Evidence Based Approaches to Curriculum Reform and Assessment

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Michigan State University

NEMC

New Orleans, Aug 9, 2018

Who am I and why am I here?

Evidence-based Approaches to Improving Chemistry Education

Professor

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517-353-1114

Lappan-Phillips Professor of Science Education

Research | Sel. Publications | CV | News | Awards/Honors

Research

(Research Description PDF)

The focus of our research is to develop evidence based approaches to teaching, learning and assessment. Our work involves a wide range of activities and methods including designing ways to assess both what students know and how they use their knowledge, developing curriculum materials, and evaluating the effects of transformation efforts both within and across disciplines.

To design effective curricula we need to know what students bring to the table both in their prior knowledge and what they are able to do with that knowledge. We also must understand how and why students develop ideas that are not scientifically sound. For example we have shown that for many students, when

Faculty & Research

- Faculty Members
- Emeritus Faculty
- Research Interests
- Research Areas
- Awards
- Lectureships
- Portraits
- Mentoring Policy (PDF)
- CNS Faculty Development/Policies
- Faculty Position

Welcome to the Cooper Research Group

Recent Updates

5/5/2018 - Katie Graduated!

Katie successfully defended her dissertation and received her Ph.D. Congratulations Katie!

About Our Group

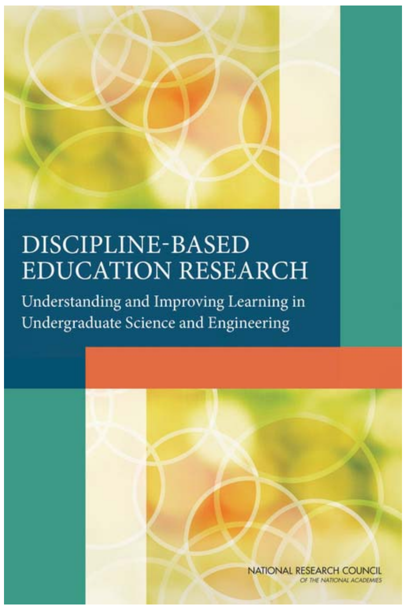
Our group focuses on improving the teaching and learning of chemistry at the undergraduate level. We use a variety of qualitative and quantitative techniques in order to examine the way that students learn chemistry and to inform the design of evidence-based curricular materials.

So what do **chemistry education** researchers in a **chemistry** department actually do?

Broadly – we try to answer the question: Why don’t students learn what we teach them?

We use theories of learning to generate evidence that can inform practice

Discipline-Based Education Research (DBER)

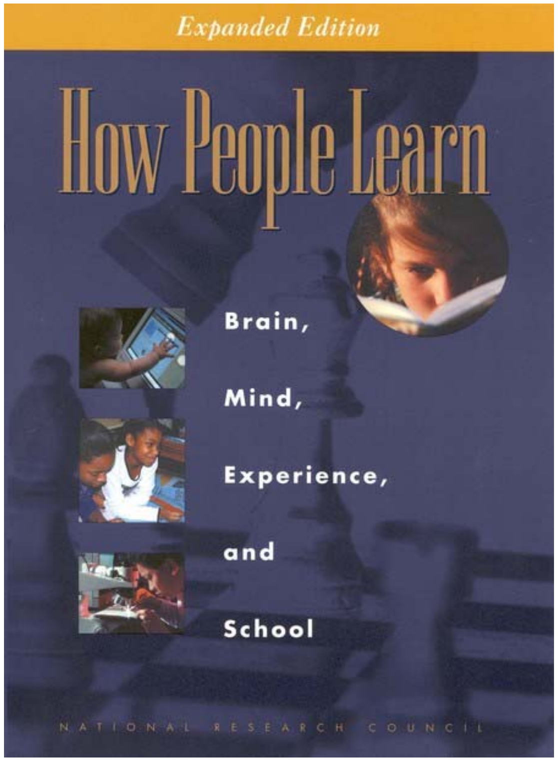


"DBER combines knowledge of teaching and learning with deep knowledge of discipline based STEM content. It describes the specific difficulties learners face and the specialized intellectual and instructional resources that can facilitate student understanding"

Discipline-Based Education Research: Understanding and Improving Learning in Undergraduate Science and Engineering. NRC 2012

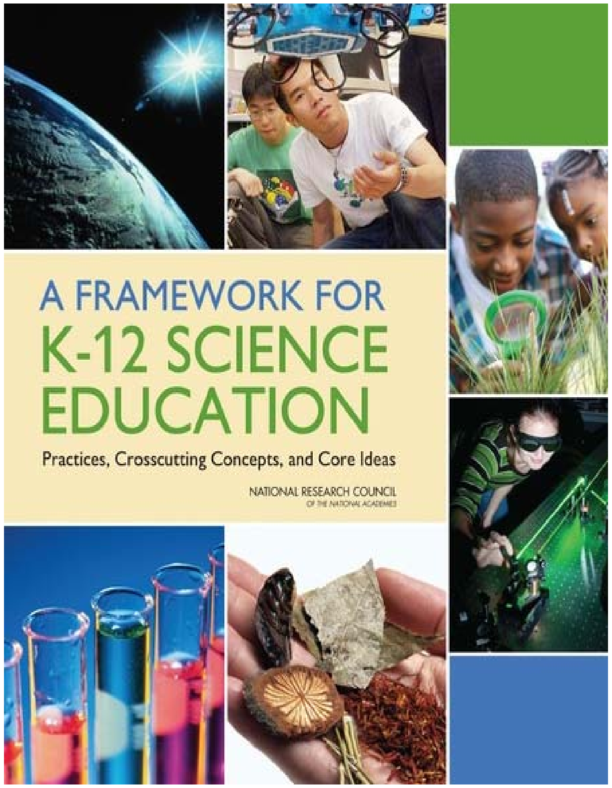
How People Learn: Key Findings

- Students are not “blank slates”
- Students construct knowledge (rather than receive it intact from the instructor)
- Knowledge must be organized and contextualized
- Reflection and metacognition are important

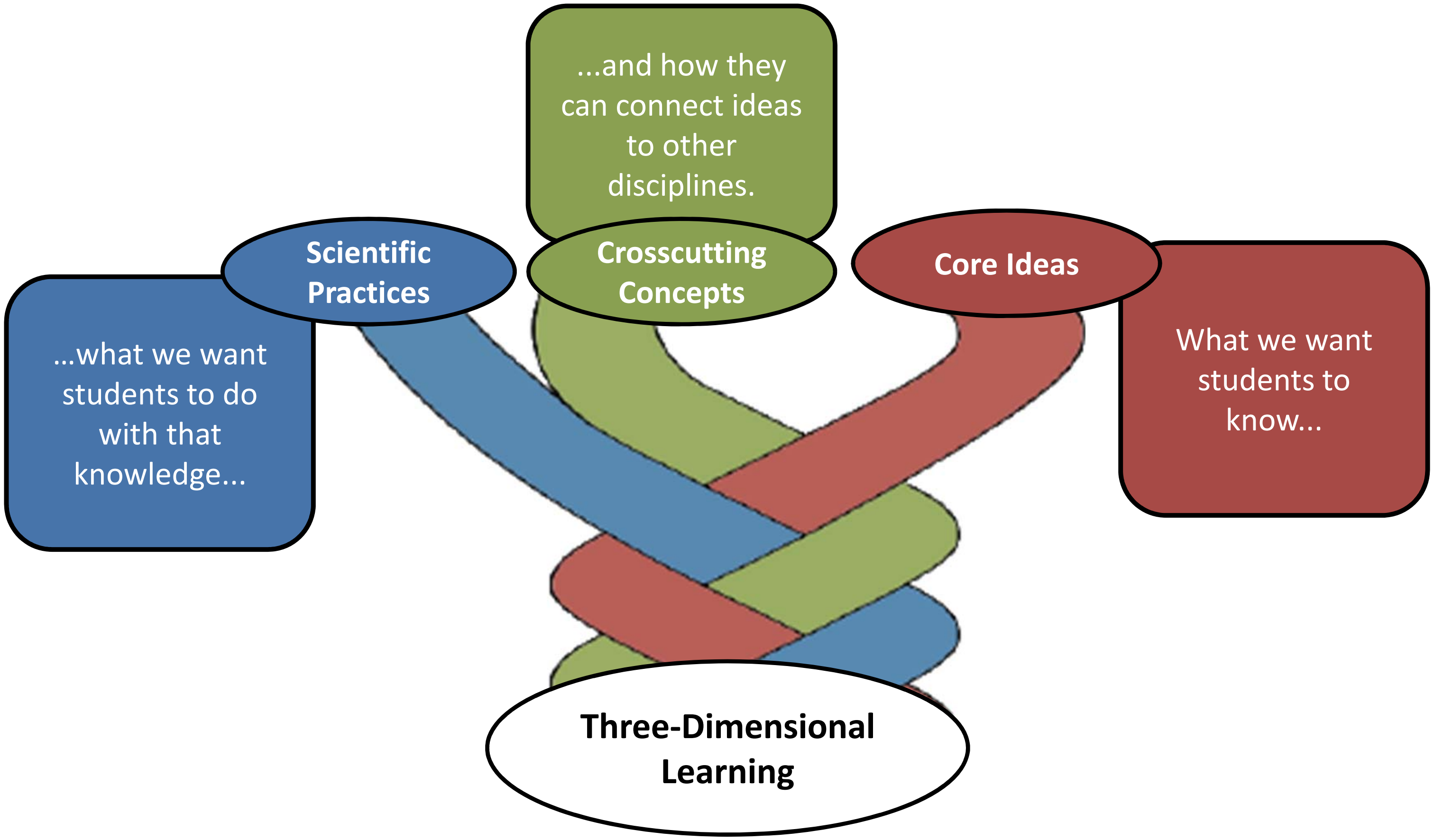


How People Learn NRC 2000

The Framework is a synthesis of the best available evidence, based on current theories of learning



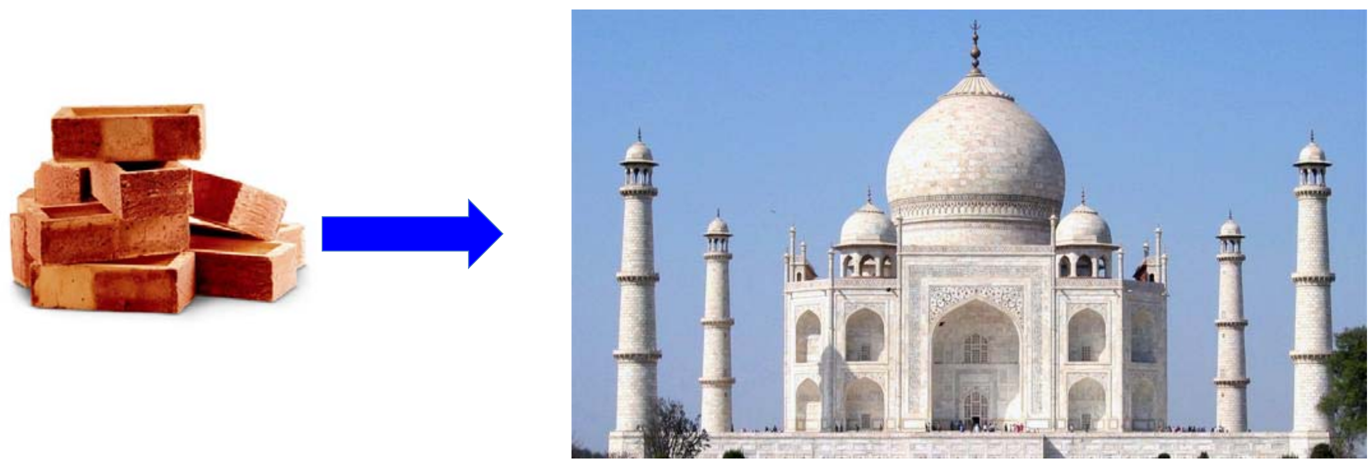
"The framework is **designed to help realize a vision for education in the sciences and engineering** in which students, over multiple years of school, actively engage in ***scientific and engineering practices*** and apply ***crosscutting concepts*** to deepen their understanding of the ***core ideas*** in these fields."



National Research Council. (2012). *A Framework for K-12 Science Education: Practices, Crosscutting Concepts, and Core Ideas.* Washington DC: The National Academies Press.

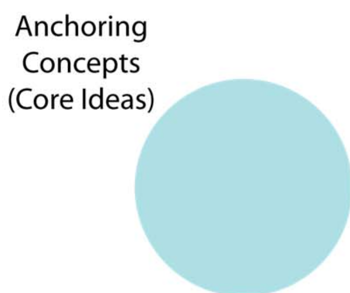
Why Core Ideas?

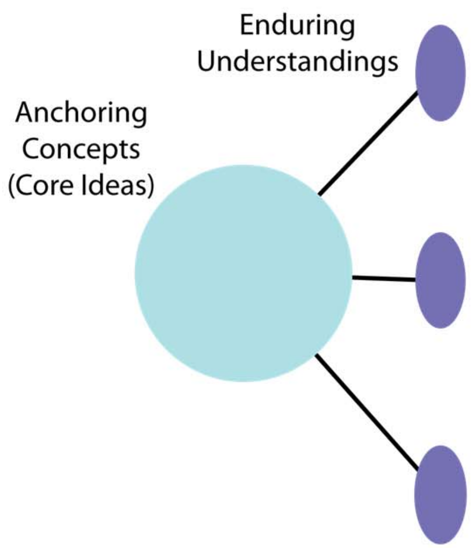
Experts' knowledge is organized into an underlying framework that reflects deep understanding of the discipline

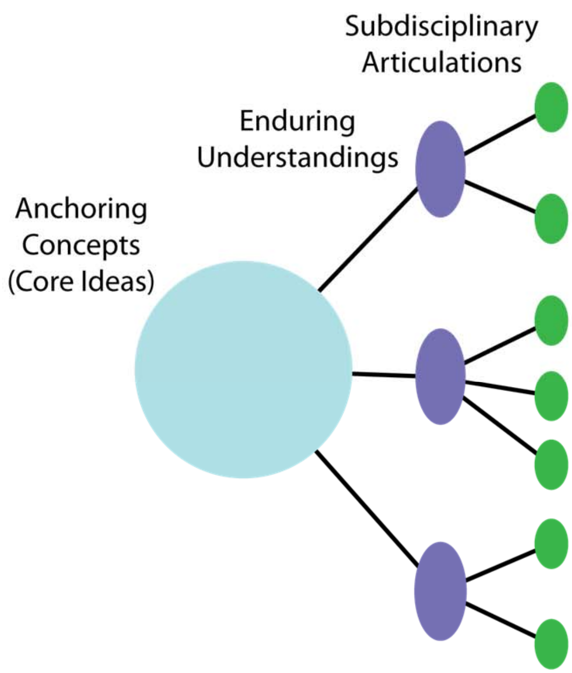


NRC: "How People Learn" (2000)

Constructing curricula around core ideas should allow students to link and contextualize knowledge


Anchoring
Concepts
(Core Ideas)


Enduring
Understandings
Anchoring
Concepts
(Core Ideas)


Subdisciplinary
Articulations
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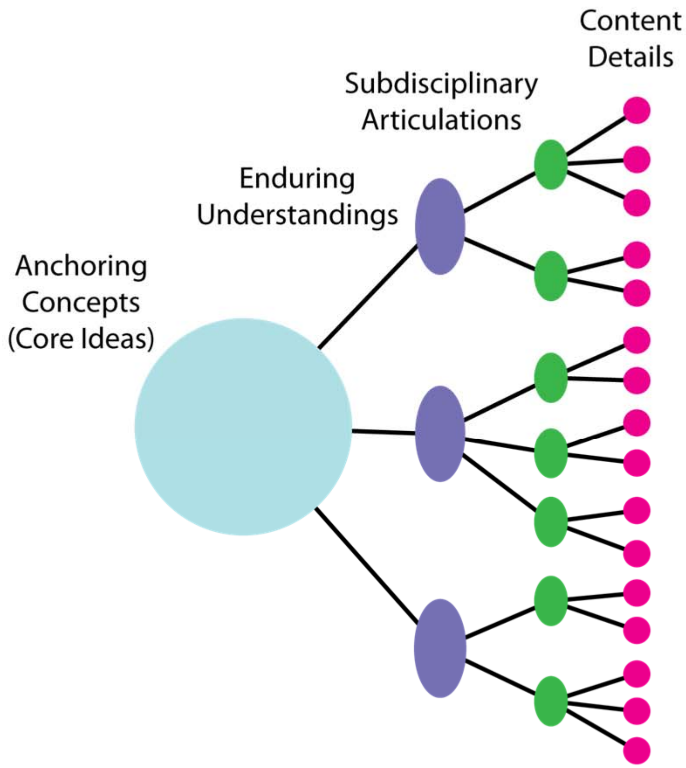
Anchoring
Concepts
(Core Ideas)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Details
Subdisciplinary
Articulations
Enduring
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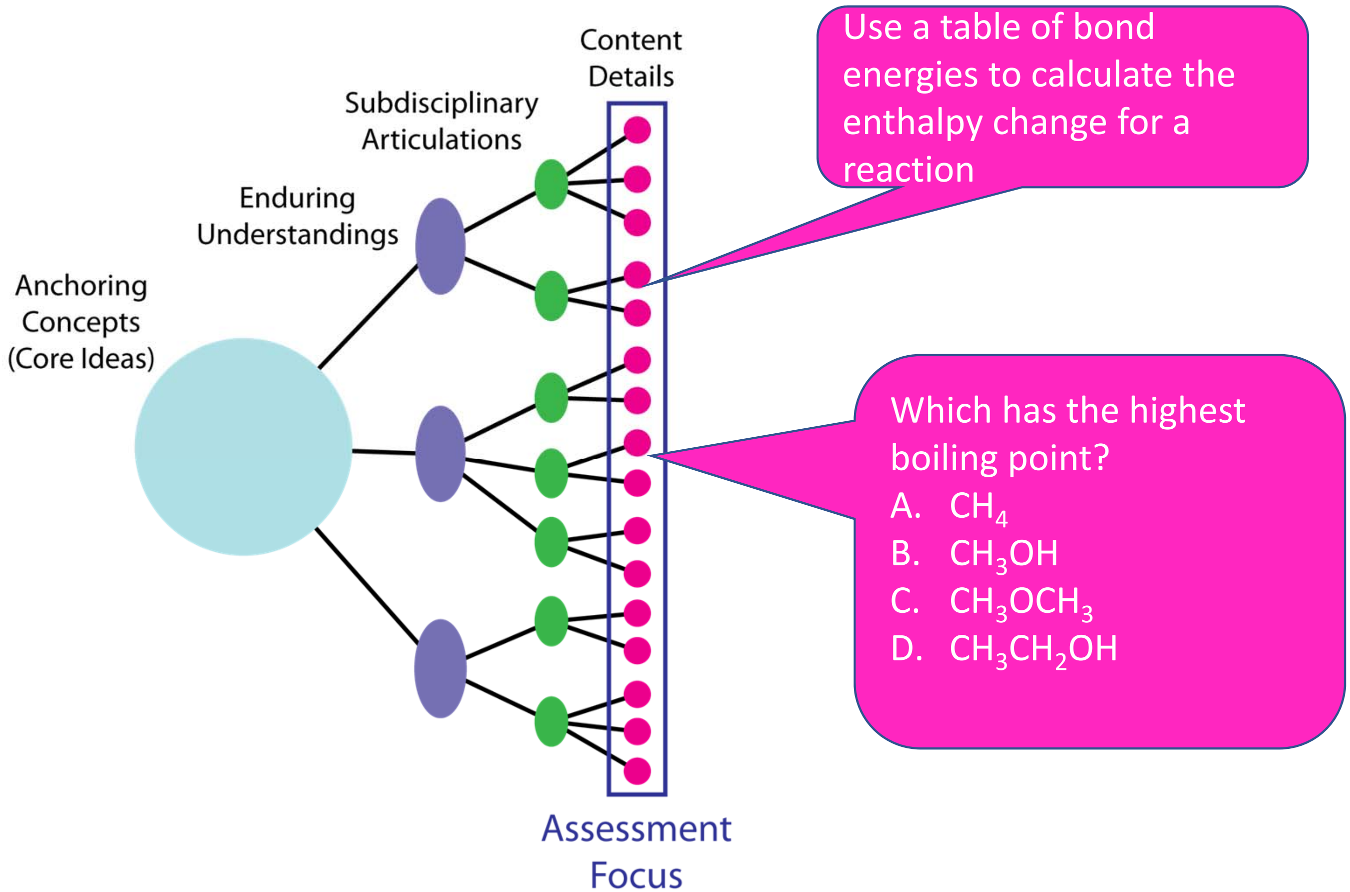
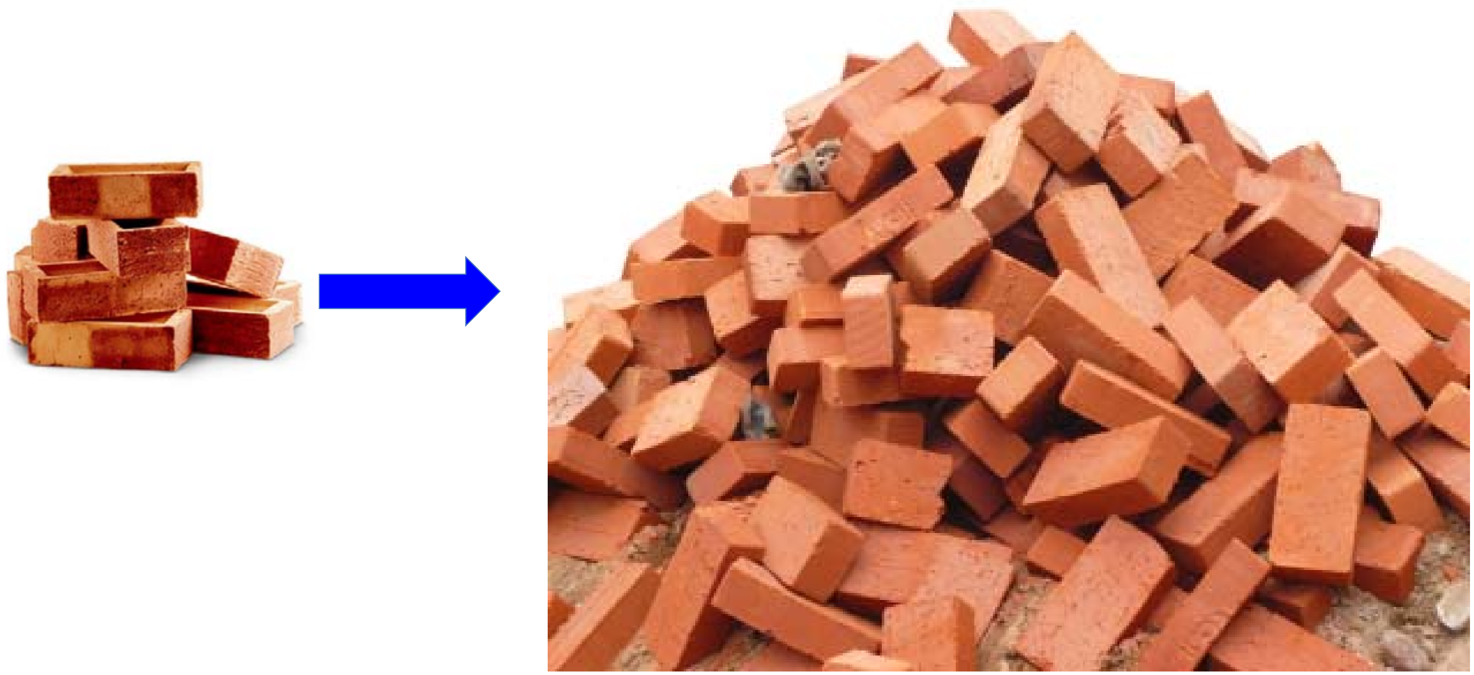

Content Details
Subdisciplinary Articulations
Enduring Understandings
Anchoring Concepts (Core Ideas)
Assessment Focus
Use a table of bond energies to calculate the enthalpy change for a reaction
Which has the highest boiling point?
A. CH_4
B. CH_3OH
C. CH_3OCH_3
D. CH_3CH_2OH

ACS Exams Institute: Anchoring Concept Levels 1-4 for Bonding

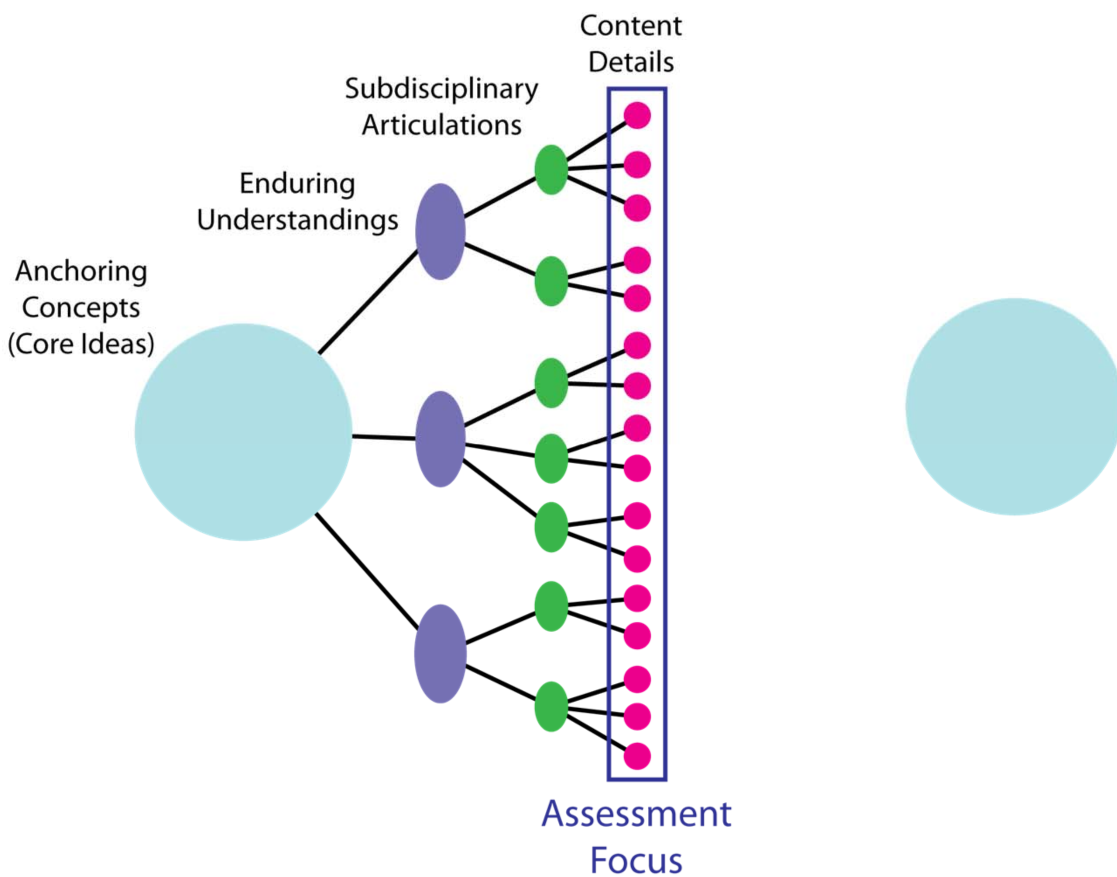
Level 1	**Anchoring Concept II. Bonding:**	**To break a chemical bond requires an input of energy.**
Level 2	Enduring Understanding D.	To break a chemical bond requires an input of energy.
Level 3	Sub-disciplinary Articulations 1.	The energy required to break a chemical bond is the bond dissociation energy.
Level 4	Content Detail a.	Bond dissociation energy is useful at the level of individual molecules; for calculations on macroscopic quantities, the value used is the bond dissociation enthalpy.
	Content Detail b.	Bond dissociation enthalpies can be used to estimate the change in enthalpy for a reaction.

In the ACS general chemistry curriculum map there are **263 content details e**ach of which may be assessed.

If fragments are not connected to core ideas…



NRC: “How People Learn” (2000)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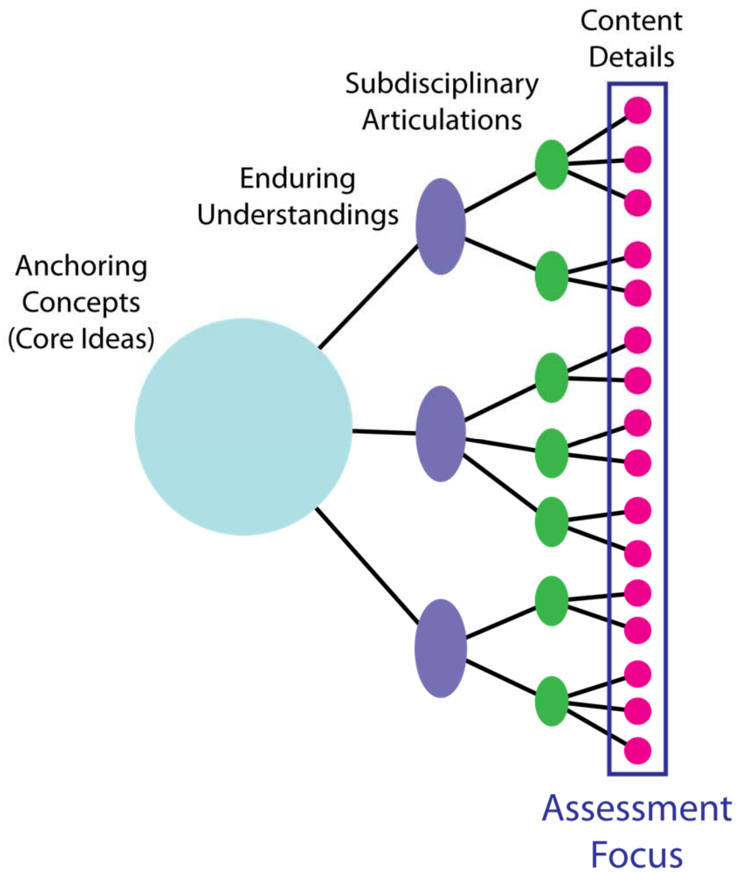
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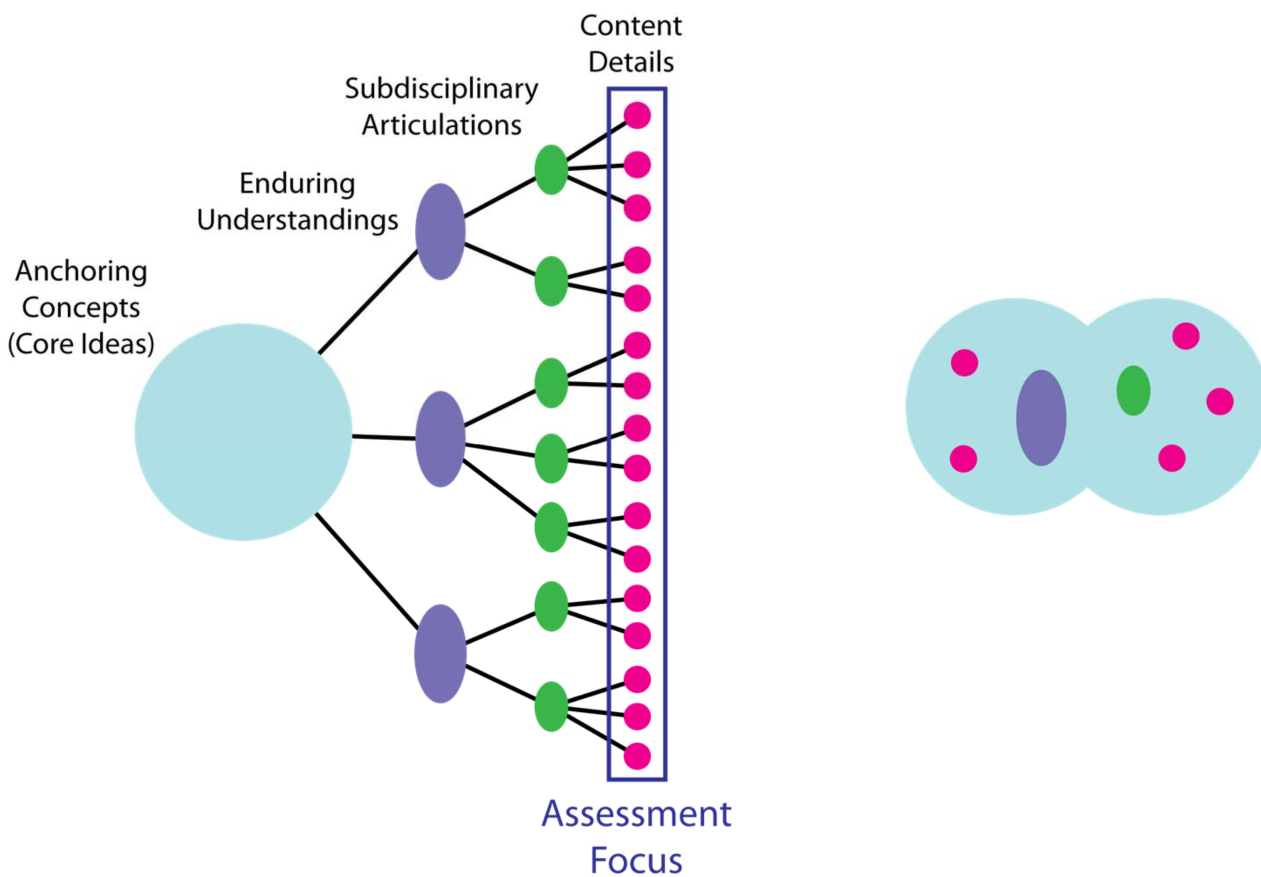
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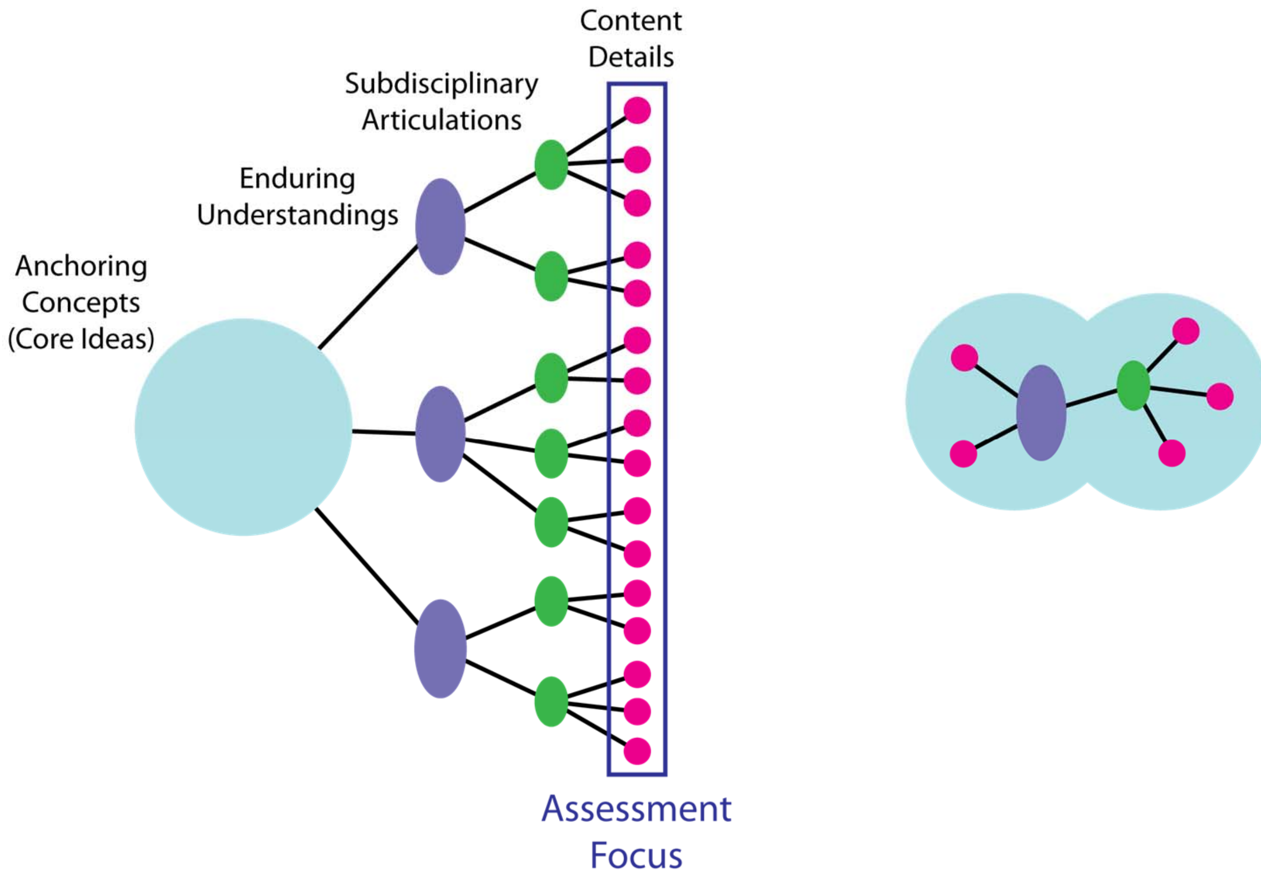
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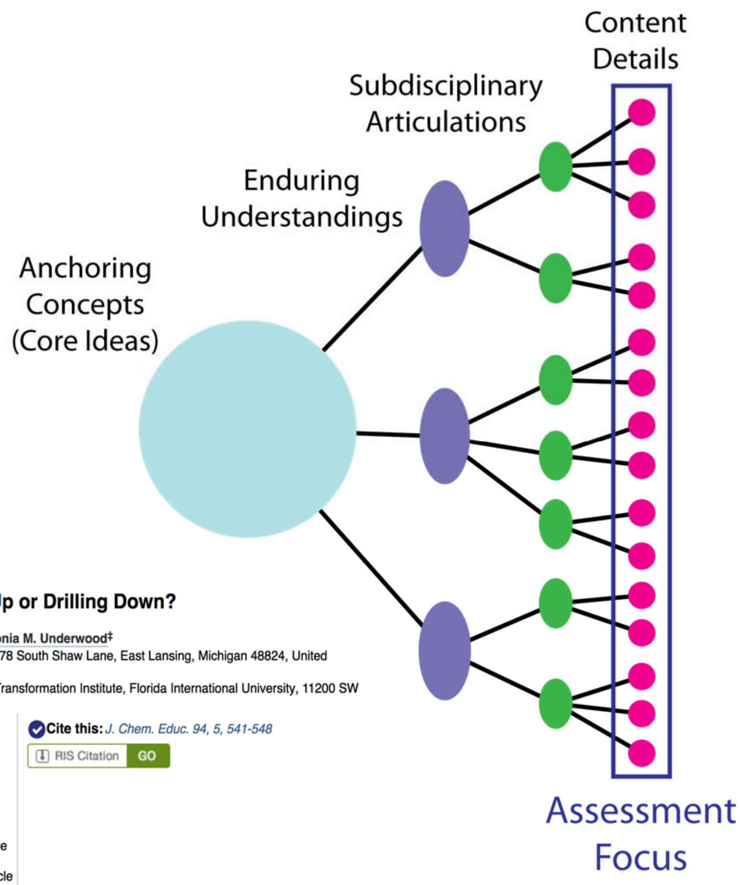

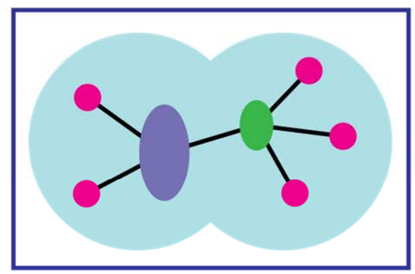

Core Ideas and Topics: Building Up or Drilling Down?

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J. Chem. Educ., **2017**, *94* (5), pp 541–548
DOI: 10.1021/acs.jchemed.6b00900
Publication Date (Web): March 16, 2017

*E-mail: mmc@msu.edu.

Cite this: *J. Chem. Educ. 94, 5, 541-548*
RIS Citation GO

Content knowledge (even “conceptual” knowledge) is not enough…

It has to be connected and useful

Why Scientific and Engineering Practices?

"Science is not just a body of knowledge that reflects current understanding of the world; it is also a set of practices used to establish, extend, and refine that knowledge. Both elements—knowledge and practice—are essential."

National Research Council. *A Framework for K-12 Science Education: Practices, Crosscutting Concepts, and Core Ideas*; National Academies Press: Washington, DC, 2012.

Scientific and Engineering Practices

How we put knowledge to use

1. Asking questions and defining problems
2. Developing and using models
3. Planning and carrying out investigations and designing solutions
4. Analyzing and interpreting data
5. Using mathematics and computational thinking
6. Developing explanations and designing solutions
7. Engaging in argument from evidence
8. Obtaining, evaluating, and communicating information

National Research Council. *A Framework for K-12 Science Education: Practices, Crosscutting Concepts, and Core Ideas*; National Academies Press: Washington, DC, 2012.

Scientific Practices

Why Cross-Cutting Concepts

"Some important themes pervade science, mathematics, and technology and appear over and over again, whether we are looking at an ancient civilization, the human body, or a comet. They are ideas that transcend disciplinary boundaries and prove fruitful in explanation, in theory, in observation, and in design."

AAAS Project 2061, 1989

Crosscutting Concepts

Ideas that cut across and are important to all science disciplines

1. Patterns
2. Cause and effect
3. Scale, proportion and quantity
4. Systems and system models
5. Energy and matter conservation, cycles and flows
6. Structure and function
7. Stability and change

NRC Framework for Science Education 2012

Ideally we want to build curricula around core ideas (not topics), that provide opportunities for students to use their knowledge – by engaging in scientific practices, and that allows connections to be made across the disciplines

3D-question

For this reaction $CH_3CH_3 + Cl_2 \rightarrow CH_3CH_2Cl + HCl$

a. Construct chemical structures for the reactants and products.

b. Using your structures, identify which bonds are broken and which bonds are formed

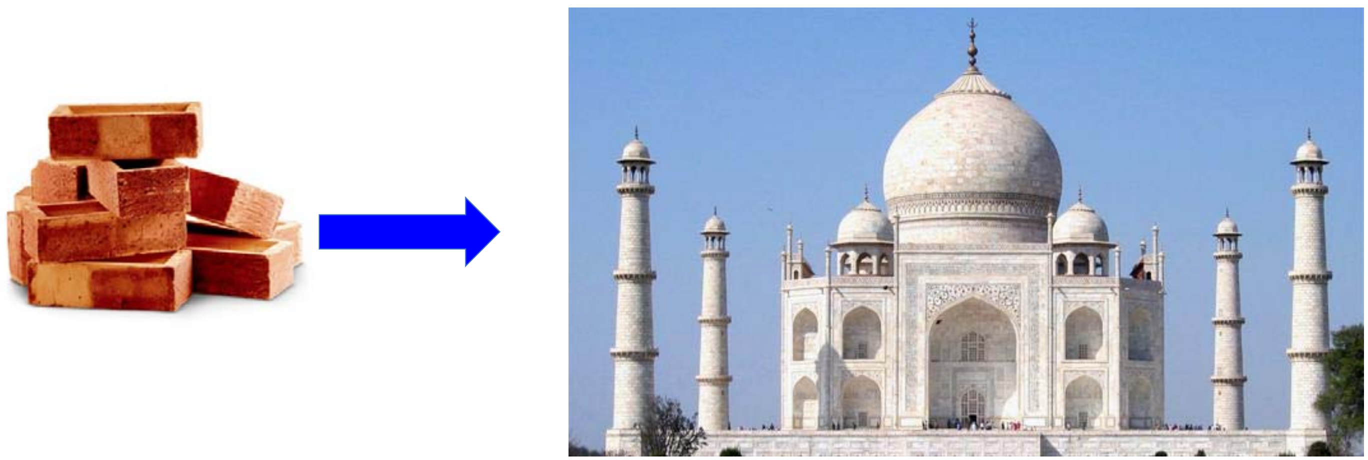
c. Explain why breaking bonds requires an input of energy from the surroundings.

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.

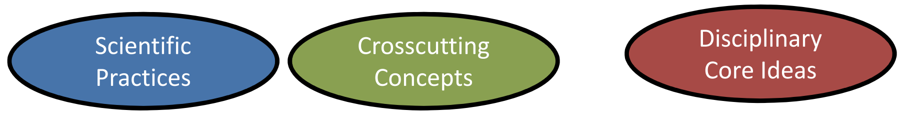
f. Construct an explanation about why the energy changes during this reaction that includes
   a. A claim about the energy change for the reaction (exothermic or endothermic)
   b. The evidence you used to make this claim
   c. Your reasoning about why this evidence leads to the claim

Three-dimensional learning offers us a vision for how to help students develop more expert-like knowledge structures



NRC: “How People Learn” (2000)

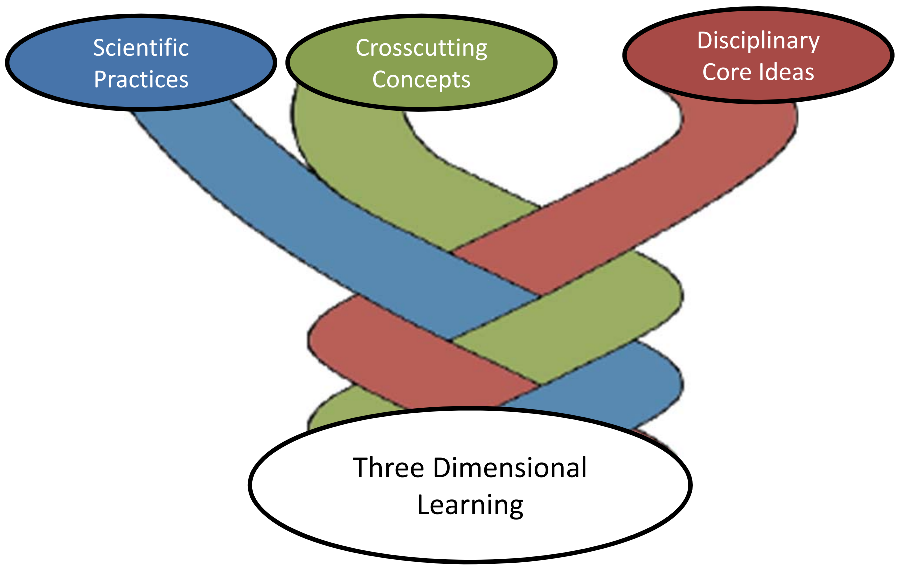
Three-dimensional learning



NRC. (2012). *A Framework for K-12 Science Education: Practices, Crosscutting Concepts, and Core Ideas.* Washington DC: The National Academies Press.

Cooper, M. M., Caballero, M. D., Ebert-May, D., Fata-Hartley, C. L., Jardeleza, S. E., Krajcik, J. S., Laverty, J.T., Matz, R., Underwood, S. M. (**2015**). Science, 350 (6258), 281–282.

the three dimensions should be blended together



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At MSU we used the Framework to provide a coherent approach to gateway course transformation

and extending

Creating a Coherent STEM Gateway at Michigan State University

A projected funded by the AAU STEM Education Initiative Project

Further funding from NSF

three-dimensional learning for undergraduate science

msu | fiu | gvsu | ksu

Cooper et. al. Science 2016

Change model: build faculty consensus around the aims and rewards of reform through:

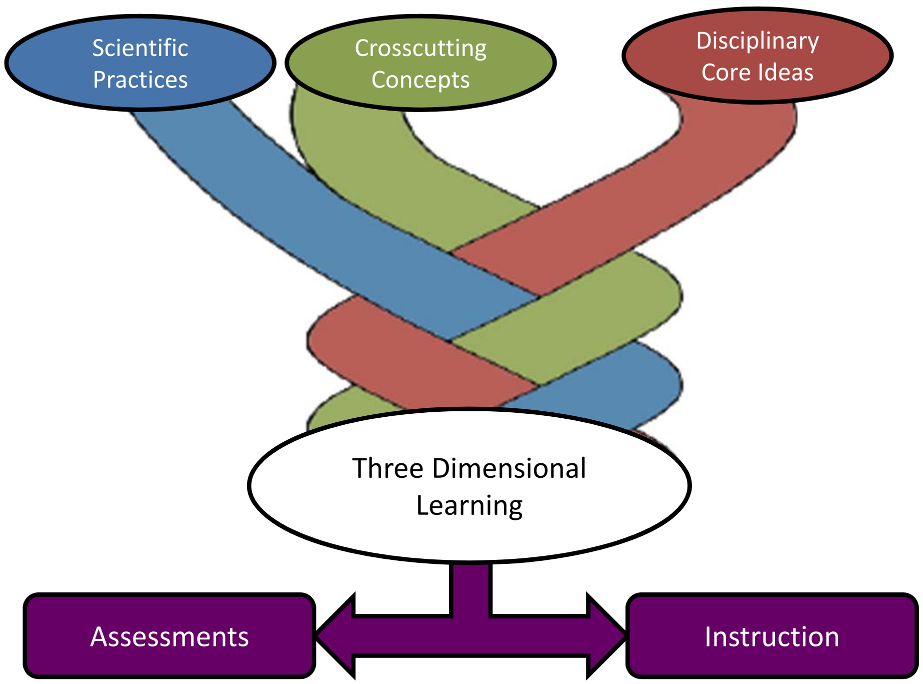
1. Developing a shared vision for gateway course transformation in biology, chemistry and physics
2. Developing policies and structures to support and reward reform

We convened faculty to discuss core ideas of the discipline, and what students should be able to do with these core ideas

We held workshops and Fellowship program around 3D-Learning

What constitutes evidence of change?

3D-learning should produce changes in both instruction and assessments



NRC. (2012). *A Framework for K-12 Science Education: Practices, Crosscutting Concepts, and Core Ideas.* Washington DC: The National Academies Press.
Cooper, M. M. et. al. (2015). Challenge faculty to transform STEM learning. Science, 350(6258), 281–282. http://doi.org/10.1126/science.aab0933

We decided to identify whether changes in assessment items and instructional behavior occurred

PLOS | ONE

RESEARCH ARTICLE

Characterizing College Science Assessments: The Three-Dimensional Learning Assessment Protocol

OPEN ACCESS

Citation: Laverty JT, Underwood SM, Matz RL, Posey LA, Carmel JH, Caballero MD, et al. (2016) Characterizing College Science Assessments: The Three-Dimensional Learning Assessment Protocol. PLoS ONE 11(9): e0162333. doi:10.1371/journal.pone.0162333

The 3D-LAP

3D-LAP provides criteria for each dimension

Developing and Using Models

Student is given or asked to construct a mathematical, graphical, computational, symbolic, or pictorial representation and use it to explain or predict an event, observation, or phenomenon.

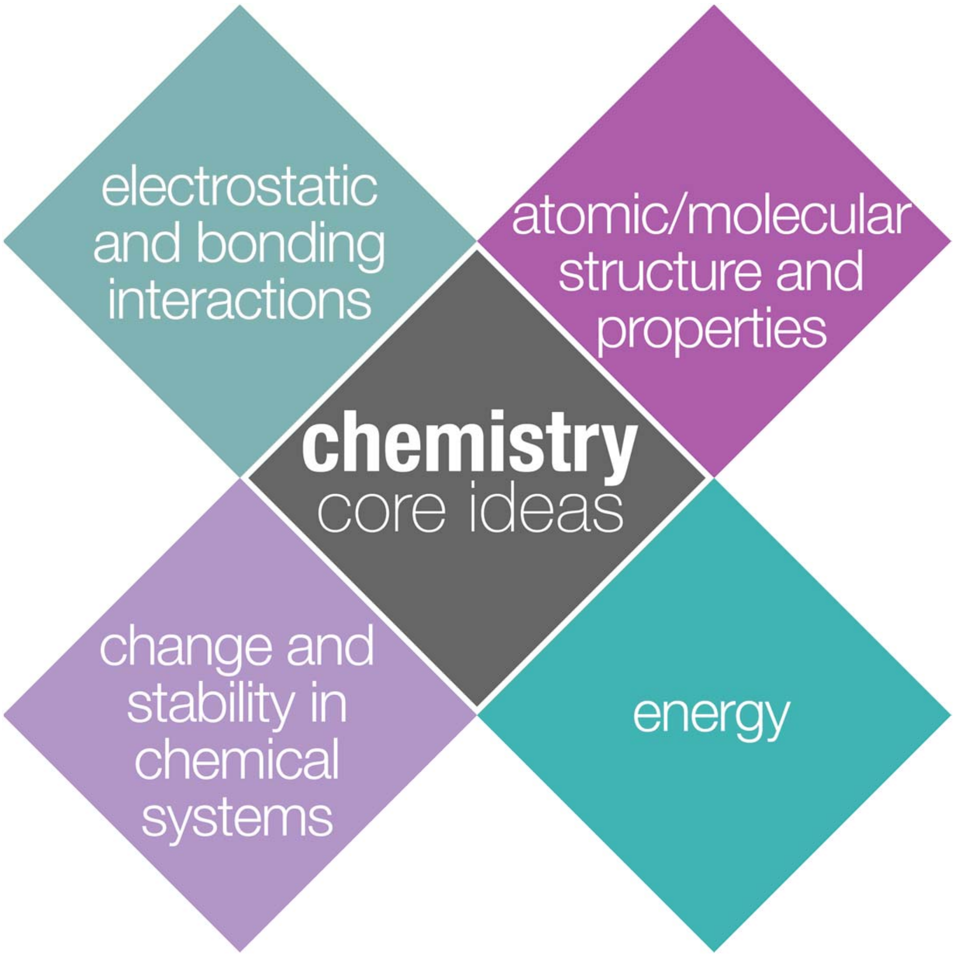
1. Question gives an **event, observation**, or **phenomenon** for the student to explain or make a prediction about.
2. Question gives a representation or asks student to **construct a representation**.
3. Question asks student to **explain** or make a **prediction** about the event, observation, or phenomenon.
4. Question asks student to provide the **reasoning** that links the representation to their explanation or prediction**.**

CLUE

CHEMISTRY, LIFE, THE UNIVERSE & EVERYTHING

A transformed curriculum built around core ideas, engaging students with scientific practices, and crosscutting concepts

Cooper. M.M. Klymkowsky, M.W. “Chemistry, Life, the Universe and Everything (CLUE): A new approach to general chemistry, and a model for curriculum reform” J Chem Educ, **2013**, *90,* 1116-1122; **DOI:** 10.1021/ed300456y

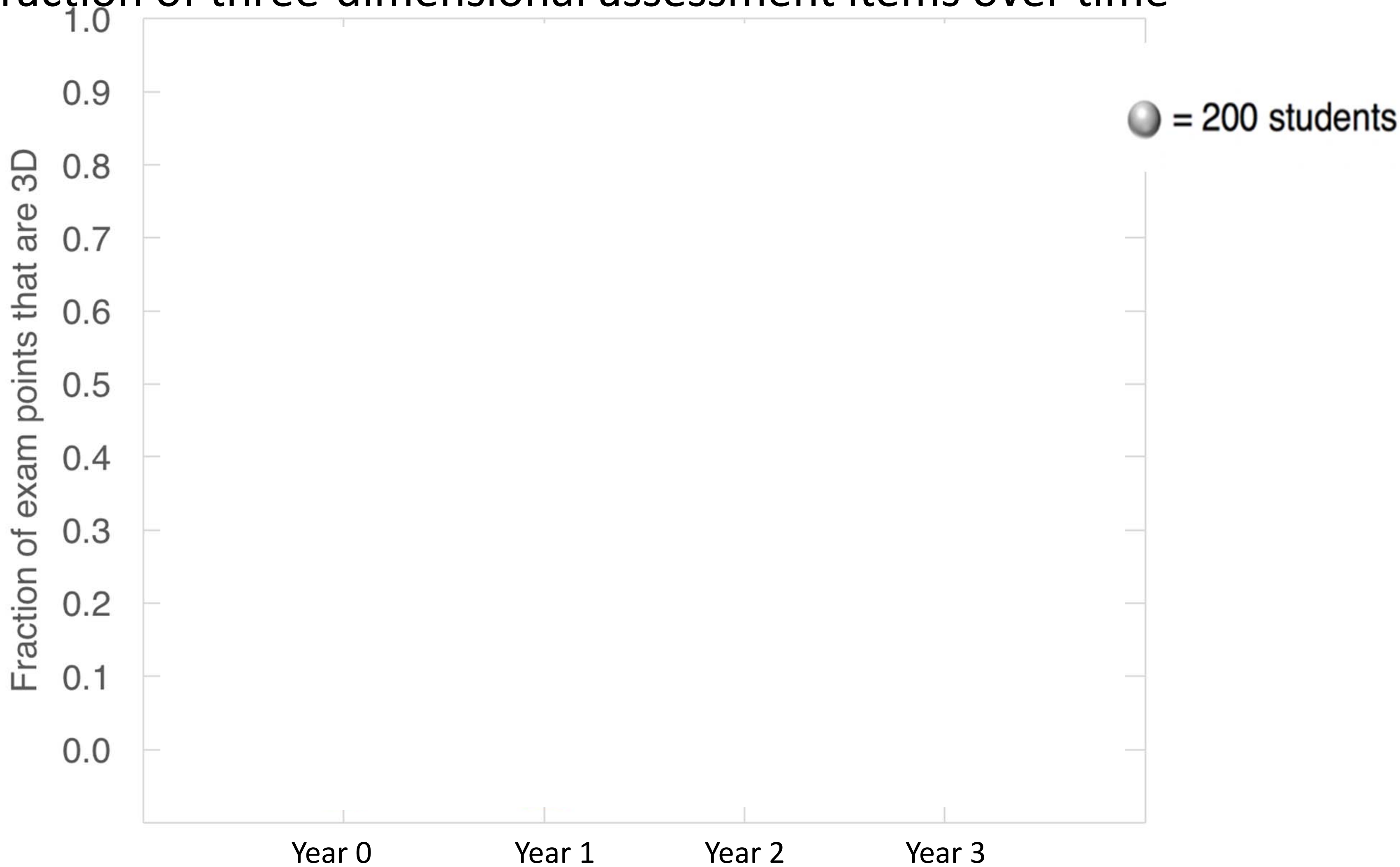


- Energy Connections and Misconnections Across Chemistry and Biology **2018**, doi: 10.1187/cbe.17-08-0169,
- Connecting Structure–Property and Structure–Function Relationships across the Disciplines of Chemistry and Biology: Exploring Student Perceptions, **2018**, https://doi.org/10.1187/cbe.18-01-0004
- Investigating Students' Reasoning about Acid–Base Reactions. *J. Chem Educ,* **2016** DOI: 10.1021/acs.jchemed.6b00417.
- When do students recognize relationships between molecular structure and properties? A longitudinal comparison of the impact of traditional and transformed curricula. *Chemistry Education Research and Practice.* **2016,** 17, 365-380, **DOI:** 10.1039/C5RP00217F
- Are Noncovalent Interactions an Achilles Heel in Chemistry Education? A Comparison of Instructional Approaches. *J. Chem. Educ.*, 2015, DOI: 10.1021/acs.jchemed.5b00619
- College chemistry students' understanding of potential energy in the context of atomic-molecular interactions" J. Res. Sci Teach. **2014,** 51. 6, 789-808, DOI 10.1002/tea.21159
- Student Understanding of Intermolecular Forces: A Multimodal Study" J. Chem. Educ., **2015**, 92 (8), pp 1288–1298, DOI: 10.1021/acs.jchemed.5b00169.
- Mechanistic Reasoning about London Dispersion Forces. J. Chem. Educ., **2016**, 93 (10), pp 1713–1724
- The Trouble with Chemical Energy" CBE Life Sci Educ. **2013**, 12(2):306-12. doi: 10.1187/cbe.12-10-0170.

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

Discipline
Chem I and II
Phys I and II
Bio 1
Bio 2
Total

Fraction of three-dimensional assessment items over time



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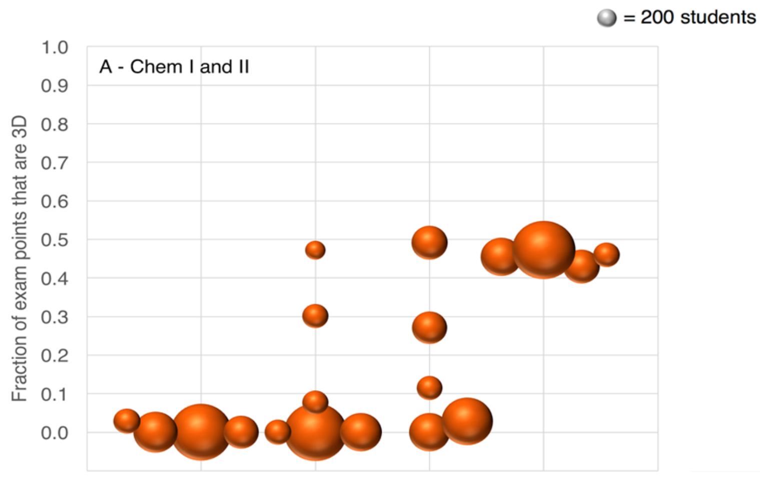

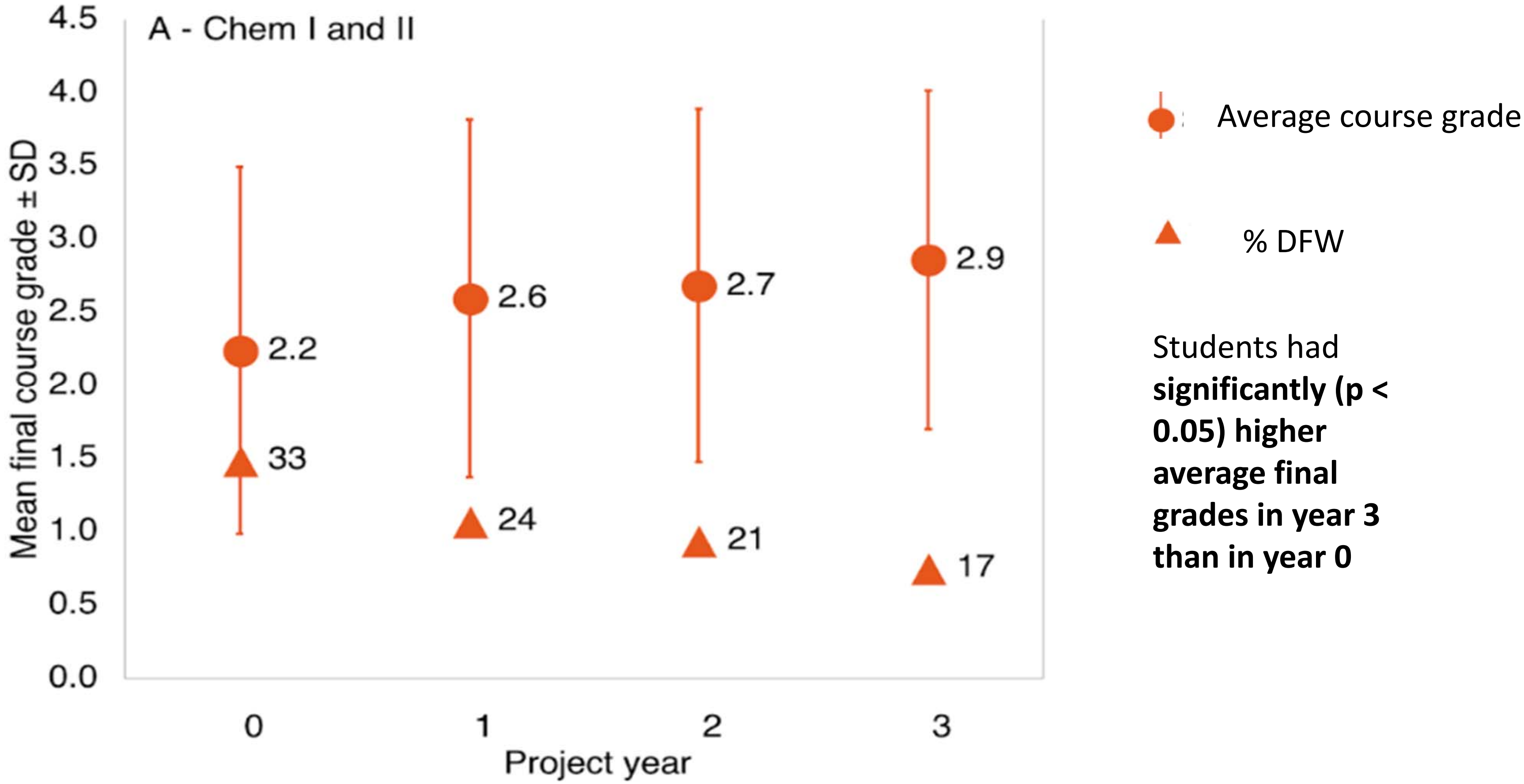

Students had **significantly ($p < 0.05$) higher average final grades in year 3 than in year 0**

This 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.

So more students pass the course – do they learn anything?

We have given the ACS conceptual exam to CLUE students in both large and small class sections –

- CLUE students score above the national average
- There is no difference by class size or institution
- Even though the exam "covers" more (and different) material

We have also published a number of papers on our findings:

- Energy Connections and Misconnections Across Chemistry and Biology **2018**, doi: 10.1187/cbe.17-08-0169,
- Connecting Structure–Property and Structure–Function Relationships across the Disciplines of Chemistry and Biology: Exploring Student Perceptions, **2018**, https://doi.org/10.1187/cbe.18-01-0004
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Summary

- Discipline Based Education Research can provide theory and evidence that can inform instruction
- Curriculum design should focus on core ideas and scientific practices
- At MSU we have implemented these ideas in gateway courses
- We have increased average grades and retention for all demographics
- We also have a LOT of evidence of improved student learning…

Discipline-Based Science Education Research

vs

Private Empiricism

Private empiricism – where we believe something because of our own personal experience – is not appropriate for scientists, yet when it comes to education, personal experience seems to be an acceptable substitute for evidence. Unfortunately, most scientists' beliefs about education are rarely based on objective evidence, but rather on what they imagine to be true. While personal experience in the classroom can give valuable insights, it is not data

Data-Driven Education Research, Cooper, M. M. *Science*, August 2007: p. 1171

Acknowledgments

3DL4US three-dimensional learning for undergraduate science
msu | fiu | gvsu | ksu

DUE-1725520

CER
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