Using an online virtual laboratory to promote undergraduate students' reasoning and conceptual understanding about chemistry: Comparison of different instructional designs

July 19, 18th BCCE, Iowa

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Purposes of the study

- Exploring student critical thinking practices using an online virtual lab program.
- Evaluating the effectiveness of different types of context-based, real world problems in promoting student critical thinking.

Critical thinking

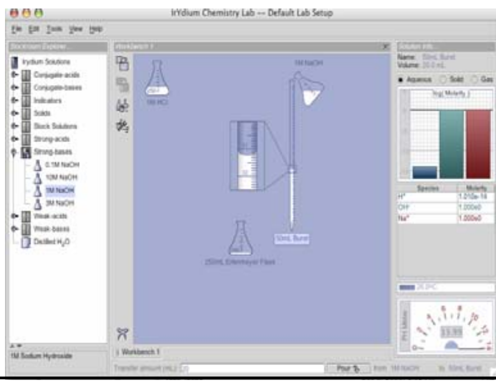
- Critical thinking is essential for students to be able to adapt to the rapidly changed world (Paul, 1993).
- *Critical thinking* is "the intellectually disciplined process of actively and skillfully conceptualizing, applying, analyzing, synthesizing, and/or evaluating information gathered from, or generated by, observation, experience, reflection, reasoning, or communication, as a guide to belief and action." (The National Council for Excellence in Critical Thinking, 1996).
- Discipline-specific conceptual frameworks are necessary to allow one to "think" effectively about the issues and problems within a given discipline (Meyers, 1986).

Indicators of critical thinking

Critical thinking practices in chemistry problem solving

- *Domain structure* (**DS**) : Recognizing the family of similar problems
- *Principled decisions* (**PD**): Chemical concepts and principles are used to guide decision-making
- *Flexibility* (**FL**): Cognitive flexibility in re-routing during problem solving
- *Evaluation* (**EV**): checking problem solution paths and critiquing on the decisions made for solving a problem

The virtual chemistry lab program



Problem types

- Chemistry virtual lab--connect the algebraic manipulations to real world chemistry problems to deepen conceptual understanding.
- Three types of problems:
  - *Online experiment*
  - *Predict and check*
  - *Layered problem*

Online experiment

Students must generate and interpret data in the chemistry virtual lab program. For example, identification of an unknown acid.

Possible opportunities for critical thinking:

- *Principled decisions* (**PD**): experimental design and interpretation
- *Evaluation* (**EV**): noticing and responding appropriately to consistent or discrepant events
- *Flexibility* (**FL**): generating and/or applying alternative solution paths
- *Domain structure* (**DS**): possibly through choice of experiments

Predict and check

Use the virtual lab to check the results of pencil-and-paper calculation or qualitative prediction. For example, design a buffer to place a protein in a specific protonation state; then build and test the buffer in the virtual lab.

- *Evaluation* (**EV**): if disagreement between target and observed properties, what went wrong
- *Principled decisions* (**PD**): decisions made during design of appropriate experiment
- *Flexibility* (**FL**): in design phase, students can consider a variety of approaches
- *Domain structure* (**DS**): possibly through problems that involve design

Layered problems

Students solve a set of problems involving same system but treated with models of different complexity. For example, the effects of acid mine drainage on a river in which the river is modeled as

(i) room temperature distilled water
(ii) with seasonal temperature changes
(iii) as buffered solution

Problem types are predict-and-check and online-experiment. Layering enhances possibility of critical thinking regarding *Domain structure* (**DS**)

Context for student observations

- Second semester freshman chemistry for scientists and engineers at a research university
- Large lecture course with multiple recitation sections
- Same-sex pairs selected from volunteers.
  - Two high-performing students as a pair
  - Two low-performing students as a pair
- The assignments were completed before exam on corresponding topics

Observed activities

Identify an unknown acid

- Students are given a solution containing an unknown acid in the virtual lab. They are asked to identify the acid from a list of possibilities and determine its concentration
- Results reported on web form that gives immediate correct/incorrect feedback

Two problems

- First solution contains a weak acid, second solution contains a strong acid (but no indication of this given to students)

Resources

- pH meter
- Stockroom of standard chemicals including various concentrations of strong and weak acids and bases.

Results--*high performing group*

Problem 1: unknown acid-weak acid

- Recognition that titration is appropriate (DS)
- Choice of NaOH based on chemical principle ("equal moles…for acid-base reaction") (PD, DS)
- Choice of concentration of NaOH based on principle of stoichiometric reaction of acid and base (PD).
- Choose 0.1M and pH jumps quickly: recognize immediately that it is "too strong". (EV)

*DS = Domain structure; PD = Principled decisions;
FL = Flexibility; EV = Evaluation

Results--*high performing group (continued)*

Problem 1: unknown acid-weak acid

- Believe they have the data: "pH jumped", they have principle for interpretation: "jumps when moles of acid equals the moles of base". (EV)
- During interpretation, rejected an approach on noting that: "the concentration of OH^- is not necessarily the concentration of H^+ for a weak acid" (PD)
- Repeated experiment 3 times in attempt to get pH at equivalence point, then note that this is something they did not yet (EV)
- Use lecture notes as resource and decide to use pH = pKa at half equivalence point (FL)

Results--*high performing group (continued)*

Problem 2 (unknown acid-strong acid)

- Repeat of process from previous sample
- Identify acid based on pH at half equivalence point and get the wrong answer
- Discussion of what could have gone wrong (EV)
- Begin with discussion of another way to determine pKa, then shift to discussion of how to determine strong versus weak (FL)
- Calculate pH of initial solution with assumption of strong acid, and take agreement as proof of strong acid (FL, PD)

Results--*low performing group*

Problem 1: unknown acid-weak acid

- Begin by trying to connect pH of starting solution to pKa, note it is not going well, and shift to determining concentration of the acid (FL)
- Note lack of understanding of relation between pH and pKa, and so go to lecture notes
- Propose new solution path: "maybe we can mix the (unknown) acid with water and see how much the pH changes." (FL, PD)
- Note that they do not know how to interpret the results of that experiment (EV)
- Perform equilibrium calculation and note that pH depends on both pKa and concentration of acid, decide to search for new approach (PD)

Results--*low performing group (continued)*

- Decide to neutralize with a base: use equal volumes of a variety of bases and see which one leads to pH=7 (For example, 100ml unknown with 100ml of a base selected from stockroom) (FL)
- Shift to adding different volumes of base, as opposed to different types of bases (FL)
- Note way to get from volume of base added to concentration of initial sample (PD)
- Titrate with weak base and try to interpret equivalence point; researcher gives hint of using NaOH for titration; students then able to get concentration, but use guesses to determine acid type (feedback form allows three guesses).

Summary of student observations

- High performing group
  - Initial problem analysis did reveal some consideration of domain structure (DS)
  - Solution pathway was mostly linear, given many opportunities for principled decisions (PD) and evaluation (EV)
  - Identification of acid as being strong or weak pushed their domain knowledge and gave opportunities for flexibility (FL)
- Low performing group
  - Initial problem analysis did not invoke a consideration of domain structure
  - Student's were immediately challenged with domain knowledge and so had many opportunities for flexibility (FL). Evaluation (EV) was not based on domain principles. There were few opportunities for principled decisions (PD).

Questions for further analysis

- Problem functions differently for low and high performing groups, but both engage in critical thinking. What are the implications for learning in these two groups?
- When students are at the limits of their domain knowledge, they engage in flexibility (FL); otherwise, principled decision (PD) and evaluation (EV) are prevalent. Can we use online feedback to ensure all students engage in a balance of critical thinking skills?
- Online experiments in the virtual lab allow students to engage in critical thinking. To what extent do the "predict and check" and "layered problem" formats promote critical thinking?

Any questions and/or comments?

Thank you!

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Project web site: http://ir.chem.cmu.edu/irproject/