentation will convey bioenvironmental concepts with practical application, as well as mechanical engineering strategies. This learning process is akin to one that can be used in a typical biological, environmental science, or engineering classroom.

Key Words: Robots, Biomimetics, RoboCupJunior, Environment, iRobot, ERI, Biology, Environmental Science, Education, Classroom, Reverse Engineering

1. **Introduction:** The educational community is of vital importance. This mentor presentation's purpose is to explore and display new, innovative ways of presenting STEM (Science, Technology, Engineering, and Math) knowledge in a classroom environment, via robotics.
   a. **Team Genius** was founded by Vivek Kumar, now a mentor, in 2010, as a private robotics team. Since its inception, it has won numerous awards, such as FIRST Robotics state championships, the FIRST Programming Awards, and the IEEE Engineering design awards. Team members now look to expand their love of science, innovation, and engineering to the international community.
   b. **Reverse Engineering** is the process of creating a device, object, or system similar to another one (the original one) after examining the original, and discovering its technological principles through an analysis of its structure, function, and operation (Wikipedia). This is an important asset to many design and manufacturing companies. It allows them to successfully compete in the corporate world. However, reverse engineering can also be of great use to the educational robotics community (see Application to RoboCup Challenges and Application by Team Genius)

2. **Theoretical Examination of Current Biomimetic Robots**
   a. Biomimetic Robots are robots that mimic organisms in structure and function. This part of the presentation will have videos/pictures or models of already existing Biomimetic Robots and prototypes, and will explain the concepts behind each one. Similarly, these robots can be used to display engineering strategies. In the reverse engineering process, this examination is referred to as a *functional analysis*.
   b. From Stanford University: *Sprawl*, a hexapod platform meant to overcome obstacles similar to an insect. Provides insight on characteristics of multi-limbed organisms' structure, muscle capabilities, and nervous signal dispersion, by utilizing mechanical concepts such as a prismatic joint (by pneumatic piston), and rotary joint.

Fig 1: Sprawl

c.   From the Massachusetts Institute of Technology: *Cheetah-inspired Quadruped*. This provides valuable insight into coordination of multi-limbed creatures, as well as muscle structure, implementing motors and other framework components.

Fig 2: Cheetah- Inspired Quadruped

d.   *Stickybot,* the gecko-inspired climbing robot. The world's first robot to use directional adhesive. This robot provides insight into multi-surface and climbing creatures, utilizing intricate gear systems to mimic the flexible motions of a gecko.
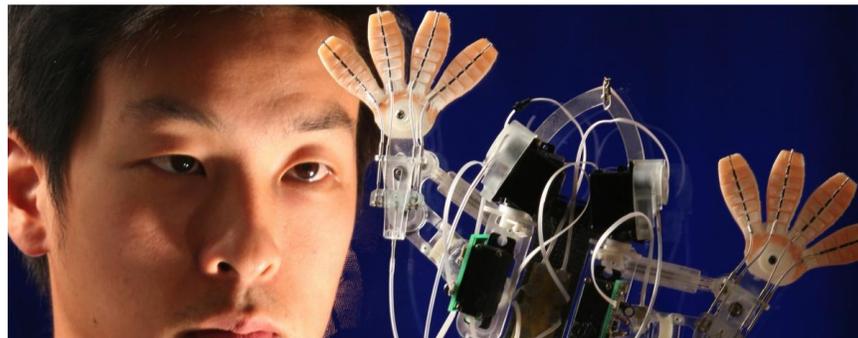

Fig 3: Stickybot

e.   From IEEE Inc., *Biomimetic Fish and Control Algorithms*, the underwater propelled robotic fish. An oscillating foil propels this fish. This robot provides valuable insight into hydrodynamics and marine creatures, as well as their differing methods of motion.
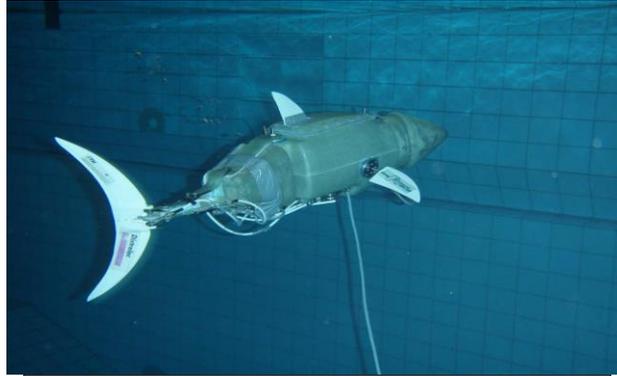
Fig 4: Biomimetic Fish

    f.   From UC, Berkeley: *Ornithopter*, a flying search robot resembling a moth, with lace wings. It provides insight into aerodynamic and airborne creatures. Students will learn about muscles, energy needed in relation to wings and time airborne, and manipulation of physics to stay aloft.
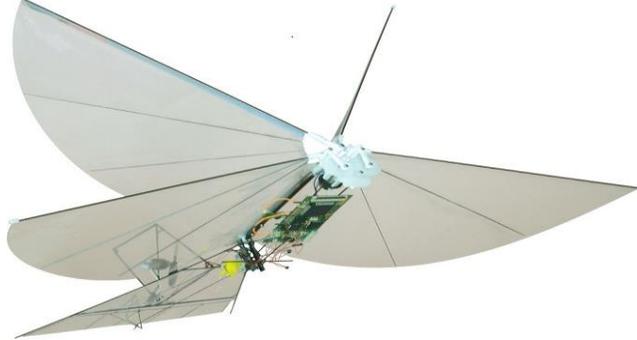

Fig 5: Ornithopter

3.   Active, working robot display and active reverse engineering.

    The three following biomimetic robots will be displayed in a corresponding environment. Parts diagrams will be provided. Parts will be from the LEGO Mindstorms NXT 2.0 kit. Each robot will perform autonomously in its environment, displaying its biomimetic properties. Later, each one will be taken apart in front of the audience, and undergo a parts structural and functional analysis. This will convey biomimetic concepts as well as engineering strategies.

    a.   **Sloth:** A tree dwelling mammal, sloths move with remarkable dexterity, albeit slowly, across tree branches. This is mainly due to the sloth's limb structure. This robot mimics the sloth's tree-climbing capabilities, by slowly making its way across a tree branch.

    b.   **Terrestrial Spider:** Arachnid anatomy is extremely complex. This robot helps to simplify the complex motions and hundreds of muscle groups that help a spider with walking. The spider robot dangles off a web and moves its legs in a walking motion

    c.   **Elephant:** Elephants are the largest land mammals on Earth. This robot is a LEGO Mindstorms EV3 bonus—an elephant that walks and picks up something with the trunk.
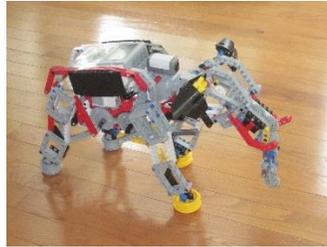
Fig 6: Elephant

d. These biomimetic robots will perform in their respective environments. This is a functional (and operational) analysis. Following this analysis, the robots will be taken apart. In the reverse engineering process, this is a *structural analysis*. Two things will be conveyed through this process- biology and engineering concepts. These concepts, or others, can be taught in a similar manner in a classroom. This process can be used in the RCJ challenges as well (see Application to RobocupJunior).
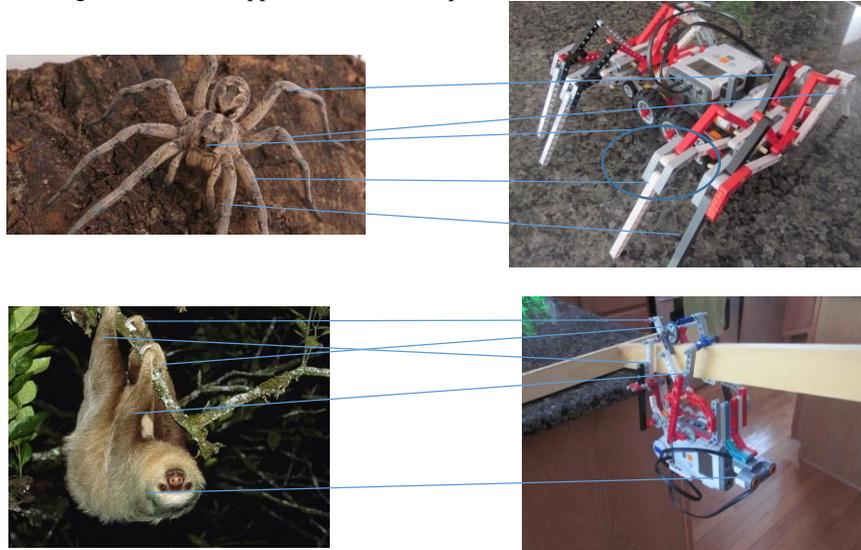

Fig 6 Cont.: LEGO Mindstorms Biomimetic Robots: Spider, Sloth and Elephant (above). Note that the robots do not yet have artificial skin

Application by Team Genius

a. Team Genius has used the reverse engineering process to implement ideas in its own inventions. An example is the Phantom Leak Charger, the US Army eCybermission national invention competition winner. In this case, Team Genius reverse-engineered a cell phone charger.
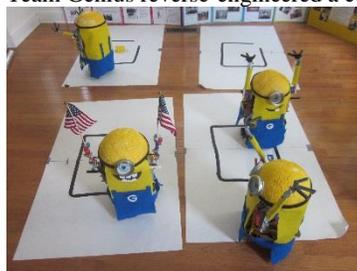

Fig. 7: Team Genius Minions

b. This presentation displays Team Genius's reverse engineering practice. Team Genius has used the reverse engineering process in building their RoboCup Junior Dance robots, the Minions. The mechanism of the robots

dance was reverse engineered from the omni-directional Roomba's mechanism, a robotic vacuum cleaner from *iRobot*.

Fig 8: Reverse Engineering by Team Genius
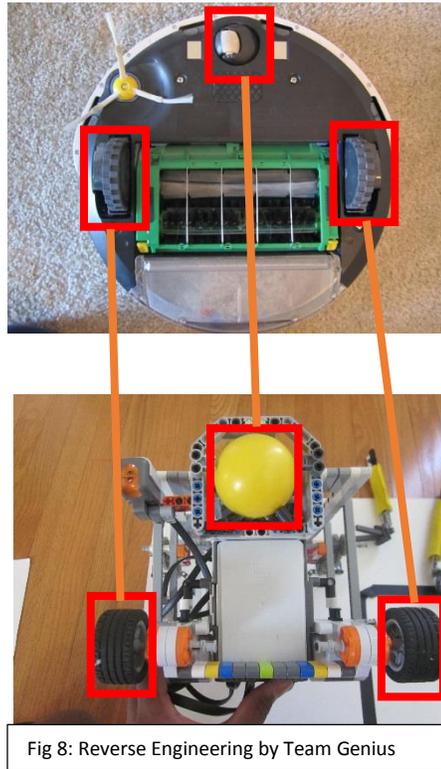
5. Application to RoboCup Challenges:

    a. It is possible for teams to reverse engineer existing products (like Team Genius has done) to aid them in completing RoboCup challenges.

    b. Rescue: Aspects of the Rescue League are reflected in other machines. For example, there are several manufacturing robots to lift cylinders in an Ebm-papst factory. Ebm-papst manufactures fans, so their robots must lift cylinders of all different weights. Similarly, existing victim rescue devices exist. This type of device can be implemented into a LEGO Robot, for instance, in the rescue challenge.

    c. Humanoid: In this case, one must follow a process very similar to the aforementioned biomimetic robots, only backwards. For example, the elephant robot could be taken apart to teach anatomical concepts pertaining to the elephant. For the humanoid league, human anatomy must be learned first, and then integrated into the robot. This is the reverse engineering process, simply from a different perspective.

    d. Soccer: Mechanisms for propelling balls are the most widely used in this world. Examples are a tennis ball machine, a cannon, a pinball machine, and countless toys. Once one examines how these work (functional analysis), it is simple to integrate these into the ball-shooter of a soccer robot.
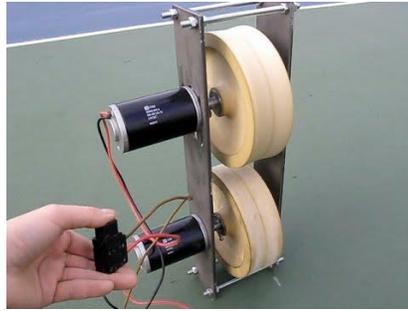
Fig. 9: Tennis ball machine mechanism-possible application in RCJ Soccer

6. **Conclusion:**
   a. In the classroom, biomimetic, engineering, or any STEM concept can be taught through the robot through reverse engineering. This project implements a wide diversity of engineering concepts in pictures, videos, and 3 main robots. It can also help one improve his or her own product/robot, by implementing other's ideas in a unique way. It also serves as a model for teachers. Reverse engineering is a unique teaching technique that engages students while still teaching valuable STEM principles.
   b. Reverse engineering is the process of viewing a visual, functional, and structural analysis. This helps people gain knowledge in mechanical design, as well as functional concept (in this case biology).

7. **References:**
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