Design and Implementation of a Studio-based General Chemistry Course at the University of Michigan

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Supplementary Material

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Table 1 summarizes the methods and materials adopted from the literature and used in Studio

Table 1: Literature Materials (Methods and Activities) Incorporated in Studio

Method	**Example/Topic**	**Literature Support**
Active Learning	Introduce periodic table; hypothesize how elements were grouped; observe properties of group 1 and group 2 metals; discuss how elements are grouped	Provides common past experience that can be linked to discussion of chemical phenomena.*(1)*
Cooperative peer learning	Students work in small groups to create presentations on the concept of dynamic equilibrium for presentation to the full class.	Learning occurs while people participate in the social activities of their learning community, transforming (i.e., constructing) their understanding as they participate.*(2)*
Real-world applications	Hot and cold packs; glow stick quiz; Watershed project as part of collaboration with community groups to study local creek	An emphasis on adaptive expertise facilitates students' quality of learning and ability to transfer concepts to novel situations.*(3)* Service learning demonstrates applicability of material to real-world scenario highlighting the topic's importance.*(4, 5)*
Kinesthetic learning	Filling atomic orbitals; acting out buffer interactions; polymerization; SEA's	Reaches kinesthetic learners*(6)*
Concept maps	Chemical bonding; acids and bases	Improves student achievement, reduces student anxiety, aids constructive learning*(7-11)*
Group Instruction	Atomic models; acids and bases production; polymer recycling	Emphasizes involving students in learning including planning, decision making, critical analysis, and synthesis *(12, 13)*
Activities Adopted	Chemical Bonding and Thermochemistry	Introducing organic molecules, fats, solubility, intermolecular forces*(14)*
	Equilibrium	Limiting reagent vs. equilibrium,*(15)* exchange of pennies,*(16)* practice problems*(17)*
	Acid Base	History*(18)*
	Electrochemistry	Activity series box;*(19)* model of galvanic cell;*(20)* Sherlock Holmes Adventure*(21)*
	Kinetics and Mechanisms	Kinetics of flipping pennies and burning candles,*(22)* blue bottle*(23)*
	Iron Wall	Iron wall remediation of contaminated water*(24)*
	Polymers	Two crosslinked balls,*(25)* slime,*(26, 27)* superabsorbant polymer *(28)*

Example of a Studio: Periodic Trends 2

Periodic Trends 2 begins with a review of Dalton's model of the atom. Students are then challenged to use a toothpick probe to identify an unknown object (paperclips, screws, bottle caps, etc.) embedded in a ball of soft modeling clay. After the results are compiled, students are shown how chemists use different types of probes to determine structure. This provides a hands-on experience to contextualize the case of "probes" and experiments by Michael Faraday (electricity decomposes substances), J. J. Thompson's (cathode ray tube) and Millikan (oil drop). The backdrop of the Ehrenhaft-Millikan controversy leads to a discussion of scientific reporting.

All of the experimental evidence is used to disprove Dalton's model. A group of students (assigned during the previous studio) presents the Plum Pudding model of the atom to the class. Then Rutherford's gold foil experiment is introduced. Students are invited to mimic Rutherford (and gain a better understanding of his gold foil experiment) by exploring a box (an atom) with a laser pointer (alpha particles). Students probe their box through the small slits around the bottom edges with the laser pointer to locate its nucleus (a mirrored object) and determine the size and shape of the nucleus. The students' experimentation is then compared to Rutherford's including a discussion of how large the box would be if their nucleus was the size of the object that they had measured. The first lab report of the semester is written on this experiment.

The Plum Pudding model is deemed disproven. A group of students presents the Bohr model of an atom. The Aufbau principle is modeled through a kinesthetic exercise where their names are drawn and they get to choose a seat in a fictional classroom. Each seat in the classroom is associated with requirements for obtaining an "A" in the class. Two seats require the least effort to earn an A, so they are filled first. The remaining seats carry criteria such that they are filled in the same pattern as atomic orbitals are filled. The Aufbau principle and the energy of orbitals are introduced and student pairs practice writing out the electron configurations of elements 3-10.

SEA: Equilibrium Representations

Student Enrichment Activites (SEAs) invite students to make connections between chemistry and other areas of their lives by highlighting analogies between chemical concepts and other concepts with which they are more familiar or more interested.

An example of an SEA assigned as homework for a group of 4-6 students:

> Your group will create a visual representation of a dynamic equilibrium. The medium is completely up to you (animation, skit, artwork, etc.), and creativity is encouraged. You should give thought to how to best display the nature of the system you have chosen in order to help your peers better understand the concept. Indeed, posing the question, "How can I present this information in the best way to help my peers understand?" is a good way to begin.
>
> The representation should demonstrate: 1) a system in stable, dynamic equilibrium; 2) a stress to the system and how it would respond according to Le Chatelier's principle.
>
> You will tell the class the system, what species (chemical or otherwise) that are present etc., but the class will have to infer the stress placed on the system by the system's response to that stress.

For the SEA described above, students have written and performed songs, poems (Figure 1), skits, and created comic books. Students were evaluated using the grading rubric in Figure 2.

Figure 1: Equilibrium *by Jeff Atkinson, Joe Donley, Eric Frey*

Wrath!
Equilibrium, the finale of reactions
Dynamic
Ever bouncing the reaction
continues
But quantities stay the same
Like two great beasts locking horns
Neither refusing to give way,
preferring
death to dishonor

Reversibility
Not unlike a fall windbreaker
Double sided, indestructible
Reactions work both ways
Products to reactants
And reactants to products
Ever battling with the merciless
bond
formations and fragmentations
Who will win this war of wills?

Constant
The K_{eq}, immortal
Products over reactants
Pure solids and water,
Like Green party candidates
Forgotten, not considered
Q, the reaction quotient
Instantaneous
When less than K_{eq}, products
formed
When equal, equilibrium is reached
When greater, reactants formed
Ever adjusting toward equilibrium
Much like the clownfish changes
sex
To produce an equilibrium between
males and females

LeChâtelier
A Frenchman with a love of
chemistry
His principle, the law of his land
When a change is imposed
On a system at equilibrium
The system will react in a direction
Reducing the amount of change
Just as a swing, pushed in one
direction
Will swing back in the opposite
direction

Concentration
The big "M" stands for moles/liter
The answer to the age old question,
"How much stuff?"
Adding more reactants drives
equilibrium toward products
Adding products has the opposite
effect
Water, from quiet sunny stream
To babbling brook
To raging river
All has a concentration of 56
moles/liter

Temperature
Bane of man's existence
From frozen mountain snows
To burning desert sands
One is never comfortable
It alone has the power to affect K_{eq}
It alone has the splendor
Adding heat will drive endothermic
reactions toward the products
While exothermic reactions will be
driven toward the reactants

Equilibrium
Quietly controlling
Calming disruption
Governing our lives.

Figure 2: Grading rubric used for Equilibrium Representations

Presentation (6)

____ (1) Asked question of another group
____ (1) Participated in guessing stress on the system
____ (2) Clear to audience, all able to hear, good use of visual aids when appropriate
____ (1) Prepared when called on to start presentation (no idle transition time); under 7 minutes
____ (1) Answered questions well

Paper (3)

Clear and concise presentation of ideas, expressed all of ideas clearly; cited references when appropriate; includes all idea criteria

Idea (11)

____ (3) The system chosen is a stable dynamic example of equilibrium; scientifically sound; appropriate medium
____ (2) Initial species all presented and accounted for
____ (2) Stress is a logical choice for demonstration
____ (2) Reaction to Le Châtlier's principle (response to stress) shown so that others could decipher stress; scientifically sound
____ (2) Rationale for choice

____ (+1) extra creativity

The SEAs (Table 2) not only help foster student creativity, but they also help students develop their communication skills as they sum up their ideas succinctly (a page or less) in written form and present their ideas to the class.

Table 2: SEAs used in Studio Chemistry

Topic	**SEA assignment**
Periodic trends	Given a set of "fictitious" elements with known properties: oxide formation, melting point, density, ionization potential, and radius, create a periodic table. Justify the trends that you used.
Chemical bonding and thermochemistry	Debate one of the following: a) the consumption of trans-fats; b) the FDA approval of olestra; c) should there be a fat tax?
Equilibrium	Create a visual representation of a dynamic equilibrium. Demonstrate the systems and then the effect of a stress on the system so that your peers can identify the cause of the stress.
Acids and base	You are a doctor. You diagnose a patient with acidosis while her young daughter is in the room. The child thinks that her mom is going to dissolve in acid like she saw in a cartoon. Create comic strip, story, or information card to help ease the child's fears.
Electrochemistry	*Sherlock Holmes and the Blackwater Escape*(21)*
Kinetics	Create a visual representation of the kinetics and mechanism of a system. Include the effects of stress and catalysts on the system's rate kinetics and mechanism.

*Many students solved the case by looking up the answer on-line so this activity is inappropriate for use outside of class.

Watershed Project: Community Building, Discovery, Service, and the Real-World

In order have students experience research and scientific discovery, a term-long project focused on the Millers Creek Watershed, a waterway running through the North Campus of the University of Michigan, became a service learning project.*(4, 5)* Students used Pasco Scientific Xplorer™ probes (which were also used in class) to constantly monitor the temperature, conductivity, pH, and dissolved oxygen content at the Glazier Way (a location) depth gauge. All of the students went on a field trip to the collection site (accessible by campus bus, escorted by the teaching staff) during an early studio period to learn to use the probes. Over the course of the semester, small groups escorted by a Graduate Student Instructor (GSI) returned to the site to collect the data recorded by the probes. The student groups then had to graph and write a brief analysis of the data that they had retrieved.

The students were also required to write a proposal for their own project within the area of water quality. With some allocated studio time, department instrumentation, and instructor assistance, projects included: the effect of a dam on water above and below it, determining the impact of a phosphate spill on a mock creek built in studio, coliform counts, and levels of lead in water from different sites around campus.

To emphasize the connection between science and public policy, a student debate concerning the recommended maximum contamination limit for arsenic in drinking water issues was organized in 2003.*(29)* Students were divided into four groups to prepare opening statements, rebuttals, and questions for opponents and assigned the outdated 50 ppb arsenic level, the current 10 ppb level, the recommended 3 ppb level, or the lowest level-of-detection possible.

Syllabus

The studio teaching method emphasizes depth over breadth in its coverage of topics. Based on our experience with entering chemistry students at the University of Michigan, we deliberately chose not to incorporate what seemed to be review topics from high school science classes, such as chemical vs. physical change, unit conversions, atomic weights, and moles that are included in the usual University of Michigan one-semester general chemistry syllabus.*(30, 31)* Rather than explicitly covering these topics, an assignment was constructed to help the students review these concepts. All students were informed that while the course would not explicitly cover any of these topics, all questions concerning these topics would be answered and that the teaching staff was available for assistance. Topics for Studio General Chemistry were selected based on: (a) their suitability for meeting the course goals of chemistry literacy and scientific discovery, (b) preparing students for subsequent courses, and (c) aiding students in developing critical thinking skills. A syllabus for the one-semester studio course is included in Table 3.

Table 3: Studio General Chemistry Syllabus 2003

Tuesday Studio	Interstudio	Thursday Studio	Lab Report/ Watershed	SEA
	Intro to studio, scientific method, fact, theory, law	PT1: safety, alchemy, history of periodic table, groups, periods		SEA 1: Build periodic table from elements, present PT3
PT 2: atomic models, scientific probes, electron configurations	Periodic trends, LEDs	Watershed Project Studio: trip to Millers creek, learn to use probes		
PT 3: periodic trends	Watershed, error analysis, bonding, Lewis structure	CB 1: bonding, octet rule, Lewis structures, polyatomic ions, fats	Lab report on PT2 due	
CB 2: VSEPR, intermolecular forces, solubility	VSEPR; Jeopardy to review for exam	CB 3: vitamins, bond energy, ΔH_f; energy in fats		
#CB4: q, hot/cold packs, calroimetry	Fats, obesity, dilithium crystals, silicon based life	AB1: equilibrium, Q, LeChatelier		SEA 2: debates on trans-fats, fat tax, or olestra, present CB4
AB 2: history, theories, production of acids/bases	Equilibrium simulations, demos, equations	AB 3: indicators, pH, titration, strong vs. weakly dissociation	Lab report on CB4 due	
Fall Break	pH/pOH, strong acids, indicators	AB4: titration	Watershed proposal meetings	SEA 3: Equilibrium representation, present AB4
AB5: polyprotic acids/bases, salts	Base equilibrium, titration	AB6: buffers	Lab report on AB1 due	
#AB review, watershed project day	Demos, oxidation numbers	Watershed project day		SEA 4: Acidosis, present AB review
EC1: balancing redox rxns, activity series, voltaic cells	Current, charge, batteries, hybrid cars	EC2: galvanic cells, Nernst, electrolysis	Lab report on AB6 due	
K1: rates, rate law, order	Kinetics, rate laws	K2: Arrhenius, mechanisms		SEA 5: Blackwater Escape*(21)* present K1
K3: Blue bottle mechanism*(23)*	Beer's law, reaction orders	IW 1*(24)*		SEA 6: kinetics representation IW1
#IW 2	Current topics	Thanksgiving	Draft watershed report	
Watershed Project	Batteries, Gatorade	Arsenic Debate	Lab report K3, IW2	
Watershed Present	Watershed data	Study Day	Final draft watershed	

PT = periodic tends; CB = chemical bonding & thermochemistry; AB = acid/base & equilibrium; EC = electrochemistry; K = kinetics; IW = iron wall # Evening exam took place on this day

Equilibrium Interview Scoring

A holistic scoring scheme was created and used. The student responses to seven scripted questions (Table 4) were scored a 0, 1, or 2, with a "0" for a scientifically incorrect response, a "1" for a mostly correct response, and a "2" for a correct response to the questions asked. For example, question 6 asked about the effect on the addition of chloride ion on the system at equilibrium. The response, "It would probably react with the pink [Co^{+2}] and turn more blue…[the concentration of $CoCl_4^{-2}$] would go up; [the concentration of Co^{+2}] would go down" earned a score of 2. The response, "…it would shift more to the right in order to obtain the balance that it wants. So there would be a little bit more cobalt tetrachloride formed. It would spike a little bit and then sorta plane off," followed by, "I don't know" when probed about the effect on the concentrations of cobalt and chloride ions was scored a 1. Finally, the response, "cobalt would be the limiting reagent," received a score of 0.

Table 4: Scripted Interview Questions

1	Why do you think that the temperature changes the color that is observed?
2	Chemists will talk about the rate of forward and reverse reactions when discussing chemical equilibrium. Would you explain to me what happens to these rates when the system comes into equilibrium?
3	Would you describe to me what is happening on a molecular level? For example, what is occurring to a single molecule of $CoCl_4^{2-}$ over the course of five seconds?
4	When the flask was heated up, more $CoCl_4^{2-}$ was formed to give the blue color. What implication, if any, does this have on the ΔH of the equilibrium?
5	Which, if any, of the flasks are currently in equilibrium?
6	Would you describe to me what would change in the equilibrium we were just talking about if more Cl^- were added to this flask at room temperature? (What would happen to the concentrations of each of the species in solution?)
7	Would you describe to me what would change in the equilibrium if more $CoCl_4^{2-}$ were added? (What would happen to the concentrations of each of the species in solution?)

Common Exam Questions

Figure 3: Common Exam Question 1

1) For the reaction system:

$$2\ HI_{(g)} \rightleftharpoons H_{2\ (g)} + I_{2\ (g)})$$

K_{eq} = 0.020 at 720 K.

If the initial concentrations of HI, H_2, and I_2 are all 1.50×10^{-3} M at 720 K, which one of the following statements is **CORRECT**?

A) The concentrations of H_2 and I_2 will increase as the system is approaching equilibrium.
B) The concentrations of H_2 and HI will decrease as the system is approaching equilibrium.
C) The concentration of HI will increase as the system is approaching equilibrium.
D) The concentrations of HI and I_2 will increase as the system is approaching equilibrium.
E) The system is at equilibrium.

Figure 4: Common Exam Question 2

2) The oxidation of sulfur dioxide to sulfur trioxide is one of the equilibria involved in acid rain formation:

$$2\ SO_{2(g)} + O_{2(g)} \rightleftharpoons 2\ SO_{3(g)} \quad \Delta H = -198.4\ kJ/mol$$

Which of the statements about this equilibrium is **FALSE**?
A) Increasing the temperature will decrease K_{eq}
B) Increasing the concentration of O_2 results in an increased concentration of SO_3
C) Adding a catalyst will cause K_{eq} to increase
D) Increasing the concentration of SO_3 results in an increase in the concentration of SO_2
E) All of the statements are TRUE

Figure 5: Common Exam Question 3

3) An aqueous solution is found to have an $[OH^-] = 1.02 \times 10^{-4}$. What is the pH of the solution?

A) pH = 4.0
B) pH = 6.0
C) pH = 8.0
D) pH = 10.
E) pH =12.

Figure 6: Common Exam Question 4

4) When a chemical reaction has reached equilibrium, which of the following statements are always **TRUE?**

(i) The K_{eq} is dependant on temperature but not on the composition of the equilibrium mixture
(ii) The concentrations of products and reactants are equal
(iii) There is no longer any formation of products or reactants

A) i
B) ii
C) iii
D) i and ii
E) ii and iii

Figure 7: Common Exam Question 5

5) 35.0 mL of 0.250 M $NaOH_{(aq)}$ are added to 20.0 mL of 0.10 M $H_2SO_{4(aq)}$.
What is $[H_3O^+]$ in the resulting solution?

a) 0.12 M
b) 0.086 M
c) 0.193 M
d) 1.2 x 10-13 M
e) 0.81 x 10-13 M

Questions 3 & 5 are considered algorithmic; questions 1, 2, and 4 are considered conceptual.

Data was analyzed (studio n= 44; nonstudio n = 347) using a logistic regression and with GPA, chemistry and math placement scores used as control variables. For questions 1 and 5, odds are even that both studio and nonstudio students will answer correctly. Odds are slightly higher that a studio student will answer question 2 correctly. Odds are significantly higher (3.4:1) that a nonstudio student will answer question 3 correctly. Odds are significantly higher (3:1) that a studio student will answer question 4 correctly.

Personal Impressions

A teaching assignment in the Studio classroom was challenging for the GSI's. Maintaining student interest and the needed flexibility with content and timing were particularly difficult. As in any class, the students periodically found themselves apathetic to the activities surrounding them and their attention had to be refocused. As one GSI described challenges she faced with students, "The students had a hard time adjusting to the overall style of the Studio class. They weren't accustomed to the idea that they were supposed to be learning through the lab activities and applying the concepts they had learned. They just wanted to make sure what they had was the right answer."

Allowing different groups to proceed through activities at their own pace often led to groups that had moved quickly through a designed activity while other groups took a very methodical, more time consuming approach. Efforts to bring these groups together to discuss their results were often received with indifference. The faster groups demonstrated little desire to take the activity a step further and explore deeper the chemical phenomena they were studying. Instead, students often preferred to discuss non-class related topics or use the internet connection to check their e-mail or surf the web. Inculcating the desire to explore chemistry in the students is quite challenging, but extremely rewarding for those students who embraced it.

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