Extending a Coherent Gateway to STEM Teaching and Learning

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Background:

In 2013 the AAU proposed a STEM Education Initiative

MSU received one of eight grants: “Creating a Coherent Gateway to STEM Teaching and Learning”

In 2017 MSU, FIU, GVSU and KSU received a large-scale NSF (IUSE) grant to continue the work: “Extending a Coherent Gateway to STEM Teaching and Learning”
AAU STEM Initiative

AAU has launched a five-year initiative in collaboration with our member universities to improve the quality of undergraduate teaching and learning in science, technology, engineering, and mathematics (STEM) fields. This is not another study or research project on STEM education. Instead, it is an effort based on overwhelming existing research to influence the culture of STEM departments at AAU universities so that faculty members are encouraged to use student-centered, evidence-based, active learning pedagogy in their classes, particularly at the first-year and sophomore levels.

https://stemedhub.org/groups/aau
Need for Widespread Change in STEM Teaching and Learning

“DBER and related research have not yet prompted widespread changes in teaching practice among science and engineering faculty. Strategies are needed to effectively promote the translation of findings from DBER into practice.”

Targeting Introductory Courses

“The first two years of college are the most critical to the retention and recruitment of STEM majors.”

Change Model: Build Faculty Consensus Around the Aims and Rewards of Reform Through:

1. Developing a shared vision for gateway course transformation in biology, chemistry and physics

2. Developing policies and structures to support and reward reform

A Framework for K-12 Science Education

We adapt this vision of STEM teaching and learning for college classrooms.

A Shared Vision for Curriculum Reform

Engage faculty in discussions to build consensus on key issues.

◦ What are the **core ideas** in the discipline?
◦ What **scientific practices** are important?
◦ What **cross-cutting concepts** make connections among disciplines?

The result – three dimensional learning.
Three-Dimensional Learning

Scientific Practices

Patterns
- Cause & Effect
- Scale, Proportion, & Quantity

Systems & System Models
- Energy & Matter

Structure & Function
- Stability & Change


Three-Dimensional Learning


Identify disciplinary core ideas, crosscutting concepts, and science practices that form the basis of the courses they teach.

Apply principles of backward design and evidence-centered design to assessment development in order to create assessment items that measure students’ three-dimensional learning.

Become part of an interdisciplinary community of faculty committed to improving undergraduate STEM education.
Implementing Three-Dimensional Learning

How do we assess outcomes?

What evidence would be convincing?
Engaging faculty to determine the core ideas, science practices and cross cutting concepts promote change leads to changes in classroom practice and changes in assessment practices.
Measuring Change

Collect data on persistence, grades, affective domain, faculty perceptions etc.

BUT...

◦ We know that grades do not necessarily equate with learning
◦ And what faculty say does not necessarily align with their practice
We are measuring change

By investigating classroom practice
  ◦ Using the Three Dimensional Learning Observation Protocol (3D-LOP)
And the nature of course assessments.
  ◦ Using the Three Dimensional Learning Assessment Protocol (3D-LAP)
Three-Dimensional Learning Assessment Protocol (3D-LAP)

Dual purpose:
◦ Help faculty improve assessments
◦ Characterize change in assessments over time

Adapting Assessment Tasks To Support Three-Dimensional Learning

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Original Task

Identify core idea(s)

What evidence would demonstrate student understanding of core ideas?

Use 3D-LAP

Three-Dimensional Assessments

Scientific Practices

Crosscutting Concepts

Core Ideas


Example traditional assessment item:

For this reaction $\text{CH}_3\text{CH}_3 + \text{Cl}_2 \rightarrow \text{CH}_3\text{CH}_2\text{Cl} + \text{HCl}$

a. Using the table of bond energies, calculate the enthalpy change for the reaction.
For this reaction $\text{CH}_3\text{CH}_3 + \text{Cl}_2 \rightarrow \text{CH}_3\text{CH}_2\text{Cl} + \text{HCl}$

a. Construct chemical structures for the reactants and products.
b. Using your structures, identify which bonds are broken and which bonds are formed.
c. Explain why breaking bonds requires an input of energy from the surroundings.
d. Using the table of bond energies, calculate the enthalpy change for the reaction.
e. Construct an energy diagram showing the overall energy change for the reaction.
f. Construct an explanation about why the energy changes during the reaction that includes:
   a. A claim about the energy change for the reaction (exothermic or endothermic)
   b. The evidence you used to make this claim
   c. Your reasoning about why this evidence leads to the claim
Comparison of 3D-LAP Characterized Chemistry Exams

<table>
<thead>
<tr>
<th>Traditional Exam Question Number</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20</td>
</tr>
<tr>
<td>SP</td>
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<tr>
<td>CC</td>
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<tr>
<td>CI</td>
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<table>
<thead>
<tr>
<th>Transformed Exam Question Number</th>
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<tbody>
<tr>
<td>Q# 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24</td>
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<tr>
<td>SP</td>
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<tr>
<td>CC</td>
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<tr>
<td>CI</td>
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</tbody>
</table>


We coded 4020 questions using the 3D-LAP over four years (Year 0 to Year 3)

<table>
<thead>
<tr>
<th>Discipline</th>
<th>Questions coded</th>
<th>Unique instructors</th>
<th>Unique exams coded</th>
<th>Total questions coded</th>
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</thead>
<tbody>
<tr>
<td>Chem I and II</td>
<td>718</td>
<td>93</td>
<td>811</td>
<td>1,529</td>
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<tr>
<td>Phys I and II</td>
<td>479</td>
<td>230</td>
<td>709</td>
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<tr>
<td>Bio 1</td>
<td>1,705</td>
<td>184</td>
<td>1,899</td>
<td>3,602</td>
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<tr>
<td>Bio 2</td>
<td>528</td>
<td>83</td>
<td>611</td>
<td>1,141</td>
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<tr>
<td><strong>Total</strong></td>
<td><strong>3,430</strong></td>
<td><strong>590</strong></td>
<td><strong>4,020</strong></td>
<td></td>
</tr>
</tbody>
</table>
Students had significantly (p < 0.05) higher final grades in year 3 than in year 0.

The decrease in DFW rate practically translates to approximately 740 more students earning a grade of 2.0 or above in Year 3 compared to Year 0.
3D-LAP Showed Increase in 3D Questions Over Four-Year Project


Three-Dimensional Learning Observation Protocol (3D-LOP)

Dual purpose:
◦ Help faculty improve instruction
◦ Characterize change in instruction over time

Current Research Question
◦ What are the features and criteria that should be included in an observational protocol to evaluate the presence of scientific practices, crosscutting concepts, and core ideas in college classroom instruction?
Why not use other existing observation protocols?

Observation protocols, such as TDOP, RTOP, RIOT, and COPUS, focus on “how” the class is being taught
- What students are doing
- What instructor is doing
- Interactions between students and instructor
- Student-centered
- Active learning techniques

No information about “what” is being taught
Developing the 3D-LOP: Initial Approach

<table>
<thead>
<tr>
<th>“How”</th>
<th>“What”</th>
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<tbody>
<tr>
<td>Clicker Questions</td>
<td>Scientific Practices</td>
</tr>
<tr>
<td>Tasks</td>
<td>Crosscutting Concepts</td>
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<tr>
<td>Interactions</td>
<td>Core Ideas</td>
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<td>Lecture</td>
<td>Phenomena</td>
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<td>Administration</td>
<td>Instructor Questions</td>
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<tr>
<td>Miscellaneous</td>
<td>Students Speaking</td>
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</table>

<table>
<thead>
<tr>
<th>Class Begins</th>
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<tbody>
<tr>
<td>Clicker Question</td>
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<tr>
<td>Task</td>
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<tr>
<td>Interaction</td>
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<tr>
<td>Lecture</td>
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<tr>
<td>Administration</td>
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<tr>
<td>Misc</td>
</tr>
<tr>
<td>Question</td>
</tr>
<tr>
<td>Phenomena</td>
</tr>
<tr>
<td>Scientific Practice</td>
</tr>
<tr>
<td>Crosscutting Concept</td>
</tr>
<tr>
<td>Disciplinary Core Idea</td>
</tr>
</tbody>
</table>
Developing the 3D-LOP: Initial Approach
Current 3D-LOP: Chunking Videos by Topic

Class sessions were sectioned into chunks

- A chunk is a coherent set of content that is focused around the same topics and can stand alone as an instructional unit; multiple activities can be part of the same chunk, but the whole chunk has to be related by content.

---

**Class Start**

5 min  | 4 min  | 8 min  | 8 min  | 37 min  | 15 min  | **Class End**

- Administration
- HW Review: Calculating Concentrations
- HW Review: Energy of exothermic dissolution
- Dilution of solutions
- Activity #1: Exothermic dissolution of CaCl₂ in water
- Activity #2: Endothermic dissolution of NH₄Cl in water
Current 3D-LOP: Coding Each Chunk for Dimensions and Classroom Engagement

Developing and Using Models

- Instruction presents an event, observation, or phenomenon for instructor/students to explain or make a prediction about.
- Instruction presents a representation or asks instructor/students to construct a representation.
- Instruction has instructor/students provide the reasoning that links the representation to their explanation or prediction.
3D-LOP Coding Example

**Scientific Practices**
- Explanation
- Math
- Models
- Models, Math, Explanation

**Core Ideas**
- Change & Stability, Energy, Interactions
- Electrostatic & Bonding Interactions, Energy, Change & Stability
- Cause & Effect, Scale, Proportion & Quantity, Systems, Energy & Matter, Stability & Change

**Crosscutting Concepts**
- Prop/Quant, Cause/Effect
- Cause & Effect, Scale, Prop/Quant, Systems, Energy & Matter, Stability & Change

**Class Start**
- 5 min
- 4 min
- 8 min
- 8 min

**Class End**
- 37 min
- 15 min
3D-LOP Coding Example

Activity #1: Exothermic dissolution of CaCl$_2$ in water

37 min

Models
Math, Explanation

Electrostatic & Bonding Interactions, Energy, Change & Stability

Cause & Effect, Scale, Proportion & Quantity,
Systems, Energy & Matter, Stability & Change

CaCl$_2$ & Water
3D-LOP Coding Example

Activity #1: Exothermic dissolution of \( \text{CaCl}_2 \) in water

Models
Math, Explanation

Electrostatic & Bonding Interactions, Energy, Change & Stability

Cause & Effect, Scale, Proportion & Quantity, Systems, Energy & Matter, Stability & Change

Activity

- When \( \text{CaCl}_2 \) dissolves in water the temperature increases.
- Draw a picture of \( \text{CaCl}_2 \) solid – show clearly what forces are holding the particles in \( \text{CaCl}_2 \) together.
3D-LOP Coding Example

Activity #1: Exothermic dissolution of CaCl₂ in water

37 min

Models
Math, Explanation

Electrostatic & Bonding Interactions, Energy, Change & Stability

Cause & Effect, Scale, Proportion & Quantity,
Systems, Energy & Matter, Stability & Change
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Activity #1: Exothermic dissolution of CaCl$_2$ in water

Models
Math, Explanation

Electrostatic & Bonding Interactions, Energy, Change & Stability

Cause & Effect, Scale, Proportion & Quantity,
Systems, Energy & Matter, Stability & Change
Activity #1: Exothermic dissolution of CaCl\(_2\) in water

- When CaCl\(_2\) dissolves in water the temperature increases.
- Draw a picture of CaCl\(_2\) solid – show clearly what forces are holding the particles in CaCl\(_2\) together
- Draw a picture of CaCl\(_2\) (aq)
3D-LOP Coding Example

Activity #1: Exothermic dissolution of CaCl$_2$ in water

- 37 min
- Models: Math, Explanation
- Electrostatic & Bonding Interactions, Energy, Change & Stability
- Cause & Effect, Scale, Proportion & Quantity, Systems, Energy & Matter, Stability & Change
Activity #1: Exothermic dissolution of CaCl₂ in water

37 min

Models
Math, Explanation

Electrostatic & Bonding Interactions, Energy, Change & Stability

Cause & Effect, Scale, Proportion & Quantity, Systems, Energy & Matter, Stability & Change

Developing and Using Models

- Instruction presents an event, observation, or phenomenon for instructor/students to explain or make a prediction about.
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- Instruction has instructor/students provide the reasoning that links the representation to their explanation or prediction.
3D-LOP Next Steps

Chunking of the 180+ classroom video recordings is complete!

Demonstrate validity & reliability
Scale up coding for large data corpus

Compare results with those from the 3D-LAP
Use as a professional development tool for faculty
Ongoing RQs

What supports faculty in applying the three-dimensional framework to their courses, and how can barriers to adoption be addressed?

In what way does participating in three-dimensional courses change outcomes for students?
Discussion Questions

What are the appropriate concessions to make with respect to 3DL when you go from sections of 30 to 400?

Do students have to participate in the science practices to be able to later engage in them on assessments?

How explicit does the tie-back to the core idea need to be (especially as ideas and systems get more complex)

What are the essential features of the framework that you would want your fellow colleagues to know and use?