Learning science through engineering design: An effective approach to STEM integration at the elementary school level

Brenda M. Capobianco, Co-Director
Chell Nyquist, Project Manager
Purdue University

Science Learning through Engineering Design
Math Science Targeted Partnership

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How do we characterize STEM?

• Instructional approaches that explore teaching and learning between and among any two or more STEM subject areas, and/or between a STEM subject and one or more school subjects.

• In the SLED Partnership, we use the engineering design process as a mechanism to facilitate and improve students’ learning of science and mathematics at the elementary school level (grades 3-6).

• Proficiency in this practice supports a better understanding of how scientific knowledge is produced and how engineering solutions are developed.
SLED Partnership

Science Learning through Engineering Design (SLED) is a partnership project of Purdue, four Indiana school districts, and community partners designed to help improve students’ science learning in grades 3-6.
SLED Partners

Purdue University
- Colleges of Education, Engineering, Science, and Technology
- Discovery Learning Research Center

School Partners
- Lafayette & Tippecanoe Schools
- Plymouth Community Schools
- Taylor Community Schools

Community Partners
- Subaru of Indiana Automotive
- RoadWorks Manufacturing
- Delphi Automotive
- Plymouth Foundry
- Caterpillar Inc.
Question guiding the SLED Partnership

If given the necessary tools and resources, cross-disciplinary support, and instructional time, could elementary/intermediate school teachers (grades 3 – 6) effectively improve students’ science achievement through an integrated curriculum based on the use of the *engineering design process*?
Problem Scoping and Information Gathering

IDENTIFY PROBLEM

Solution Formulation [Idea Generation]

SHARE AND DEVELOP A PLAN

Solution Production and Performance [Project Realization]

CREATE AND TEST

COMMUNICATE RESULTS

Communication and Documentation of Performance Results

IMPROVE AND RETEST

Optimization
Design Challenge

Can you design a better candy bag?

Identify the problem

• What is the problem?
• Who is the client and what are the client’s needs?
• What are the constraints?

Develop and create a plan

• Draw a diagram & make a list of materials
• Create your better candy bag
Testing, Evaluating, and Redesigning

• How could you test your bags?
• Which science concepts could be introduced or applied?
• How would you evaluate the performance of your design compared to another team’s design?
• How would you foster redesign?
• As a teacher, how and what would you assess?
Teacher Challenges

First-order challenges

• Time
• Resources
• Space
• Classroom management

Second-order challenges

• Assessment
• Mental to physical models
• Testing
Presenting our designs & findings

Share your designs

- What worked?
- What did not work?
- If you could improve on your design, what would you do?
Big Plan

Mass the bag can hold

\[ \text{g} \, \text{Kg} \]
SLED Components

1. Faculty Design Teams and Task Development
2. Inservice Teacher Professional Development
3. Preservice Teacher Preparation
4. SLED Research related to Student and Teacher Learning
Adaptation/Development of Design-Based Curricular Materials
SLED Activity Creation Cycle

Design Team:
STEM Faculty
Grade 3-6 Teacher
Science Educator

Student and Teacher Learning Research and Teacher Feedback

Design Task Development, Testing, and Refinement

Classroom Implementation
Essential Features of Design Briefs

1. Is client-driven and goal-oriented
2. Provides an authentic context
3. Includes constraints
4. Use of materials, tools, and equipment that are familiar to students
5. Yields a product that is either an artifact (prototype) or process
6. Yields multiple solutions
7. Requires team work
# Examples of SLED Design Tasks

<table>
<thead>
<tr>
<th>Task</th>
<th>Grade</th>
<th>Goal</th>
<th>Science concepts</th>
</tr>
</thead>
<tbody>
<tr>
<td>Designing a Prosthetic Leg</td>
<td>5</td>
<td>Create a prototype of a prosthetic leg to kick a soccer ball</td>
<td>Mass, Volume, Density, Forces</td>
</tr>
<tr>
<td>Creating Compost Column</td>
<td>5</td>
<td>Identify a process for making a better compost</td>
<td>Abiotic and biotic factors, Decomposer</td>
</tr>
<tr>
<td>Roller Coaster</td>
<td>6</td>
<td>Design a prototype of a roller coaster that results in the greatest total loop diameter at the lowest cost.</td>
<td>Potential &amp; kinetic energy, Transformation of energy</td>
</tr>
<tr>
<td>Solar Panel Tracker</td>
<td>6</td>
<td>Develop a solar panel system that can be easily moved to track the sun, so that the panel can collect as much solar energy as possible</td>
<td>Direct and indirect rays, Four seasons</td>
</tr>
</tbody>
</table>
Example of a SLED Design Task
Prosthetic Limb

Boiler BioTech, a company in Warsaw, Indiana, needs assistance in designing a prosthetic leg for a young child so he/she can kick a soccer ball. Your team is responsible for designing and testing a prototype of a prosthetic leg that mimics the same movement of a hinge joint.

See sledhub.org for more examples.
In-Service Teacher Professional Development
In-Service Teacher Professional Development

- Teacher professional development is anchored by a two-week summer institute designed to introduce teachers to engineering design as a way to teach science.

- Teachers work with design teams and test design tasks, visit a community partner to engineering in action, develop skills through mini-workshops, map curriculum, and develop personal lesson implementation plans.
In-Service Teacher Professional Development

- Follow-up activities during the school year include progress reports and reflection sessions.
- Online activities on content and pedagogy are available via the project’s electronic hub (sledhub.org).
Pre-Service Teacher Preparation
Pre-Service Teacher Component

• Pre-service teachers apply to participate in the SLED summer institute.

• They then participate in a special section of an elementary science methods course focused on engineering design.

• Pre-service teachers are paired with SLED in-service teachers to co-develop, implement, and assess their implementations of SLED task during an 8 week field experience
SLED Research
SLED Research

- Partnership Development
  - Support implementation
  - Promote sustainability
  - Impact on all partners, including STEM faculty

- Teacher Learning
  - Implementation
  - Effectiveness
  - Challenges

- Student Learning
  - Children’s conceptualizations
  - New science content knowledge
  - Transfer of learning
Measures of Effective STEM Teaching

• Interviews (individual and focus group)
• Classroom observations
  • Developed the *Engineering Design-based Classroom Observational Rubric*
• Implementation Plans
  • Adapted version of the Penn Science Teacher Institute’s Science Lesson Plan analysis Instrument (SLPAI) (Jacobs, Martin, & Otieno, 2008).
• Teacher reflections
• Surveys
• Supporting documents (i.e., teacher implementation plans, teacher-created resources, and student work)
### Evidence of teachers’ plans for implementation

<table>
<thead>
<tr>
<th>Year</th>
<th># of plans (14 teams)</th>
<th># of tasks</th>
<th># of schools</th>
</tr>
</thead>
<tbody>
<tr>
<td>2011-2012</td>
<td>29</td>
<td>10</td>
<td>6</td>
</tr>
<tr>
<td>2012-2013</td>
<td>56</td>
<td>16</td>
<td>7</td>
</tr>
</tbody>
</table>
Quality of implementation plans 2011-2012

Implementation plans (n=29)

<table>
<thead>
<tr>
<th>Distribution of plans</th>
<th>Mean score</th>
</tr>
</thead>
<tbody>
<tr>
<td>Grade 5</td>
<td>64.3</td>
</tr>
<tr>
<td>Grade 6</td>
<td>67.5</td>
</tr>
<tr>
<td>All plans</td>
<td>66.0</td>
</tr>
</tbody>
</table>

Maximum score = 80
### Teachers’ instructional attempts at integrating engineering design-based pedagogies

**Dimensions of Engineering Design-based Teaching Observational Protocol**

<table>
<thead>
<tr>
<th>Dimension</th>
<th>First Implementation Mean Score</th>
<th>Second Implementation Mean Score</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lesson Design and Implementation</td>
<td>2.42</td>
<td>2.57</td>
</tr>
<tr>
<td>Content</td>
<td>1.64</td>
<td>1.77</td>
</tr>
<tr>
<td>Portrayal and Use of SLED-endorsed engineering practices</td>
<td>2.51</td>
<td>2.60</td>
</tr>
<tr>
<td>Overall Score</td>
<td>2.19</td>
<td>2.41</td>
</tr>
<tr>
<td>Portrayal and Use of SLED-endorsed Engineering Practices</td>
<td>Mean</td>
<td></td>
</tr>
<tr>
<td>--------------------------------------------------------------------------------------------------------------------------</td>
<td>------</td>
<td></td>
</tr>
<tr>
<td>Teacher facilitated the identification of the problem</td>
<td>4.00</td>
<td></td>
</tr>
<tr>
<td>Students and teacher used a variety of materials</td>
<td>3.20</td>
<td></td>
</tr>
<tr>
<td>Students actively engaged in questioning and their comments determined the focus and direction of design</td>
<td>2.10</td>
<td></td>
</tr>
<tr>
<td>Students actively engaged in planning (individually and in teams)</td>
<td>3.80</td>
<td></td>
</tr>
<tr>
<td>Students actively engaged in the construction of their designs</td>
<td>3.40</td>
<td></td>
</tr>
<tr>
<td>Students tested their designs</td>
<td>1.76</td>
<td></td>
</tr>
<tr>
<td>Students generated a feasible solution that aligns with the client’s needs, criteria, and constraints</td>
<td>1.96</td>
<td></td>
</tr>
<tr>
<td>Students analyzed data collected in the testing of their designs</td>
<td>1.24</td>
<td></td>
</tr>
<tr>
<td>Students communicated the results of their designs and performance of their designs</td>
<td>2.44</td>
<td></td>
</tr>
<tr>
<td>Students engaged in re-design</td>
<td>1.15</td>
<td></td>
</tr>
</tbody>
</table>
Measures of Effective STEM Learning

• Think-Aloud protocols
• Knowledge tests
• Open-response tasks
• Indiana Statewide Testing for Education Progress [ISTEP]
Evidence of student learning through design: Prosthetic Leg Example

- Overall (Total = 18 points)
  - Implemented in 4 schools by 14 teachers (matched cases, n = 386)

<table>
<thead>
<tr>
<th></th>
<th>Pre- Test</th>
<th>Post-Test</th>
<th>Gain Score</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Mean</strong></td>
<td>8.29</td>
<td>11.26</td>
<td>2.97&lt;sup&gt;b&lt;/sup&gt;</td>
</tr>
<tr>
<td><strong>St. dev.</strong></td>
<td>2.63</td>
<td>2.95</td>
<td>2.78</td>
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</table>

<sup>b</sup> p< 0.05
Prosthetic Leg (Cohort 1)

Pre-test distribution
Cohort 1

Post-test distribution
Cohort 1

Distribution of Pre Scores
Mean = 8.20
Std. Dev. = 2.63
N = 366

Distribution of Post Scores
Mean = 11.26
Std. Dev. = 2.954
N = 366
Prosthetic Leg (Cohort 2)

• Overall (Total = 12 points)
  – Implemented in 5 schools by 14 teachers (matched cases, n = 487)

<table>
<thead>
<tr>
<th>Total Score (Cohort 2)</th>
<th>Pre- Test</th>
<th>Post-Test</th>
<th>Gain Score</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mean</td>
<td>5.93</td>
<td>8.02</td>
<td>2.09(^a)</td>
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<tr>
<td>St. dev.</td>
<td>1.95</td>
<td>2.22</td>
<td>2.38</td>
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</table>

\(^a\) p < 0.05
**Prosthetic Leg (Cohort 2)**

**Pre-test distribution**
Cohort 2

**Post-test distribution**
Cohort 2

- **TOTALPRE**
  - Mean = 5.33
  - Std. Dev. = 1.56
  - N = 487

- **TOTALPOST**
  - Mean = 0.02
  - Std. Dev. = 2.21
  - N = 457
Data Sources for Think-Aloud Protocols

- Student Drawings
- Session Notes
- Video File
### Analysis

<table>
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<th>CODE</th>
<th>TIME</th>
</tr>
</thead>
<tbody>
<tr>
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<tr>
<td>2</td>
<td>DE</td>
<td>00:02.2</td>
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<tr>
<td>3</td>
<td>DE</td>
<td>00:01.4</td>
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<tr>
<td>4</td>
<td>DE</td>
<td>00:10.3</td>
</tr>
<tr>
<td>5</td>
<td>DE</td>
<td>00:01.6</td>
</tr>
<tr>
<td>6</td>
<td>DE</td>
<td>00:06.7</td>
</tr>
<tr>
<td>7</td>
<td>AN</td>
<td>00:01.2</td>
</tr>
<tr>
<td>8</td>
<td>DE</td>
<td>00:23.2</td>
</tr>
<tr>
<td>9</td>
<td>PR</td>
<td>00:03.7</td>
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<tr>
<td>10</td>
<td>AN</td>
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<tr>
<td>11</td>
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<tr>
<td>13</td>
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<td>DE</td>
<td>00:11.2</td>
</tr>
<tr>
<td>15</td>
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</tr>
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<td>18</td>
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<tr>
<td>19</td>
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<tr>
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<tr>
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</tr>
<tr>
<td>22</td>
<td>DE</td>
<td>00:34.0</td>
</tr>
<tr>
<td>23</td>
<td>PR</td>
<td>00:03.2</td>
</tr>
<tr>
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<td>00:04.7</td>
</tr>
<tr>
<td>25</td>
<td>DE</td>
<td>00:11.4</td>
</tr>
</tbody>
</table>

### Sensing Vibrations Transfer Problem 10/26/11

- **AN:** Analyzing - 13%
- **MO:** Modeling - 6% (4.1 sec)
- **NC:** No Code - 2%
- **PR:** Predicting Results - 7%
- **QH:** Questioning / Hypothesis - 7%
- **DF:** Defining Problems - 5%
- **DE:** Designing - 66%

**SLED Project Halfin Code Key**
- **AN** Analyzing
- **CO** Computing
- **DE** Designing
- **DF** Defining Problems
- **ID** Interpreting Data
- **MA** Managing
- **MO** Modeling
- **NC** No Code
- **PR** Predicting Results
- **QH** Questioning / Hypothesis
- **TE** Testing
For more information, contact:

- E-mail: sled@purdue.edu
- Web: http://sledhub.org