SPICE | Science Projects Integrating Computing and Engineering

Aligning Next-Generation Curriculum and Assessment Design Across Science, Engineering, and Computational Thinking

Principal Investigator: Kevin W. McElhaney, SRI International. Co-principal Investigators: Gautam Biswas, Vanderbilt University; Jennifer L. Chiu, University of Virginia; Christopher J. Harris, SRI International.

Senior Personnel: Nonye M. Alozie, Satabdi Basu, Ron C. Fried, Reina Fujii, Christine Korbak, Alyssa Lim, Tallie Wetzel, SRI International; Leidy Klotz, University of Virginia; Ningyu Zhang, Vanderbilt University.

Project Overview

SPICE addresses the critical need for curriculum materials that integrate science, engineering, and computational thinking (CT). Classroom materials will blend disciplinary core ideas, science and engineering design practices, and crosscutting concepts across science, engineering, and CT as called for in the Framework for K-12 Science Education and the Next Generation Science Standards (NGSS).

SPICE research and development timeline:

Phase 1 (currently underway)	Phase 2	Phase 3
• Initial development of curriculum materials, computational modeling environment, and assessments • Early classroom pilot-testing	• Design-based classroom curriculum studies • Technology usability studies • Assessment refinement studies • Teacher professional development	• Main classroom study on implementation and learning • Analysis

Development Goals

- **An NGSS-aligned, technology-enhanced curriculum unit** for upper elementary school Earth science that integrates engineering and computational thinking (CT).
- **A computational modeling environment** (CME) for upper elementary students to model earth systems and related engineering solutions.
- **Embedded and pre-post assessments** aligned with the curriculum to collect evidence of effectiveness and inform teachers about student learning
- **Educative features** to support teachers' enactment

Research Questions

- How can a technology-enhanced curriculum unit that integrates science, engineering design, and computational modeling help upper elementary students achieve proficiency with these disciplines along the three dimensions of the NGSS?
- What domain-specific supports do upper elementary students need to develop computational models of Earth systems and use computational models to develop engineering solutions?
- How can supporting resources educate elementary teachers and support their implementation of science curriculum materials integrating engineering and computational thinking?

Design Perspectives

- **Evidence Centered Design** (e.g., Mislevy & Haertel, 2006): Articulates how observable features of student performance provide evidence for students' proficiency and promotes coherence in the design of curriculum, learning technologies, and assessment
- **Equitable design** (e.g., Lee, Quinn, & Valdes, 2013): Enables design of curriculum, technology, and assessment that is accessible and fair to diverse student populations
- **Knowledge Integration** (e.g., Linn & Eylon, 2006): Promotes learning from science inquiry and engineering design by engaging learners in an iterative cycle of eliciting, adding, distinguishing, and sorting out ideas
- **Informed engineering** (e.g., Burghardt & Hacker, 2004): Focuses specifications and constraints of a design challenge around underlying science learning objectives

Design Process

NGSS Performance Expectations (PEs)

Earth and Space Science (ESS)

5-ESS3-1: Obtain and combine information about ways individual communities use science ideas to protect the Earth's resources and environment.

Engineering, Technology, and Society (ETS)

3-5-ETS1-1: Define a simple design problem reflecting a need or a want that includes specified criteria for success and constraints on materials, time, or cost..

3-5-ETS1-2: Generate and compare multiple possible solutions to a problem based on how well each is likely to meet the criteria and constraints of the problem.

3-5-ETS1-3: Plan and carry out fair tests in which variables are controlled and failure points are considered to identify aspects of a model or prototype that can be improved.

Domain Analysis

1 **UNPACKING**
- Earth science DCI
- Obtaining information practice
- Systems & system models CC
- Engineering design DCIs and practices
- Computational thinking

Focus on upper elementary grade band

2 **INTEGRATED DIMENSION MAP**
Coherent map of the domain integrating 3 NGSS dimensions

3 **LEARNING PERFORMANCES**
Assessable, integrated performance statements

Design specifications and development products

4 **CURRICULUM ACTIVITIES**

5 **COMPUTATIONAL MODELING ENVIRONMENT**

6 **ASSESSMENTS**

Aligned to NGSS

1 Unpacking the Dimensions

Unpacking the dimensions entails gathering substantive information about how knowledge and skills are acquired and used in the domain.

Engineering DCIs and practices

Process	Components
Defining and Delimiting Problems	Problem statement/need; constraints; success criteria
Gathering information	Gather existing solutions; learn about tools and techniques; engage in science inquiry
Generating solutions	Conduct tests; analyze tests; compare solutions
Evaluating solutions	Plan and carry out fair tests in which variables are controlled and failure points are considered to identify aspects of a model or prototype that can be improved.
Refining and optimizing solutions	Choose features; combine solutions; optimize solutions
Communicating solutions	Communicate design specifications; communicate design argument

Computational thinking

Aspect	Example (Control Structures)
Essential knowledge and skill	Non-nested conditions, boolean logic and operators, types of loops
Proficiency boundaries	Students are not expected to use nested conditionals
Prior knowledge	Program execution can be non-sequential because of loops or events
Student challenges	Students struggle to express terminating conditions of a loop
Equity considerations	When teaching conditionals, choose scenarios related to students' everyday experiences

2 Integrated Dimension Map

Integrated dimension maps describe essential disciplinary relationships and link them to aspects of the targeted practices and crosscutting concepts.

Building —is proportional to→ **Human Environmental Impact**

Human Environmental Impact —informs→ **Engineering Solutions**

Engineering Solutions —alters→ **Building**

SEP
- Define problems
- Obtain information
- Develop/use models
- Use computation

LP 1, 2, 3, 4

SEP
- Develop/use models
- Use computation
- Develop/refine solutions
- Evaluate solutions
- Communicate solutions

CC
- Systems and system models
- Cause and Effect

LP 5, 6, 7

3 Learning Performances

Learning performances represent intermediate targets for curriculum and assessment design aligned with the PEs.

LP 1: Define and delimit an engineering problem concerning the effect of building on water runoff. (Define problems)

LP 2: Obtain and combine information about the relationships among building variables, rainfall, and water runoff.

LP 3: Develop a pictorial model that explains the relationships among building variables, rainfall, and water runoff.

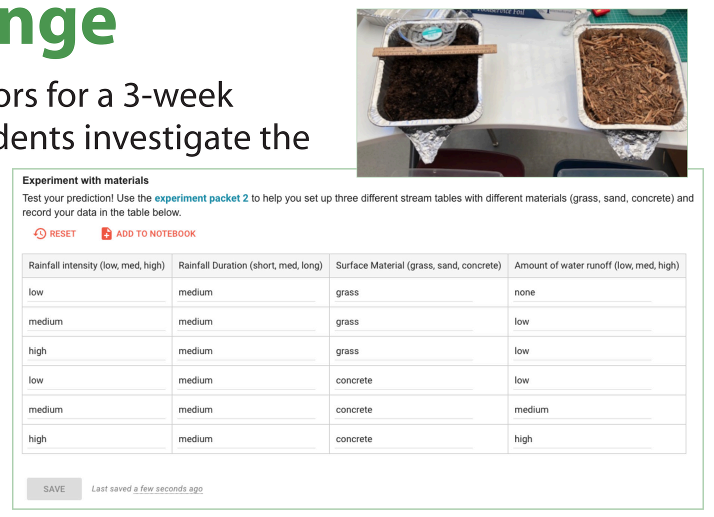
LP 4: Develop and use a computational model that explains the relationships among building variables, rainfall, and water runoff.

LP 5: Develop a solution using a computational model to mitigate the effects of building on water runoff.

LP 6: Evaluate and refine a solution using a computational model to mitigate the effects of building on water runoff. (Conduct investigations)

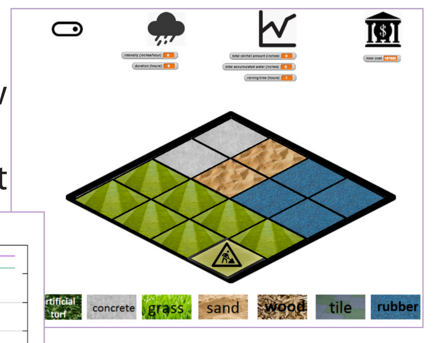
LP 7: Communicate a solution (using evidence from a model) that mitigates the effects of building on water runoff. (Engaging in argument)

4 Curriculum Unit : The Playground Design Challenge

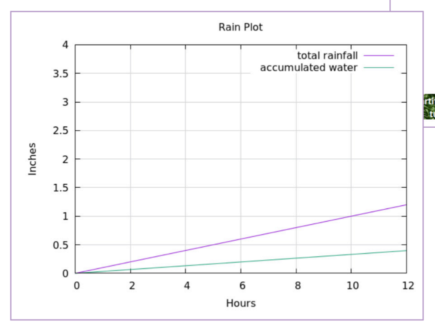


- Learning performances constitute anchors for a 3-week curriculum activity sequence where students investigate the cause of urban water runoff, and design a playground that minimizes runoff
- Students engage in hands-on activities and technology-supported inquiry using the Web-based Inquiry Science Environment (WISE) (Linn & Eylon, 2006)

5 Computational Model



- Students use a computational model to (1) determine how rainfall intensity, rainfall duration, and surface material affect water runoff and (2) test playground designs against design criteria
- In Phase 2, students will develop the model using a block-based programming interface



6 Assessment Tasks

- **Pre-post and embedded assessment tasks** will provide evidence of students' 3-dimensional proficiency with the target PEs
- Design specifications guide the design of NGSS-aligned assessment tasks (below)

Assessment design specifications for a task addressing Learning Performance 1

Learning goal	**LP 1:** Define and delimit and engineering problem concerning the effect of building on water runoff.
Evidence statements	• Student appropriately describes a problem concerning urban runoff • Student lists relevant design constraints pertaining to an urban runoff problem • Student describes a success criterion for an urban runoff problem
Prerequisite knowledge	• Knowledge about design criteria • Knowledge about a city council's role as client
Example Task features	• Task uses a familiar building context

Example Assessment Task

A grassy area downtown has been replaced by a new tennis center. Since the tennis center was built, a shopping area next to the center floods after heavy rain.

(a) Explain why this is a problem for people living in the town.

(b) A city council member asks you to redesign the tennis center to solve the problem. One of the criteria for redesigning the tennis center is to keep rebuilding costs low. **List two other criteria the city council** could give you to redesign the tennis center.

(1) Keep rebuilding costs low

(2) ____

(3) ____

(c) How will the city council decide if your design is successful?

Implications

- A detailed domain analysis enables coherent integration of the science, engineering, and computational thinking disciplines
- Learning performance statements enable the alignment of curriculum materials, learning technologies, and assessments to specific NGSS performance expectations
- Assessment task design specifications help ensure that pre-post assessment tasks are appropriately aligned with the curriculum materials and that embedded assessments are informative to teachers

Next Steps

- Score and analyze data from classroom pilot study underway (3 teachers and 18 science classes)
- Identify aspects of the computational system model students can build using block-based code
- Develop an approach for elementary teacher professional development to support students across science, engineering, and computational thinking

SRI Education | University of Virginia Curry School of Education | Vanderbilt School of Engineering

spiceprojects.org
PI Contact: kevin.mcelhaney@sri.com

This material is based in part upon work supported by the National Science Foundation under NSF Award DRL-1742195 (A Study of a Technology-enhanced Curriculum Integrating Science, Engineering Design, and Computational Modeling to Achieve Synergistic Learning with Elementary Students). Any opinions, findings, and conclusions or recommendations expressed in this material are those of the author(s) and do not necessarily reflect the views of the National Science Foundation.