Virtual Labs and Scenario-Based Learning for Introductory Chemistry

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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

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

Virtual lab problem types

- Predict and check
- Virtual experiment
  - Puzzle problems (open-ended and inquiry based experiments)
- Layered problems

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

Predict and Check

- Traditional calculation

  Coffee: Calculate the amount of 10^0C milk that must be added to 250ml of 95^oC coffee to lower its temperature to 90^oC. Check your answer in the virtual lab.

- As part of design activity

  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

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
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

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Puzzle Problems

Oracle: *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.*

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

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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Observational studies: Qualitative reasoning

Challenge problem involving multiple interacting chemical equilibria (a weak acid dye binding to DNA)
- Student strategies were much more sophisticated than instructors anticipated based on students' ability to manipulate these concepts algebraically
- Suggests the new manipulatives of the virtual lab have potential for supporting and assessing qualitative understanding

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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

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Observational studies: What makes heat hard

- Difficulty appears to scale with how visible the source and sink of heat are
  - Solid-solid or solid-liquid
  - Liquid-liquid
  - Reaction occurring in liquid

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
- HTML problem description can be included

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

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
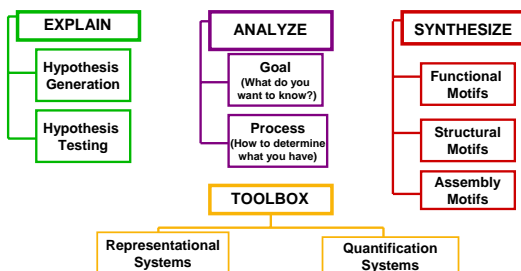

Domain Analysis

- 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]

Domain Map – The Big Picture

EXPLAIN
- Hypothesis Generation
- Hypothesis Testing

ANALYZE
- Goal (What do you want to know?)
- Process (How to determine what you have)

SYNTHESIZE
- Functional Motifs
- Structural Motifs
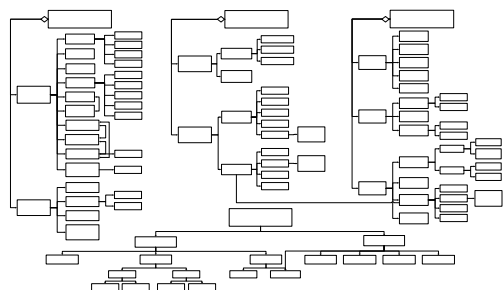- Assembly Motifs

TOOLBOX
- Representational Systems
- Quantification Systems

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

Full domain map

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

Mixed Reception

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)
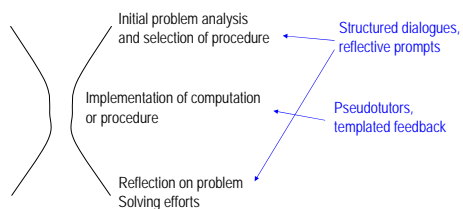- Ozone destruction (kinetics)

Future work: Feedback

- Based on hourglass view of problem solving

Initial problem analysis and selection of procedure — Structured dialogues, reflective prompts

Implementation of computation or procedure — Pseudotutors, templated feedback

Reflection on problem Solving efforts

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

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 ($R^2=0.01$)

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

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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