Functionalized Bricks with Embedded Intelligence (FBEI):

- Over 100 learning modules have been developed under funding from NSF Engineering Research Center for Wireless Integrated Micro Systems (WIMS) during 2000 – 2010 (Award # EEC-9986866)
- FBEI modules are based on a concept called TASEM (technology assisted science, engineering and mathematics) developed at Michigan State in collaboration with U of Michigan.

- Doctoral students, involved in cutting-edge research in micro and nano technologies, interacted directly with K-12 students and teachers to develop TASEM.
- An example of a FBEI module, also called Nanobricks, and the related business model is shown in the figure:

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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).

TASEM: Technology Assisted Science, Engineering and Mathematics
KPD: From Kindergarten to Ph.D. (KPD)
FNEI: Functionalized Nanobricks with Embedded Intelligence
FBEI: Functionalized Bricks with Embedded Intelligence

Lego Gear Train Demonstrating Macro, Micro and Nano Dimensions
(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

2 Yrs

BUBBLE MAKER ROBOT

7 Yrs

PROTOTYPE NANOBRICK

LED

Functionalized Nanobrick Containing a Capacitor and a Protection Circuit
(a) Motion, Energy, Batteries, Wireless, Math, Si Crystals, contd.

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

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(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

LED-Based Solar Cell on a Breadboard
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

Measure Area of Circle

Compute Trigonometric Functions

BASIC CONCEPT:
- Beam c, hinged at origin, can move keeping c constant but changing θ
- Hanging beam b always makes 90° angle with the fixed beam a
- Angle θ, between beams a and c, can change from 0 to 360

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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 Rubik Cube

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

LEGO Milling Machine

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

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

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(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

Motor Control by Static Charges

Functional Models of NMOS Switches

Motor in a Circuit

Static Charge Piano:
Played by Static Charges

Low Frequency Buzzer

STATIC CHARGE ‘PIANO’

High Frequency Buzzer

Source Gate Drain

NMOS Switch

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(b) Computer Switches: Applications

Two Ways to Generate 7-Bit ASCII Code:

- Mechanical Switches
- Transistor Switches

Keyboard Uses

Used in a PC Keyboard

ASCII Game: *How Computers Understand ABC?*

Learners 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.

<table>
<thead>
<tr>
<th>Letter</th>
<th>Bit Number</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>1 0 0 0 0 0 1</td>
</tr>
<tr>
<td>B</td>
<td>1 0 0 0 0 1 0</td>
</tr>
<tr>
<td>C</td>
<td>1 0 0 0 0 1 1</td>
</tr>
<tr>
<td>D</td>
<td>1 0 0 0 1 0 0</td>
</tr>
</tbody>
</table>

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(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**

- NMOS and PMOS Sensors
- Charge Indicator LEDs
- 9 V Battery

1. **Negative Charge Indicator**
2. **PMOS BS 250**
3. **NMOS BS 170**
4. **Positive Charge Indicator**
5. **Current through this LED is the sum of currents through NMOS and PMOS circuits.**
6. **LED used as a resistor and fuse**

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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

Finger Capacitor

(c) Sensors and Miniaturization. contd.

Functional Lego Combdrive

Hanging

Fixed

Embedded AI Interconnects

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Cantilever Capacitive Sensor: 
Principle of Actuation by Static Charges from NXT-Controlled LEGO VD Graaff Generator

(c) Sensors and Miniaturization, contd.
Nano Concepts

Lego Gear Train Demonstrating Macro, Micro and Nano Dimensions

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

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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 showing LEGO models of fabrication processes for micro and nano switches, including steps like diffusion furnace, gas supply, fab, etc.]
(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*

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(f) System Integration, continued

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

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

**Programmable:**

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

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

Programmable Robot Using MSP430F2012 Microcontroller
Packaging: A Diamond Neural Probe Packaged Using LEGOs

LEGO/Fisher VDG Charge Generators: Innovative VD Graaff Generators Built Using Plastic Blocks

(f) System Integration, contd.

Static Charge Control: RCX Robot Equipped with a Computer Switch Control
Innovative Maple-seed Robotic Fliers (MRF): Very simple to Very Complex Systems Demonstrated

Simple MRFs

2 Wing
Thick Paper
LEGOb Plate
Thin Paper

1 Wing

4 Wing
Thick Paper
Thin Paper

(f) System Integration (contd)

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

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Complex MRF Systems

(f) System Integration (contd)

Wireless Communication Between MRFs

Measure RPM

Explain Operation of EM Switch

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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 Two Digital Fundamentals:** A-T and G-C Base Pairs for NS and Zeros and Ones for MS
- **NS uses Proteins 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's 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
(g) Transdisciplinary Topics, contd.

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

*Computer Model of a Multi-Functional Dendrimer*

- Therapeutic Agent
- Apoptosis Sensor
- Targeting Agent
- Detecting Agent
- Dendrimer Platform

**LEGO Dendrimer** with Functional Sensors

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(g) Transdisciplinary Topics

How Does the E. Coli Know When We Drink Milk?:

*It Uses three Genes to Detect the Presence of Lactose*
Use Static Charge to demonstrate the Killing of LEGO-based Cancer Cells

Robotic VD Generator

Cancer Cell

Electrodes

Lego Neural Probe

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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**

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Technology Assisted Cognitive Training (TACT):

- LEGOos and other everyday items are used to excite elderly.
- The LEGO creations are designed for them 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 (techn. assisted dancing) may be used in TACT.