

## Using and Authoring Virtual Lab Activities for Introductory Chemistry

David Yaron, Michael Karabinos, Jordi Cuadros, Emma Rehm,  
Tim Palucka, Rea Freeland, D. Jeff Milton  
Department of Chemistry, Carnegie Mellon University  
Gaea Leinhardt, Karen Evans, Baohui Zhang  
Learning Research and Development Center, University of Pittsburgh

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## Learning challenges and interventions

- Promoting flexibility and applicability
  - From mathematical procedures to chemical phenomena (*use in chemistry*)
    - Virtual laboratory
  - From chemical phenomena to real world (*transfer to real world*)
    - Scenario based learning
- Promoting coherence
  - "Big picture" of chemistry

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## Use in chemistry: Virtual laboratory

- Flexible simulation of aqueous chemistry
- New mode of interaction with chemical concepts
- Ability to "see" inside a solution removes one level of indirection in chemical problem solving



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### Installing the Virtual Lab

- To install the lab from the CD
  - Add a folder named "virtualLab" in your "My Documents" folder
  - Drag the contents of the CD-ROM to your folder
  - Go into the virtualLab/ folder and click on autorun.exe
- Ways to run the lab in your classroom
  - From [www.chemcollective.org](http://www.chemcollective.org)
  - From CD-ROM
    - Feel free to make copies of the CD yourself, or request packs from us
  - Install on your local computer system

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### Introducing the lab to your students

- Demo the lab in class
  - Show how to pour
  - Show information available in the viewers
  - Show how to use the "load homework" menu item
- Ask students to watch the brief video demonstrating how to use the lab
- Ask students to do the step-by-step walkthrough
- A basic user guide with instructions for using each feature of the lab is also available

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### A survey of Virtual lab problems

- Current topic list
  - Molarity
  - Quantitative analysis
  - Solubility
  - Acids and bases
  - Stoichiometry
  - Chemical equilibrium
  - Thermochemistry
- Problem types
  - Predict and check
  - Virtual experiment
    - Puzzle problems (open-ended and inquiry based experiments)
  - Layered problems

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### How to use in your classroom

- During recitation
- As take-home work
- Pre- and post-labs
- Lab make-ups
- Supplement to in-class demonstrations

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### Predict and Check

*Students use the virtual lab to check the results of a pencil-and-paper calculation or qualitative prediction*

- Potential benefits
  - Encourages students to see connection between calculations/qualitative predictions and an experimental procedure
  - Design of the appropriate experiment can be challenging
  - Observations indicate that the shift from paper and pencil to lab activity can be difficult for students
  - Students can make use of intermediate results in locating errors

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### Predict and Check

- Traditional calculation

*Thermochemistry/Coffee: Calculate the amount of 10°C milk that must be added to 250ml of 95°C coffee to lower its temperature to 90°C. Check your answer in the virtual lab.*
- As part of design activity

*Thermochemistry/Camping 3: Using the virtual lab, create two solutions, initially at 25°C, that, when mixed together in equal volumes, cause the temperature of the mixture to increase from 25°C to 60°C*

Can be done as predict and check, but is often done in iterative process with some predict and check steps

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### Virtual Experiments

*Students generate and interpret data in the chemistry virtual lab program*

**Typical textbook problem**

"When 10ml of 1M A was mixed with 10ml of 1M B, the temperature went up by 10 degrees. What is the heat of the reaction between A and B?"

**Virtual Lab problem**

Thermochemistry/Camping 1:  
"Construct an experiment to measure the heat of reaction between A and B?"

- Students who could perform the textbook procedure had difficulty designing the experiment, and needed help from a human tutor.
  - The procedure is not triggered in response to relevant prompt
  - The Virtual Lab format prevents students from using strategy of matching words to equations
- See also: <http://ry.chem.cmu.edu/oldlab/> for unknown acid with feedback

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### Puzzle Problems

Stoichiometry/Oracle 1 and 2: *Given four substances A, B, C, and D that are known to react in some weird and mysterious way (an oracle relayed this information to you within a dream), design and perform virtual lab experiments to determine the reaction between these substances, including the stoichiometric coefficients. You will find 1.00M solutions of each of these chemical reagents in the stockroom.*

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### Oracle Problem Observations

- Intent was to give practice with determining reaction coefficients  
 $A + 2B \rightarrow 3C + D$
- Observation  
When A is mixed with B, some A remains, so the reaction must be:  
 $A + B \rightarrow C + D + A$   
Reveals misunderstanding of limiting reagent concept (even though they could easily perform textbook limiting reagent problems)
- This may be a good opportunity for an Elicit-Confront-Resolve instructional strategy

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### Layered Problems

- A set of activities involving the same chemical system, but modeling the system with varying levels of complexity and approximation.
- The approximations can either be removed or invoked as one moves through a series of problems.
- These interconnected layers, particularly with the addition of structured debriefing, invite students to reflect on how the removal or an addition of an assumption changes both their problem solving approach and the predicted results.

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### Layered Problems

- Acid Mine Drainage Scenario treats river at three levels
  - As distilled water at room temperature
  - As distilled water with seasonally-varying temperature
  - As a buffered solution
- For all three models, student predicts amount of Fe precipitated in the river bed
- See <http://ry.chem.cmu.edu/AMD/>

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### Authoring a virtual lab activity

- Add chemical species and reactions (if desired)
  - Can create "fictional" proteins, drugs etc.
- Create Stockroom Solutions
- Specify available functionality
  - Viewers
    - For example, turn off "Solution Contents" for exercises involving unknowns
  - Transfer mode
    - Precise: student enters exact amount to transfer
      - Facilitates comparison with paper and pencil problems
    - Realistic: simulates accuracy attainable in real lab
      - Forces student to use correct apparatus (buret for titration)
    - Significant figures transfer mode
      - Teaches relation between experimental technique and accuracy
- HTML problem description can be included

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### Assessing your activity

- Be explicit about your learning goals
- Design questions that test whether you have achieved your learning goal
- OLI course management system collects trace data

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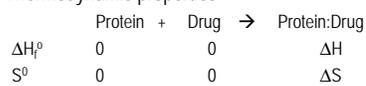
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### Fictitious chemicals

- Protein-drug binding
  - Add 3 species: Protein, Drug, Protein:Drug
  - Add reaction: Protein + Drug  $\rightarrow$  Protein:Drug

- Thermodynamic properties



Determine  $\Delta H$  and  $\Delta S$  from K at two different temperatures

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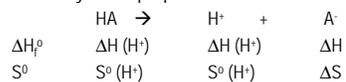
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### Fictitious chemicals

- Add a new acid
  - Add 2 species: HA, A<sup>-</sup>
  - Add reaction: HA  $\rightarrow$  H<sup>+</sup> + A<sup>-</sup>

- Thermodynamic properties



Determine  $\Delta H$  and  $\Delta S$  from K at two different temperatures

- We also have a "Chemical Database Management System" that will generate thermodynamic data from a list of K's etc.

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### ChemCollective: Modes of user participation

- Use activities and give feedback
  - Current: Amazon-style comments
  - Future work: Aggregation of assessment data (currently have ability to trace all student interactions with virtual lab)
- Modify and create activities
  - Current: Virtual lab activities
  - Future work: Scenario collections
- Low-volume, high-quality discussions
  - Current: Experiences with particular activities
  - Future work: Strategies for teaching specific topics

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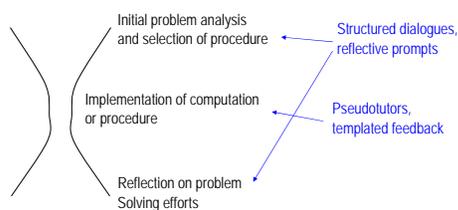
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### Future work: Feedback

- Based on hourglass view of problem solving



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### Pseudotutors

|                                  |   |   |  |                                       |
|----------------------------------|---|---|--|---------------------------------------|
| DNA + DYE → DNA-DYE $K = 0.0014$ |   |   |  |                                       |
| Initial                          | <input type="text" value="20.1"/> $\mu\text{M}$ | <input type="text" value="2000"/> $\mu\text{M}$ | <input type="text" value="0"/> $\mu\text{M}$   |                                       |
| Change                           | <input type="text" value="-x"/> $\mu\text{M}$   | <input type="text" value="-x"/> $\mu\text{M}$   | <input type="text" value="+2x"/> $\mu\text{M}$ | <input type="button" value="Hint"/>   |
| Equilibrium                      | <input type="text"/> $\mu\text{M}$              | <input type="text"/> $\mu\text{M}$              | <input type="text"/> $\mu\text{M}$             | <input type="button" value="Submit"/> |

Mock up of pseudotutor for creation of ICE table in equilibrium calculations. Student has entered the data in the boxes, and the system turned "+2x" red to indicate an error. Feedback on this error is provided if the student clicks the hint button. (May be extended to include making approximations on x for large and small K.)

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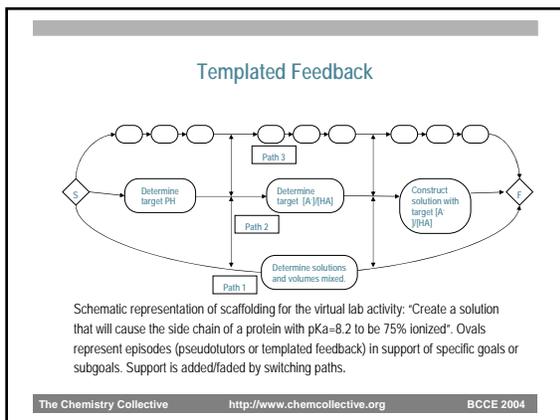
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### Structured Dialogues

- Motivations
  - Students learn the topics in a disconnected manner, such that they can not apply them after the course (Lovett found this to be true in statistics education)
  - Students are not given much practice in procedure selection: practice occurs only in narrow part of funnel since procedure is obvious from context (standard wording of problems, location of problem in course or text etc.)
  - Students do lots of problems, but don't get as much as they could out of them because they fail to reflect on similarities and differences etc.

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### Structured Dialogues

- Initial problem analysis
  - Categorize information as given or requested
  - Drawing of diagrams that summarize problem statement and goals (ala Bodner)
  - Where does this problem lie in the domain
    - Explanation: Which of the conceptual frameworks do you think may help explain this phenomena?
    - Analysis: Are you being asked for a qualitative or quantitative analysis?
    - Synthesis: Which of the following processes do you think is most likely to work here?

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### Structured Dialogues

- Debriefing dialogues
  - See the big picture
    - How does the current activity fits into the domain of chemistry?
  - Cluster knowledge
    - How is a particular problem like other problems you have done?
  - Distinguish knowledge
    - What is unique about this problem in term of technique, theory, principles, or circumstance?
- Linked problems (such as layered problems)
  - Promote clustering and distinguishing knowledge

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### Stoichiometry module

- Objectives
  - The mole and molarity
  - Composition stoichiometry
    - Percent composition
    - Empirical and molecular formula
  - Reaction stoichiometry
    - Stoichiometric conversion
    - Limiting reagents
  - Titration

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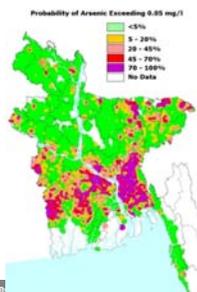
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### Stoichiometry module

- As in Bangladesh groundwater



- Measurement of As concentration
- Remediation

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### Stoichiometry module: Measure As concentration I

- Molecular mass and molarity
  - Given a groundwater sample with As concentration in M, determine if exceeds World Health Organization (WHO) guidelines of 10 µg/liter
  - Prepare a "standard solution" with a concentration of 10 µg/liter of As. [AsO<sub>3</sub> starting solution brings in some composition stoichiometry.]
  - Use "standard solution" in spectrometer to measure concentration of groundwater sample. [Spectrometer will report concentration as ratio to the sample.]

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### Stoichiometry module: Remediation

- Macroscopic to microscopic connection
  - Determine the amount of As absorbed by a sample of powder
  - What does this tell you about the sites that are absorbing the As (distance between sites etc.)?
  - What happens if we grind the powder finer?
  - How about a zeolite structure?

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### Stoichiometry module: What form of As is present?

- Empirical formula
  - Isolate solid compounds and send off for % composition. What is the empirical formula?
- Molecular formula
  - Given % composition and MW of an As species in solution, what is its molecular formula?
- % composition
  - Given a soil sample with two forms of As, what is their ratio?

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### Stoichiometry module: Quantitative analysis?

- Gravimetric determination of As concentration
- Colorimetric titration for As concentration
- Summarizing activity
  - Given a sample of well water, how often does that family need to change its water filter?

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### Assessment Efforts at Carnegie Mellon

- Course
  - 150 students in second semester freshman course for scientists and engineers
- Three segments
  - First segment: observations
  - Second segment: control
  - Third segment: comparison of three problem types
- Data collection
  - Surveys (with student names), homeworks, observations of small groups of low, mid and high performers
  - Practice exams and exams
  - Trace files of students in virtual lab

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### Preliminary data

- Student surveys (data is % response)

|                   | Not helpful |    | helpful |    |
|-------------------|-------------|----|---------|----|
| Lectures          | 0           | 10 | 33      | 40 |
| Reading           | 8           | 34 | 25      | 10 |
| Textbook problems | 10          | 33 | 25      | 7  |
| Graded HW         | 5           | 7  | 34      | 37 |
| Vlab              | 10          | 18 | 28      | 25 |
| Recitation        | 2           | 16 | 30      | 34 |

- Attitude towards virtual lab correlates strongly with confidence measures ( $R^2=0.82$ )
- Confidence does not correlate to performance ( $R^2=0.01$ )

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### Preliminary results

- Final exam
  - Final constructed to have 8 items parallel to past years and 2 items that were more difficult; student averages went up 6 points.
- Correlations
  - Effort spend on Virtual Lab problems in third segment of course was correlated with score on most recent hour exam ( $R=0.21, p<0.05$ )
  - Effort spend in layered problem on acid mine drainage is correlated with score on pre-exam 3 ( $R=0.31, p<0.001$ )
- Critical thinking
  - Based on 2 videos of student problem solving (of 9 total)
  - Problem functions differently for low and high performance group, but both engage in critical thinking
  - Nature of critical thinking varies depending on whether students are at boundary of their domain knowledge

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### Summative assessment plan

- Fully online course for stoichiometry
  - Replaces current mastery exam system in first semester freshman chemistry course at Carnegie Mellon
  - Implemented in Carnegie Mellon's Open Learning Initiative (OLI) system (allows full trace analysis)
  - Within and between subject controls

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### Off-Site Assessment Studies

- Setting
  - University of British Columbia
  - Studies compared student performance in a course using the virtual lab to that from previous years.
- Success rates (% students scoring above 75% on exam)
  - Calculations in volumetric analysis: from 30% to 90%
  - Knowledge of analytical glassware: from 30% to 95%

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### Current dissemination strategies

- Web site (<http://ir.chem.cmu.edu/> and <http://www.chemcollective.org>)
  - 1000 page requests per day, 125 instructors on mailing list, 36 requests to become test sites next year
  - >10,000 students have performed one or more activity in the virtual lab
- Booths at conferences
  - Demonstrate materials for about 75 instructors per day of 3 to 4 day conference

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### The ChemCollective

- Build community around a specific educational goal
  - Digital Libraries can combine expertise through remote and asynchronous collaboration
  - Digital Libraries can support an iterative development process
- Ways to participate
  - Use activities and give feedback
  - Participate in assessment studies
  - Modify and create activities
  - Discussions around activities and topics

*For more information on the ChemCollective, please see: S418 Using Digital Libraries to Build Educational Communities: The ChemCollective [Tues 1:35 Scheman 179] or stop by our booth #63 in the exhibition hall.*

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### Transfer to real world: Scenarios

- Scenario based learning
  - Embed the procedural knowledge of the course in a scenario that highlights its utility
  - Scenarios that touch down at various points in the course may promote coherence
- Outcome of design process
  - Attempt to organize scenario development led to a "concept map" of the domain

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### Traditional Course Structure

- CA state standards
  - Standard 1 Atomic and Molecular Structure
  - Standard 2 Chemical Bonds
  - Standard 3 Conservation of Matter and Stoichiometry
  - Standard 4 Gases and Their Properties
  - Standard 5 Acids and Bases
  - Standard 6 Solutions
  - Standard 7 Chemical Thermodynamics
  - Standard 8 Reaction Rates
  - Standard 9 Chemical Equilibrium
  - Standard 10 Organic Chemistry and Biochemistry
  - Standard 11 Nuclear Processes
- Chemistry AP exam guide's are similarly structured around chemistry topic list

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### Domain Analysis

- Evidence of the domain as practiced
  - Nobel prizes for past 50 years
  - NY Times Science Times for 2002
  - Scientific American News Bites for 2002
- Evidence of the domain as taught
  - CA state content standards
  - Best selling textbooks

*For more info, see: S279 Karen Evans: Chemistry in the Field and Chemistry in the Classroom: A Disconnect? [Tues 10:45 Scheman 275]*

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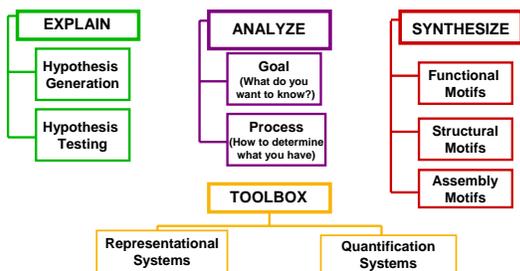
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### Domain Map – The Big Picture



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### Comparison

- Domain as practiced
  - Scientific literature spread equally between these three subdomains
- Domain as taught
  - Textbooks and standards found only in Toolbox and Analyze subdomain

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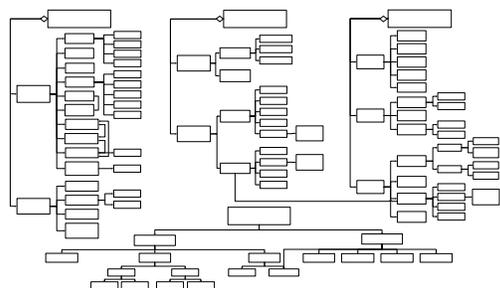
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### Full domain map



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### Domain Map as Basis for Course Design

- Guide development of scenarios
  - Ensure distribution at both upper and lower levels
- Mediate conversation between traditional and reformed course
  - Encourage students to reflect on how the course concepts fit into chemistry as a domain

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## Mixed Reception



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## Scenarios: Examples

- Mixed reception (molecular weight, stoichiometry)
- Cyanine dyes binding to DNA (equilibrium, Beer's law)
- Meals read-to-eat (thermochemistry)
- Mission to mars (redox, thermochemistry)
- Arsenic poisoning of wells in Bangladesh (stoichiometry, titration, analytical spectroscopy)
- Ozone destruction (kinetics)

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## Current and Previous Team Members

### Carnegie Mellon

- Donovan Lange
- D. Jeff Milton
- Michael Karabinos
- Jordi Cuadros
- Tim Palucka
- Emma Rehm
- Rea Freeland
- Jef Guarent
- Amani Ahmed
- Giancarlo Dozzi
- Katie Chang
- Erin Fried
- Jason Chalecki

- Greg Hamlin
- Brendt Thomas
- Stephen Ulrich
- Jason McKesson
- Aaron Rockoff
- Jon Sung
- Jean Vettel
- Rohith Ashok
- Joshua Horan

### LRDC, University of Pittsburgh

- Gaea Leinhardt
- Karen Evans
- Baohui Zhang

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