Functionalized Bricks with Embedded Intelligence (FBEI)

Prof. Dean Aslam:  aslam@msu.edu ; www.egr.msu.edu/~aslam

- FBEIs, using custom-made LEGO-compatible bricks containing electronic circuits & sensors based on new micro & nano technologies, spark the interest of learners with different backgrounds and preparation levels from kindergarten to Ph.D.

- The use of technology dates back to 20,000 Years. FBEI modules are based on a concept called TASEM (technology assisted science, engineering and mathematics) developed at Michigan State U during 2000 - 2010. Doctoral students, involved in cutting-edge micro and nano research, interacted with K-12 students and teachers to develop TASEM.

- By allowing user-designs, FBEIs focus on research-oriented and entrepreneurial learning.

- Over 100 FBEI learning modules developed benefiting over 2,500 learners nationally and globally.

Funded by:

- MATHWORKS; 2012 – 2013

What is a FBEI?

Typically a FBEI brick, fabricated by 3D inkjet printing and containing smart components (sensors, microcontrollers, etc.) and circuits, counter fits into commercial plastic systems (LEGO, Megabloks, others) allowing the learners to use their old bricks and motors to build a FBEI learning module, e.g., a smart robot (FBEI # 2 in picture).

As the FBEIs involve extremely simple to extremely complex (see FBEI # 3; maple-seed inspired microdrones) multidisciplinary engineering/science learning, they have become very popular locally, nationally and Internationally. They promote engineering education and research at all levels of K through Ph.D. (KPD).
EXAMPLES OF FNEI/FBEIs: **Over 100** modules have been developed

(a) Motion, Energy & Batteries, Math, Si Crystal
(b) Computer Switches,
(c) Sensors and Miniaturization,
(d) Nano Concepts,
(e) Micro, Nano and Microsystems Fabrication,
(f) System Integration and
(g) Trans-disciplinary Topics
(related to Technology
Assisted Dancing, Psychology,
Cognitive-Training and Cancer).

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Mind-Controlled Robot

Lego Gear Train Demonstrating Macro, Micro and Nano Dimensions

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(a) Motion, Energy, Batteries, Wireless, Math, Si Crystals

PreK - 3 Modules: Children Ages 2 – 7

Showing Interest In Nano, Micro and Macro Modules

Low-Cost Modules: LED, Packaged and Unpackaged 1 Farad Capacitors for Energy Storage

2nd Grader Builds a Card Sorter Robot

A Nano Scientist

LED

Functionalized Nanobrick Containing a Capacitor and a Protection Circuit

BUBBLE MAKER ROBOT

Prototype Nanobrick

PROTOTYPE NANOBRIK
(a) Motion, Energy, Batteries, Wireless, Math, Si Crystals, contd.

Low-Cost Modules:
Gear Train, Generator, Motor as a Generator, Energy Generation and Storage

Energy Generation and Conversion

LED

Motor

Motor as generator

LEGO Car and Generator

Charging Capacitor Battery by Generator

Energy storage
(a) Motion, Energy, Batteries, Wireless, Math, Si Crystals, contd.

Windmill Using LEGO Parts: Design, Building and Testing of Multiple Windmill Design Options
(a) Motion, Energy, Batteries, Wireless, Math, Si Crystals

**Energy Modules:**
- LED-Based and Commercial Solar Cells
- (bottom right)
- Energy Scavenging
  (below)

**Scavenging Energy from Static Charges**

- VD Graaff Generator
- Electrostatic Energy
- Voltage: 900 V
- Ground: 900 V

LED-Based Solar Cell on a Breadboard

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Math Modules: Simple Math (bottom left), Trigonometric Functions and Angle Measurement by NXT Controlled Servo Motor (not visible) Attached to FBEI Module (right), Programmable Robots Measuring Area of Circles (bottom middle)

PreK - 3 Math

Compute Trigonometric Functions

Measure Area of Circle

4 – 12 Grade Math

Measure Angle Using NXT

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(a) Motion, Energy, Batteries, Wireless, Math, Si Crystals, contd.

Other Modules:
Wireless Control by (a) Static Charge or Light and (b) use of an Optical Bench to Connect Nodes 2 and 3, and (c) Directions in a Crystal Important for Micromachining of Si to Create Microsystems or MEMS.

Use of Rubik Cube to Demonstrate directions in a Si crystal

Use of Wood Blocks for Explaining Miller Indices
(a) Motion, Energy, Batteries, Wireless, Math, Si Crystals, contd.

LEGO Milling Machine

LEGO AFM
Technology Assisted Business Innovations (TABI):

Developed at Michigan State U for Introduction of RFID Technology to Grades 6 - 16

RFID: Radio Frequency Identification

A table-top factory concept: A robot takes inventory of processed parts and reports to the factory manager
(b) Computer Switches

Computer Switches are Controlled by Static Charges

A LEGO Model of Microsystems/MEMS K-12 Chip:
Micro & Nano Computer Switches, Fabrication, Sensors & Actuators, Power Sources, Functional Modules of NMOS and FinFET, etc.
(b) Computer Switches: Applications, contd.

**PreK – 8:**
Beeper Controlled by Positive Charge

Sheet with Positive Charge

**Static Charge Piano:**
*Played by Static Charges*

Motor Control by Static Charges

Motor in a Circuit

Functional Models of NMOS Switches

NMOS Switch

Low Frequency Buzzer

High Frequency Buzzer

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(b) Computer Switches: Applications

ASCII Game: How Computers Understand ABC?

Learners Can Play This Game:

- Two teams, provided with 7-LED device and code for A, B, C and D, communicate through zeros (LED is off) and ones (LED is on).
- One team uses the device to send letters (A, B, etc.) and words (DAD, CAB, etc.) to the other team and vice versa.

► The switches can be switched on & off by static charges.
(c) Sensors and Miniaturization

Static Charge Sensors

Capacitive Sensor: Principle of Operation

Balloon Levitation Using Static Charges

Positively charged Al Foil attached to balloon

Positively charged glass rod

Circuit used in Sensor

LED used as a resistor and fuse

Current through this LED is the sum of currents through NMOS and PMOS circuits.

Negative Charge Indicator

PMOS BS 250

NMOS BS 170

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(c) Sensors and Miniaturization, contd.

Capacitive Sensors: Operated by Static Charges

Miniaturization: Macro, Micro and Nano Sensors

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Actual Neural Probe

Pressure Sensor

LEGO Neural Probe

Si Wafer

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(c) Sensors and Miniaturization, contd.
Cantilever Capacitive Sensor: *Principle of Actuation by Static Charges from NXT-Controlled LEGO VD Graaff Generator*
LEGO Gear Trains: Explain Nano & Micro Concepts, Gear Ratios, Torque, Energy of Gears with Different Speeds, Measurement of RPM and Speeds of all the Gears

Using an NXT-Controlled Servo Motor with One Degree Precision
(d) Nano Concepts, contd.

**Innovative Nano Modules:**

(d) K-12 Chip with Nano Gas Sensors (left);
(a) Soap Bubble Skin Thins due to Evaporation Causing Changing Colors and (b) Bubble Levitation due to Static Charges (b)
(e) Micro and Nano Fabrication

LEGOs: Used to Explain Processes for Fabrication of Micro & Nano Switches

Diagram: Micro and Nano Fabrication Processes using LEGO models.
(e) Micro and Nano Fabrication, contd.

**LEGOs:** Used to Explain Resist Spinners and Plasma Oxidation Processes (Furnace Exhaust and Dispenser Nozzles for the Spinner are also Shown)
(e) Microsystems Fabrication

Sensors Fabrication: Acceleration Sensor (left), Cantilever Beam Sensor (below)
(f) System Integration

Bottom-up Assembly: *NXT Robot for Assembling Systems*

**PreK - 3:** A 4-Years Old Interacts with an NXT Robot; Helped by an 11th Grader

Interesting Robots: A Robotic Doll and a Wall-climber Robot

Year 2005

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LEGO Motor
Powered
Microcontroller:
An MSP430C2211 microcontroller, programmed to blink an LED, gets power from a LEGO motor which can turn clockwise or anti-clockwise and run at different speeds

(f) System Integration, continued

Bridge Rectifier Circuit Uses LEDs to Visualizes the Charge Flow

Green LED Used as a Voltage Regulator
(f) System Integration, continued

Inexpensive:
A 50 Cents Motor Used in a Robot that is Controlled by Static Charges

Programmable:
A $ 17 LEGO Motor Used in a Line Tracker Robot Programmable in C

Programmable:
Two $ 17 LEGO Motors Used in a Line Tracker Robot Programmable in C Code

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(f) System Integration, contd.

**Static Charge Control:**

**RCX Robot Equipped with a Computer Switch Control**

**Packaging:**

*A Diamond Neural Probe Packaged Using LEGO*.

**LEGO/Fisher VDG Charge Generators:**

*Innovative VD Graaff Generators Built Using Plastic Blocks*.

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Innovative Maple-seed Robotic Fliers (MRF): Very simple to Very Complex Systems Demonstrated

Simple MRFs

1 Wing
Thick Paper
LEG0 Plate
Thin Paper

2 Wing

4 Wing
Thick Paper
Thin Paper

Wires
Battery
Cu Tape
8 mm

Assembly of 2-Wing MRF with Electro Mechanical Switch, LED and Battery

Electro-mechanical Switch

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Complex MRF Systems: Microdrones

(f) System Integration (contd)

Wireless Communication Between MRFs

Explain Operation of EM Switch

Measure RPM

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(f) System Integration: Microdrones

Maple-seed Robotic Flier (MRF): Extremely Simple to Extremely Complex Systems
(f) System Integration: Next generation of microdrones
(f) System Integration: Wall Climber

Wall Climbing Robot: Can Climb Smooth Walls
Each Foot: 5.5 V Vacuum Pump, Pressure Sensor & Valve
Robot Body: Two Servo Motors, PIC Microcontroller, Driver ICs, Battery, Gears
New Learning Concept: Nature-Made Systems (NS) and Microsystems (MS) have Similarities and Differences:

- **NS and MS both have** four digital fundamentals: A, T, G and C bases for NS and four MOS logic types for MS
- **NS uses proteins, neurotransmitters and Enzymes** but MS uses electrons and holes for operational control
- **In NS, genes Consist of base pairs but, in MS, logic gates consist of Metal Oxide Semiconductor (MOS) devices**
(g) Transdisciplinary Topics

Nature-Made Systems (NS)

Storage and Computation Happen at the Same Time and in the Same Place

Microsystems (MS)

Processor and Memory are Physically Separated
(g) Transdisciplinary Topics

Creation of Life by Humans: As new bacterial Species Have Been Created by Scientists in the Lab, Learning Has Become Very Exciting on One Hand But Very Challenging on the Other.

How to Make Learning Fun?

• Use LEGO to Create Structures Mimicking Cells, Genes, DNA, Cancer-Killing Nano Particles (see next slide), etc.
• Develop Trans-Disciplinary Learning Areas that are Unusual and Game-Changing
Technology Assisted Cancer Education (TACE) Using Intelligent LEGO Creations: *Chemicals can accumulate in the developing breast tissue during ages of 10 – 15 years. Studies show that breast cancer, in majority of cases, is caused by these chemicals 25 – 30 years later; using LEGO creations, this program creates awareness about the dangers of toxic chemicals at an early age.*

**Nano-particle for targeted killing of cancer cells**

[Diagram of a computer model of a multi-functional dendrimer]
Use Static Charge to demonstrate the Killing of LEGO-based Cancer Cells
How Does the E. Coli Know When We Drink Milk?:

*It Uses three Genes to Detect the Presence of Lactose*
Technology Assisted Dancing (TAD):

- Motion Sensors, Attached to the Fastest Moving Parts of a Dancer’s Body, Switch (on and off) Light and Sound Devices
- TAD Can Help Learn Technologies Across Many Disciplines

Technology Assisted Psychology (TAP): Inter-Robot Wireless Communication Used to Address Bullying; B-bully, N-victim & C-bystander robots
Neural Engineering:

- **Elderly**: LEGO creations are designed for elderly based on their (a) skills in their pre-retirement life and (b) interests in their current life. These activities are expected to relieve stress and improve quality of life. TAD (technology assisted dancing) may also be used for elderly.

- **Device Used**: Mindwave ([http://www.neurosky.com](http://www.neurosky.com)) can be used to check the state of mind (focus, meditation, etc.) as this device has a built-in EEG (electro-encephalo-graphy).

- **Work in Progress**:
  - Personal healthcare devices; sleep, movements, blood pressure, condition of muscles, etc.
  - Monitor/measure happiness.
(g) Transdisciplinary Topics, contd.

**Mind-controlled Robots**: Robots, built using FBEI and LEGO components, are controlled by signals picked up by using non-invasive single-electrodes EEG (electroencephalogram) system (2013).
DNA Inspired Active Network Arrays (DIANA)

(c) E-NMOS BS 170
S G D
1 3 4
7
Interconnected on backside

(a) DIANA
(b) CMOS Logic

(b) E-NMOS
E/D NMOS Logic

D-NMOS

E-PMOS
E/D PMOS Logic

Circuit Board

DIANA Learning Module
Fabric Embedded Mind-control for a LEGO Robot
**Innovative Inexpensive Undergraduate Flipped-Lab Using Smartphones**

<table>
<thead>
<tr>
<th>Week</th>
<th>Experiment</th>
<th>Type</th>
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<tbody>
<tr>
<td>Week 1</td>
<td>No class</td>
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<tr>
<td>Week 2</td>
<td><strong>Course Introduction (Prof. Dean Aslam), Get MatLab Mobile (GSI)</strong>&lt;br&gt; Experiment # 1: Mind-controlled Games Using Brainwaves; use smartphone App&lt;br&gt; Experiment # 2: Counting Steps Using MatLab Mobile</td>
<td>In-class</td>
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<td>Week 3</td>
<td>Experiment # 3: Create an App for Smartphone Using MIT’s App Inventor</td>
<td>Complete Flipped Hands-on Experiments and E-mail Individual Quizzes to GSI Before Coming to Lab</td>
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<td>Week 4</td>
<td>Experiment # 4: Programming Basics Using Smartphone IDE (Integrated Development Environment)</td>
<td>In-Lab Discussions and Brief Group Quizzes</td>
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<td>Week 5</td>
<td>Experiment # 5: Study Ohm’s Law Using Simulation Apps and Circuits on Breadboard</td>
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<td>Experiment # 6: Monitoring your Body/Brain Using a Smart Bracelet and Smartphone</td>
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<td>Experiment # 7: Build a Digital Microscope Using a LASER Pointer and Smartphone</td>
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<td>Experiment # 8: Create an App that Blinks an LED Through a Bluetooth Link Between a Smartphone and an MSP430 Microcontroller</td>
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<td>Experiment # 9: Create an App that Controls a Motor/Robot Through a Bluetooth Link Between a Smartphone and an MSP430 Microcontroller</td>
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<td>Week 10</td>
<td>Project Selection in Weeks 9-10</td>
<td>Possible Projects Ideas: Possibly all projects related IDE and App development</td>
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**Smartphone Screen:** Bluetooth Control of LEGO robot

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Fig. 39 All components on breadboard mounted on a robot; (a) prototype and (b) circuit schematics.