Using Construct-Centered Design to Align Curriculum, Instruction, and Assessment Development in Emerging Science

Jim Pellegrino, University of Illinois, Chicago
Namsoo Shin, University of Michigan
Overview of the Seminar

• Introduction to Construct-Centered Design
  • Rationale & Overview of its Components

• Examples of application within NCLT
  • Research: Learning progressions (UM)
  • Student materials: Curriculum materials and Learning technology (UM, UIUC, & UIC)
  • Teacher materials: Professional development (Purdue & UIC)

• Lessons Learned & Future Applications

• Questions and Discussion
Center Mission & Vision

Mission: **Build national capacity** in Nanoscale Science & Engineering (NSE) Education (grades 7-16)

Vision: **Develop a globally competitive** NSE workforce and train a national cadre of leaders in NSE education

Learning and teaching through inquiry and design of nanoscale materials and systems for applications
Part 1

Construct-Centered Design as a Unifying Approach for Center Work on Curriculum, Instruction, & Assessment tied to the “Big Ideas”
What & Why of “Big ideas”

• What are big ideas?
  • the core concepts and principles of a field

• Why big ideas?
  • help learners understand a variety of ideas about a field provide ideas/models to explain a range of phenomena
  • allow learners to intellectually make individual, social, and political decisions regarding science and technology
  • provide insight into the development of the field or have a key influence on explaining the major ideas in the domain
The Big Ideas in NSE

Size & Scale
Structure of Matter
Quantum Effects
Forces & Interactions
Size-Dependent Properties
Self-Assembly
Tools & Instrumentation
Models & Simulations
Science, Technology & Society
How do we use the big ideas?

To help define construct domains & learning goals that can be used to align curriculum development, instruction, assessment, and teacher education.
Construct-Centered Design (CCD)

• What is CCD?
  • Adaptation of aspects of learning-goals-driven design (Krajcik, McNeill, & Reiser, 2007) and evidence-centered design (Mislevy, et al., 2003; Pellegrino, et al., 2001)
    • Define knowledge domains (construct)
    • Use construct to align development of curriculum, instruction, and assessment

• Why use CCD?
  • Provides a systematic approach to developing instructional materials (for students and teachers), and assessment (formative & summative)
  • Facilitates the development of principled, coordinated research on teaching and learning
Stages of CCD Process

1. Define Construct
2. Unpack Construct
3. Develop Claim
4. Define Evidence
5. Design Tasks
   - Student Materials
   - Teacher Materials
   - Assessment
6. Review Products
   - internal review
   - pilot materials
   - outside review
1. Define the Construct

- These might be derived from a set of "big ideas" in science or from standards or benchmarks.

- Includes concepts that are not just related somehow to a big idea, but necessary for building understanding of the big idea.

- Approach and "grain size" depend on the desired final product and intended use.
2. Unpack Construct

**define context**

- Grade level?
- What subject?
- How long is the intervention?

**specify science content**

- alternative conceptions
- prerequisite knowledge

**relevant phenomena**

- potential student difficulties
- links to standards
3. Develop Claims

- A claim is about what the student “knows” and “understands” and how they do so.
- Incorporates both content and cognitive skills.
- Uses descriptive and specific verbs to clarify learning performances. For example:
  - describe, analyze, compare and contrast, design
  - explain content using evidence and reasoning
  - build and describe models
<table>
<thead>
<tr>
<th>Level I Performances:</th>
<th>Level II Performances:</th>
<th>Level III Performances:</th>
</tr>
</thead>
<tbody>
<tr>
<td>Simple behavioral/cognitive objectives</td>
<td>Behaviors requiring application of more complex mental operations</td>
<td>Behaviors requiring application of more complex mental operations</td>
</tr>
<tr>
<td>After . . . the student will be able to . . .</td>
<td>After . . . the student will be able to . . .</td>
<td>After . . . the student will be able to . . .</td>
</tr>
<tr>
<td>find</td>
<td>prove</td>
<td>synthesize</td>
</tr>
<tr>
<td>gather data</td>
<td>organize data</td>
<td>infer</td>
</tr>
<tr>
<td>describe</td>
<td>apply</td>
<td>generalize from data</td>
</tr>
<tr>
<td>do</td>
<td>construct</td>
<td>predict</td>
</tr>
<tr>
<td>make</td>
<td>distinguish between (or among)</td>
<td>deduce</td>
</tr>
<tr>
<td>compute</td>
<td>state a problem</td>
<td>discuss critically</td>
</tr>
<tr>
<td>Measure</td>
<td>contrast</td>
<td>integrate</td>
</tr>
<tr>
<td>use</td>
<td>compare</td>
<td>discover</td>
</tr>
<tr>
<td>illustrate</td>
<td>interpret</td>
<td>formulate hypotheses</td>
</tr>
<tr>
<td>examine</td>
<td>identify the variables</td>
<td>reorganize</td>
</tr>
<tr>
<td>manipulate apparatus</td>
<td>differentiate</td>
<td>manipulate ideas</td>
</tr>
<tr>
<td>recognize</td>
<td>relate</td>
<td>propose reasons and defend them</td>
</tr>
<tr>
<td>identify</td>
<td>discriminate</td>
<td></td>
</tr>
<tr>
<td>classify</td>
<td>reformulate</td>
<td></td>
</tr>
<tr>
<td>recognize and cite evidence for</td>
<td>justify</td>
<td></td>
</tr>
<tr>
<td></td>
<td>estimate</td>
<td></td>
</tr>
<tr>
<td></td>
<td>specify the limitations and assumptions</td>
<td></td>
</tr>
<tr>
<td></td>
<td>analyze</td>
<td></td>
</tr>
</tbody>
</table>
4. Define Evidence

- What will you accept as evidence in support of a claim that a learner has the desired knowledge?

- Specific learner performances and/or work products that you would accept as indicative that a claim has been satisfied.

- The features of the work products and performances that you expect to see and their value and importance in supporting a claim
5. Design Situations or Tasks

• What particular tasks, questions or situations will help students develop knowledge and bring about a response that will provide sufficient evidence to support the student learning claim.

• A single task or situation may provide evidence for more than one claim.

• Multiple tasks and performances may be necessary to provide evidence in support of a single claim.
6. Review Products

- Based on the internal and external reviews and pilot studies, iterate through relevant portions of the design process.

- Confirm that the products meet all CCD criteria
  - who they are intended for
  - how they are intended to be used
A Possible Metaphor for What the NCLT is Trying to Do Using Construct-Centered Design
Self-Assembly

Is it a “big idea”?

What concepts are affecting it?

Which concepts to unpack?

At what level should they be unpacked?

Can self-assembly be used as a vehicle for learning about these concepts?

What claims can be formulated using this approach?

What evidence can support the claims?

What tasks can demonstrate the evidence?

How to develop instruction that aligns with the claim-evidence-task?

What prior knowledge to consider?

Where and how should design activities be incorporated?

Can one instruction respond to more than one claim?

What instructional method/sequence is optimal?
Part 2
Areas Where CCD is Being Applied
CCD Examples

- **Research**
  - Learning Progressions (UM)

- **Student Materials**
  - Summer Science Camp (UM & UIUC)
    - Curriculum with learning technology
  - Learning Technology (UIC)

- **Teacher Materials**
  - Professional Development (Purdue & UIC)

*These applications encompass development of curriculum materials, learning technology, teacher education, and assessment, in addition to research efforts.*
Research

• Research on Learning Progressions: UM

• Purpose
  To empirically derive a learning progression that describes the development of grade 7-14 students’ models of the structure and interactions of atoms as they relate to nanoscale science and engineering (NSE)

• Big ideas
  Structure of Matter, Forces & Interactions (and ultimately also Size-Dependent Properties and Quantum Effects)
Research

Content
Kinetic theory: Particles/atoms are always in motion (except at 0° K)

<table>
<thead>
<tr>
<th>Claim</th>
<th>Evidence</th>
</tr>
</thead>
</table>
| *The student is able to:* incorporate particle motion into their descriptions of the structure of matter | *The student work should include:*
| 1. a description of the behavior of the particles that make up matter |
| 2. a model of matter that includes: |
| - all matter is made up of particles/(atoms) |
| - the particles are too small to see with the naked eye. |
| - the particles that make up matter are in constant motion |
| - the inherent motion is often called thermal energy |
Kinetic theory: Particles/atoms are always in motion (except at $0^\circ K$)

**Task**

*Interview Protocol*

If we have a special instrument that allows us to zoom in and see what this metal is made of, what would we see? Draw what you think it will look like and explain your model.
Research: Developing Instrument

Assessment type

- interview, multiple-choice item, open-ended item, work product, or performance

Presentation Type

- How tasks are presented
- How tasks are scheduled to be administered

Scoring Process

- How evidence is identified, scored, and accumulated
Student Materials

• Curriculum development for Informal Education (UM & UIUC)

• Purpose
  To develop 2-week curriculum unit for middle school students

• Big Idea
  Size and Scale
## Big Idea: Size and Scale

<table>
<thead>
<tr>
<th>Claim</th>
<th>Evidence</th>
</tr>
</thead>
<tbody>
<tr>
<td><em>The student is able to:</em></td>
<td><em>The student work should include:</em></td>
</tr>
<tr>
<td>estimate the sizes of a range of scientifically important objects in terms of a convenient and familiar reference object</td>
<td>an estimate of how many times smaller they are relative to a small, macroscopic reference object, within a factor of two.</td>
</tr>
</tbody>
</table>
# Student Materials

## Big Idea: Size and Scale

<table>
<thead>
<tr>
<th>Task (Learning)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Hand-on instructional activities</strong></td>
</tr>
<tr>
<td>Measure the thickness of a hair by seeing how many line up across a millimeter.</td>
</tr>
<tr>
<td>Using the microscope, compare the thickness of a hair on a slide to your own cheek cells and to a prepared slide of skin cells.</td>
</tr>
<tr>
<td>Using the tracing of the sizes of hair, skin cell, and Staphylococcus Aureus at 2000X magnification obtained through the projecting microscope, calculate the size in micrometers of these three objects.</td>
</tr>
</tbody>
</table>
Student’s Artifacts

- Skin Cell
- Staph A

Thickness of Hair
Big Idea: Size and Scale

**Task (Learning)**

*Computer simulation*

Using the images of hair, skin cell, staph A, HIV, rhinovirus, DNA, and atom, calculate the relative and absolute size of these objects.
Big Idea: Size and Scale

<table>
<thead>
<tr>
<th>Task (Assessment)</th>
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</thead>
<tbody>
<tr>
<td>Relative Size</td>
</tr>
<tr>
<td>How many times smaller is the Staph A compared to the skin cell?</td>
</tr>
<tr>
<td>How many times smaller is the skin cell compared to the width of a hair?</td>
</tr>
<tr>
<td>How many times smaller is the Staph A compared to the width of a hair? How did you figure this out?</td>
</tr>
</tbody>
</table>
Student Materials

• Learning Technology: UIC

• Purpose
  To develop curriculum materials for middle school students to teach Interactions of energy with matter

• Big ideas
  Forces & Interactions, and Self-Assembly
## Student Materials

**Big idea: Forces & Interactions, and Self-Assembly**

<table>
<thead>
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</table>
| *The student is able to:* predict how changes of energy affect the movement of atoms as materials change structure. | *The student work should include:* *(Shown a comparison of the same material at different temperatures), a written description of*  
- every substance has heat, regardless of its temperature.  
- that the system has less heat/energy at lower temperatures, while at higher temperatures it has more |
Task (Learning)

Computer simulation

[Given a simulation of four atoms exhibiting random motion in a system whose energy can be manipulated by a heat gauge]

Describe the movement of these atoms and what happens when the temperature of the system is increased or decreased. Why does this occur when the temperature is changed?
**Contextualization**
- connect content to real world, and define relevant phenomena and driving (focus) question

**Learning Tasks**
- incorporate: activities, relevant phenomena, and simulations/animations
- scaffold student learning using text, discussion, and activities

**Instructional Sequence**
- create a logical progression
- define sub-learning goals *(may require mini-unpacking step)*

**Assessment Strategies**
- formative: potential discussion questions
- summative: posttest (written, oral, project, etc.)

**Assessment Tasks**
- Assessment type, Presentation type, and Scoring Strategies.
Teacher Materials

• Professional Development: Purdue and UIC

• Purpose
  To develop educative curriculum materials for high school teachers

Big Idea
  Self-Assembly
Big idea: Self-Assembly

<table>
<thead>
<tr>
<th>Claim</th>
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</tr>
</thead>
<tbody>
<tr>
<td><strong>The student will:</strong> have an awareness of the</td>
<td><strong>The student work should include:</strong> A written discussion of comments on</td>
</tr>
<tr>
<td>nature of design, specifically design of</td>
<td>using discoveries in nature as a basis for design, considering multiple</td>
</tr>
<tr>
<td>components and systems at the nanoscale.</td>
<td>components at the same time, and iterative nature of design process.</td>
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Teacher Materials

Big idea: Self-Assembly

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Students design a model of a self-assembling system using legos and blocks with magnets and Velcro. Following the activity, there is a discussion on what it means to design with emphasis on the following ideas: iteration, systems, and using nature as a basis for design.
Background Knowledge

- science content the teacher needs to know to be prepared to teach and deal with students’ ideas and preconceptions

Teaching Strategies

- suggestions for lesson setup and student motivators
- eliciting students’ ideas, questions, and interests

Students’ Ideas

- prior knowledge, prior life and academic experiences
- potential student difficulties, alternative ideas, and students’ interests

Supporting Inquiry

- teacher- vs. student-directed inquiry

Adaptation

- rationales for instructional material design decisions
- multiple phenomena, first-hand experiences, and hints for contextualizing

Assessment Strategies and Tasks
Part 3
Lessons Learned & Future Applications within NCLT
Uses & Benefits

• Helps to organize the content within the big idea

• Helps ascertain how well an activity or performance characterizes student understanding of all of the content within the big idea

• Provides a clear chain of reasoning from big idea to curriculum, instruction & assessment to help ensure coherence and construct validity, as well as alignment.
Suggestions

• Unpack systematically
  – First, specifying all of the content in the big idea (or learning goal)
  – Second, unpacking the rest of the components in a more organized way

• Provide concrete examples to clarify the process
Limitations

- The initial part of the process (define a construct and unpack a construct) can be very specific and too narrow -- need to consider a “useful grain size” and avoid infinite regress.
- It’s a process, not a cookbook recipe, so it is still difficult to create assessment and curriculum materials.
- There are challenges in identifying the differences among claims, evidence, and tasks.
Ways We are Supporting the Process
NCLT has developed a Center-wide systematic approach to developing assessments. This approach includes mapping out the knowledge domains associated with nanoscale science and technology and developing assessments of that knowledge for various purposes, including supporting instructional design and understanding how students’ ideas of nanoscale science develop over time. Designing good assessments for evaluating student understanding is critical for all aspects of work in the NCLT. To unify our assessment approaches in a consistent, principled way, we propose using a method that aligns with ideas discussed in the contemporary literature on designing and constructing valid assessment items. This document is designed to provide directives and definitions for application of an NCLT version of an “Evidence-Centered Assessment Design” process. The process includes unpacking a big idea, making claims about what students should know, defining evidence that supports such claims, and developing tasks that will provide the proper evidence. Below is a summary of the guidelines. You can download the guidelines, which also contains examples below.

Assessment Design Process

Step 1. Select the big idea you wish to assess
- Use big Idea document (http://www.hice.org/projects/nano/index.html) to select the ideas to examine.

Step 2. Identify the grade level of the students
- What grade range of learner are you concerned with? Students at different grade ranges have different knowledge and experiences that influence their learning and that are appropriate targets for instruction and assessment.

Step 3. Unpack the big idea (this is possibly the most time-consuming and difficult process.)
- Unpacking – Unpacking involves taking the big idea (construct), breaking it apart and expanding the various concepts to identify and explicitly describe the critical components important for understanding the big idea. (See example 1)
  1. Identify and clarify critical concepts
     - Identify and clarify the important concepts/ideas that you are trying to help students learn and assess. Explain what each of these ideas mean. At what level and depth of understanding do you expect learners to understand the idea/concept? Creating a concept map can help identify the ideas students will need to know and identify the links among ideas.
  2. Identify prior knowledge
     - Identify and describe what prior knowledge students will need to understand before learning these concepts.
Part 4
Questions & Discussion
Frequently Asked Questions

• Where to stop the unpacking process and call it prerequisite knowledge and do so in a principled way?

• What cognitive skill/process skill to use in each claim, in a principled way?

• What are the differences between claims, evidence, and tasks?