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Frustrated Lewis Pair Pedagogy: Expanding Core Undergraduate Curriculum and Reinforcing Fundamental Thermodynamic Concepts

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Frustrated Lewis Pair Pedagogy: Expanding Core Undergraduate Curriculum and Reinforcing

Fundamental Thermodynamic Concepts

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CONTENTS

Abstract	2
Keywords	2
Introduction	3
Methods	5
Participants	5
Structure of CHEM 151B	5
Incorporation of FLP material	6
Assessments	7
Questionnaire	9
Results	10
Incorporation of FLP material	10
Influence of FLP coverage on understanding thermodynamics	11
Discussion	14
Conclusions	16
Notes	17
Acknowledgement	17
Author Information	17
References	18
Appendix 1	22

ABSTRACT

For over a decade, the Frustrated Lewis Pair (FLP) concept has helped to extend the frontiers of main-group chemistry. The present-day maturity of the field, coupled with recent research developments highlighting the continuity between FLP chemistry and classical Lewis acid-base chemistry, suggest that FLP chemistry should be introduced into the mainstream undergraduate chemistry curriculum. Herein is described the experience of a pilot project to incorporate FLP chemistry into the undergraduate main-group inorganic chemistry course at the University of California, Santa Cruz. The presentation of the material, which stresses the thermodynamics-based continuity that links classical Lewis acid-base chemistry and FLP chemistry, also suggested that coverage of the FLP material might provide a means of solidifying fundamental concepts from chemical thermodynamics from earlier courses. Preliminary quantitative and qualitative data have been acquired that support this hypothesis.

KEYWORDS

Frustrated Lewis Pair, FLP, Lewis acid base, thermodynamics, pedagogy, undergraduate

INTRODUCTION

The articulation of the Frustrated Lewis Pair (FLP) concept by Stephan and coworkers less than 20 years ago helped contribute to a contemporaneous and ongoing resurgence in main-group inorganic chemistry. Viewing chemical systems through the FLP lens has allowed significant discoveries to be made in the areas of small-molecule activation and catalysis [1-3]. Reactions that had previously lain solely within the purview of transition-metal chemistry were now accessible with main-group systems. Most notable is the reversible activation of H_2 and the catalytic hydrogenation chemistry it enables [4,5]. Other important examples include the capture of NO and N_2O [6,7], and the capture and reduction of SO_2 [8], CO [9], and CO_2 [10].

Although this chemistry will inevitably find important synthetic applications, perhaps the greatest contribution of FLP chemistry has been in providing chemists with a new paradigm through which to view, interpret, and predict chemical reactivity [11]. Despite having firm roots in main-group inorganic chemistry, an ever-widening scope of systems continue to be interpreted in an FLP manner, including transition-metal chemistry, enzymatic catalysis, and heterogeneous catalysis [12]. By allowing chemical systems to be viewed in a new light, the FLP concept is enabling the discovery of new chemistry [13,14].

Investigation into the very nature of FLP chemistry has complemented the discovery of new chemical transformations with equally important novel fundamental knowledge. Theoretical and experimental investigations into the mechanism of H_2 activation led to the postulation of the encounter complex, which might play a role across a range of different chemistries [15-18]. Recent studies that uncovered the single-electron counterpart to classical two-electron FLP chemistry have also suggested that these two paradigms might simply reflect extreme limits of a unifying underlying continuum [19-22]. In a similar manner, investigation into the FLP reactivity of Lewis pairs that are not fully frustrated has revealed that the key to observing FLP chemistry is accessing the dissociated acid and base [23-25].

In the case of a classical FLP, steric bulk drives the dissociation to completion, but in cases far from this limit, FLP chemistry can be observed, provided that the Lewis adduct is in equilibrium with the dissociated acid and base. The presence and importance of these equilibria, as well as the potential role of dispersive interactions in stabilizing encounter complexes, provides a clear path for introducing FLP chemistry into the undergraduate inorganic chemistry curriculum.

Although there are no reports in the chemical education literature on best practices for teaching FLP chemistry, anecdotal data suggest that it has generally been reserved for graduate or upper-division undergraduate courses. In these contexts, it is frequently introduced as an example of cutting-edge research. FLP chemistry certainly qualifies as such and incorporating research topics into undergraduate instruction can be a valuable strategy for not only engaging students, but engaging faculty as well [26]. In very recent years, FLP chemistry has even started to appear in undergraduate inorganic chemistry textbooks, often as an “advanced topic” or “research application” of the fundamental Lewis acid-base chemistry being discussed [27]. One of the most compelling features of FLP chemistry is, however, its simplicity. Lower-division undergraduate students have already been exposed to all of the key material needed to grasp the FLP concept. If the students have the tools to understand the material, the instructor’s primary task is to find a compelling and constructive way to introduce them to that material.

As noted above, research into the role that dynamic equilibrium plays in the FLP chemistry exhibited by associated Lewis pairs revealed that FLP chemistry is a natural – even inevitable – extension of classical Lewis acid-base chemistry. Consideration of these equilibria provides a means of smoothly incorporating the FLP concept into the core material of an undergraduate inorganic chemistry course, rather than treating it as an additional/advanced topic. Moreover, the important role that these equilibria and their thermodynamic descriptors play in FLP small-molecule activation suggests that this material could provide a means of reinforcing fundamental thermodynamic concepts.

These notions were explored in CHEM 151B: *Chemistry of the Main-Group Elements*, a main-group chemistry course offered at the University of California, Santa Cruz (UC Santa Cruz) in the spring of 2020. The course is typically taken by upper-division undergraduate and graduate students, all of whom have received prior instruction in fundamental chemical thermodynamics. This report details the results of a pilot project to incorporate FLP chemistry into the curriculum of CHEM 151B as a natural extension of Lewis acid-base chemistry and preliminary results on whether including this topic in the course can help consolidate students' understanding of fundamental chemical thermodynamic concepts.

METHODS

Participants

This pilot study analyzed data collected during the instruction of CHEM 151B: *Chemistry of the Main-Group Elements* at UC Santa Cruz in the spring academic quarter of 2020. A total of 13 students were enrolled in the course. Nearly two thirds (N=8) were undergraduates and the remainder were doctoral students. All participants were chemistry majors or enrolled in the graduate program of the Department of Chemistry & Biochemistry. Over two thirds (N=9) self-identified as male and all students were taking the course for a letter grade. It is noteworthy that the course took place in the midst of the global COVID-19 pandemic and instruction was performed remotely over the internet.

Structure of CHEM 151B

This main-group chemistry course reviews acid-base chemistry, discusses general trends within main-group chemistry, and provides a descriptive treatment of the chemistry of each of the families of the s and p blocks of the periodic table (Table 1). During Topic 1 (Acid-Base Chemistry), the general

notion of the acid-base dichotomy as a foundational organizing principle within chemistry is discussed. The various acid-base definitions and their usefulness in different situations is then described. When discussing Brønsted acidity/basicity, the students are encouraged to examine the following topics through the lens of chemical equilibria: the influence of conjugate acid/base stability on basicity/acidity; solvent-induced variation in acidity/basicity; non-nucleophilic basicity; solvent-based leveling effects; super-acidity (e.g., magic acid and fluoroantimonic acid); and the use of acidity/basicity scales (e.g., gas-phase acidity, gas-phase basicity, and proton affinity) to predict reactivity. When the Lewis acid/base paradigm is encountered, the students are encouraged to consider the role of the equilibria governing adduct formation on: the thermodynamic parameters used as acidity/basicity scales (e.g., fluoride ion affinity, BF_3 affinity, I_2 affinity); the use of hard-soft acid-base theory to qualitatively predict reactivity; the use of absolute hardness and the multiparameter Drago-Wayland scale to quantitatively predict reactivity; the influence of steric and electronic properties on acid/base strength.

Table 1. Topics Covered in CHEM 151B at UC Santa Cruz in Spring 2020

Topic 1	Acid-Base Chemistry
Topic 2	Hydrogen
Topic 3	s Block (Alkali Metals and Alkali Earth Metals)
Topic 4	General Trends in the p Block (+ Nomenclature)
Topic 5	Group 13
Topic 6	Group 14
Topic 7	Group 15 (Pnictogens)
Topic 8	Group 16 (Chalcogens)
Topic 9	Group 17 (Halogens)
Topic 10	Group 18 (Noble Gases)

Incorporation of FLP material

Allowing the student to view the aforementioned topics through the lens of chemical equilibria leads naturally to a discussion of the influence of induction and resonance on acid/base strength and Lewis adduct formation. The influence of steric bulk on the equilibrium is also readily introduced and exposes the students to the notion of a sterically frustrated pair. The final step of adding an unhindered “Lewis amphoteric” substrate to the frustrated pair leads the student smoothly to the notion of FLP

reactivity. This treatment of the material (Figure 1) facilitates discussion of the importance of combined Lewis acidity/basicity on small-molecule activation and the notion that FLP chemistry can be accessed from compounds that appear to be stable Lewis adducts.

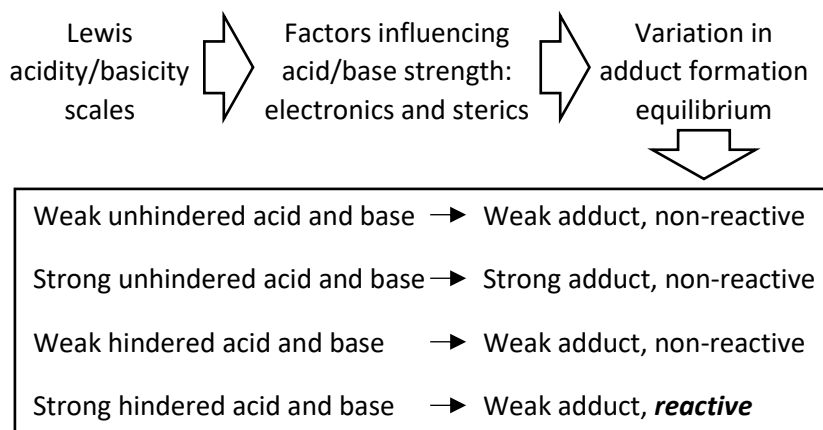


Figure 1. Schematic depiction of the incorporation of FLP material into the core curriculum of an undergraduate inorganic chemistry course.

Assessments

The following three questions provide examples of assessments used in a problem set and an exam. These questions were designed to not only assess the student's comprehension of the thermodynamics influencing FLP reactivity, but to also serve as a primary point of learning.

Example 1

- a) Consider the activation of H_2 by an acid A and a base B to give $[\text{BH}]^+$ and $[\text{AH}]^-$. Refer to your notes on Born-Haber cycles and construct a thermodynamic cycle for the reaction of H_2 with A and B assuming that A and B are an FLP (i.e., there is no dative interaction between them). Ignoring solvation energies, derive an expression for ΔH_{rxn} by writing out the necessary series of chemical equations and assigning them approximate ΔH values based on the following information:

$$\text{H}_2 \text{ bond dissociation energy} = 436 \text{ kJ mol}^{-1}$$

H atom ionization potential = $1312.2 \text{ kJ mol}^{-1}$

H atom electron affinity = 72.8 kJ mol^{-1}

Use " ΔH_B " as a variable for the enthalpy of the reaction of B with H^+

Use " ΔH_A " as a variable for the enthalpy of the reaction of A with H^-

- b) Note that ΔH_B and ΔH_A are related to thermodynamic descriptors of basicity and acidity that we discussed in lecture, such as proton affinity and hydride ion affinity. Under the assumption that this reaction is primarily driven by enthalpy, for what values of ΔH_B and ΔH_A will H_2 activation occur spontaneously?

Example 2

- a) Repeat example 1 without the assumption that A and B are a fully dissociated acid-base pair.

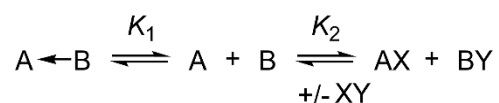
The Lewis adduct A-B can still react with H_2 to form $[BH]^+$ and $[AH]^-$. Write out the new overall chemical reaction, provide a new thermodynamic cycle, and give a formula for ΔH_{rxn} incorporating the dissociation of A-B into A and B, which has an enthalpy $\Delta H_{dissociation}$.

- b) Given that A behaves as a Lewis acid and B behaves as a Lewis base, what will be the signs (negative or positive) for the values of ΔH_B , ΔH_A , and $\Delta H_{dissociation}$? Explain.
- c) In the limit of a very stable adduct A-B formed from strong, unhindered acid and base, what limiting value does $\Delta H_{dissociation}$ approach? What is the implication for the ΔH_{rxn} of the H_2 activation reaction?
- d) If the substituents on A and B were made larger, what effect would that have on the $\Delta H_{dissociation}$?
- e) We can think of Frustrated Lewis Pair (FLP) chemistry as simply a limiting case of the more general chemistry of acid-base adducts. In the limit of substituents on A and B so large that A and B don't interact at all, what value does $\Delta H_{dissociation}$ assume? What is the consequence for ΔH_{rxn} ?

- f) The answer from (e) might be surprising. Provide an explanation for why you do not get an expression for ΔH_{rxn} equivalent to that obtained in Example 1.

Example 3

Consider activation of the small molecule XY by the Lewis pair A-B as a series of two equilibria (shown below).



- a) If the acid or base is made stronger, what would happen to K_1 (as defined by the direction of the reaction as written)?
- b) If the acid or base is made bulkier, what happens to K_1 (as defined by the direction of the reaction as written)?
- c) Observation: tris(2-methylphenyl)phosphane and trichloroborane activate XY but trifluoroborane and tris(2-methylphenyl)phosphane do not. Suggest an explanation for this variation in reactivity.
- d) Observation: tris(2-methylphenyl)phosphane and trichloroborane activate XY but trichloroborane and tris(4-methylphenyl)phosphane do not. Suggest an explanation for this variation in reactivity.

Questionnaire

One week prior to the start of the academic quarter, the students enrolled in CHEM 151B were contacted by the instructor of record (TCJ) via email with the following: a link to an online questionnaire; an explanation of the fact that their input was being solicited to help learn more about strategies used to teach main-group chemistry; and assurances that their participation was completely voluntary, their answers would have no impact on their standing in the course, and that they would remain anonymous.

The questionnaire was administered through Google Forms with the settings chosen to keep records fully anonymous.

The questionnaire is reproduced in full as Appendix 1. It features six multiple choice questions that assessed elements of the student's understanding of fundamental chemical thermodynamics. The concepts tested included: the definition of an equilibrium constant (Question 1); the relationship between equilibrium constants and concentrations (Question 2); the use of an equilibrium constant to represent the extent of a reaction (Question 3); the use of thermodynamic cycles to obtain ΔH or ΔG for a reaction (Question 4); the notion that chemical systems in dynamic equilibrium will respond to variations in concentration so as to reestablish equilibrium (Question 5); the constancy of the equilibrium constant during fluctuations in concentrations (Question 6).

The questionnaire was re-administered in the sixth week of the academic quarter following coverage of FLP chemistry during lecture and administration of assessments on this topic in a problem set and a midterm exam. In this second installment of the questionnaire, the students were also given the following prompt: "Did you find that use of the Frustrated Lewis Pair concept in our discussion of main-group chemistry helped you to better understand certain concepts in fundamental chemical thermodynamics? Any feedback you can give about how or why would be greatly appreciated." The narrative answers given by the students were categorized as "yes," "somewhat," or "no."

RESULTS

Incorporation of FLP material

The University of California, Santa Cruz offers two undergraduate inorganic chemistry courses: *CHEM 151A: Chemistry of Metals* and *CHEM 151B: Chemistry of the Main-Group Elements*. In accordance with the results obtained by surveys administered by a subset of the 2014 Inorganic

Chemistry ACS Exam Committee [28,29], these two courses fall under the broad classifications of “Fundamentals and Selected Topics” and “Advanced Inorganic: Selected Topics.” The material covered in CHEM 151B (Table 1) would clearly be compatible with a discussion of FLP chemistry and this topic could easily be included as an “advanced topic” or as an example of an application of main-group chemistry in current research. Instead, a decision was made to structure the course in a manner that reveals the natural place of FLP chemistry within the broader field of Lewis acid-base chemistry (Figure 1). This organizational structure facilitates course design because the FLP concept is not introduced as an ad hoc construct that is needed to understand experimental results. This alternative approach instead highlights to students that the FLP concept is the inevitable consequence of the behavior of Lewis acids and bases. With regards to the structure described in Table 1, FLP chemistry was introduced in Topic 1: Acid-Base Chemistry as a part of the coverage of the Lewis acid-base paradigm. Although the FLP concept is presented as core material in CHEM 151B, the treatments of most of the Topics from Table 1 were ended with discussions of primary literature research articles; the seminal paper by Stephan et al. on the reversible activation of H_2 was used for Topic 1.[4] Importantly, however, the FLP concept was not introduced with that paper. Rather, the paper was a research application of a chemical principle to which they had already been introduced.

Influence of FLP coverage on understanding thermodynamics

In addition to establishing the fluidity with which the FLP concept can be readily introduced into the inorganic chemistry canon at UC Santa Cruz, the use of the FLP concept in cementing students’ knowledge of fundamental thermodynamic concepts was explored. It is noteworthy that no *new* thermodynamic concepts were introduced in CHEM 151B; the FLP concept was being explored as a tool that could help consolidate information that students had encountered previously in their general chemistry and physical chemistry education. The questionnaire administered to the students before the

start of the academic quarter (“pre-questionnaire”) allowed a baseline level of knowledge to be established. All students completed this initial questionnaire. Re-administration of the same questions following coverage of the FLP material in the course (“post-questionnaire”) provided insight into whether the main-group inorganic chemistry material, including the coverage of FLP chemistry, helped to ameliorate their understanding of these key fundamental chemical thermodynamic concepts. Ten of the thirteen students enrolled in the course completed the post-questionnaire. The proportions of students giving the correct answers to each of the questions on both the pre-questionnaire and the post-questionnaire are shown in Figure 2.

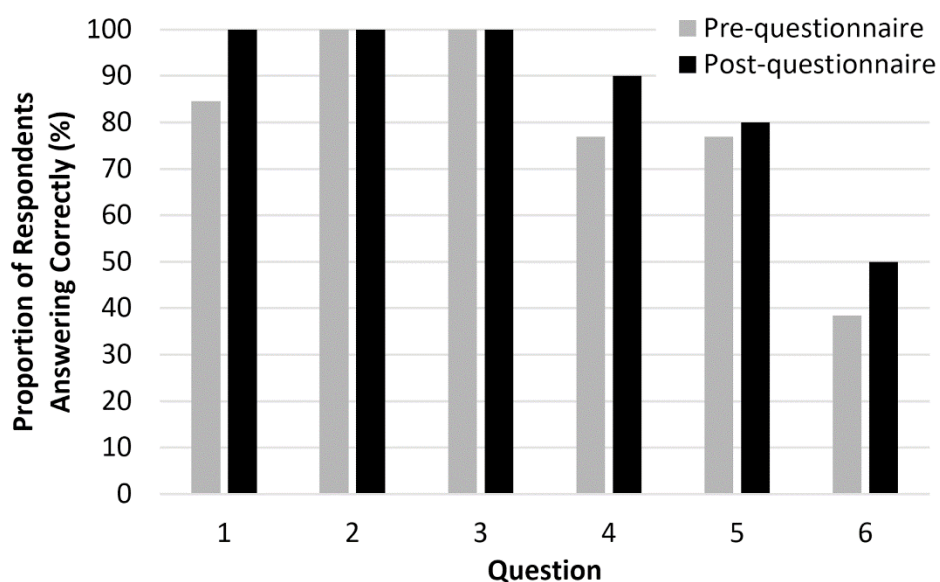


Figure 2. Results from responses to the pre-questionnaire (N = 13) and the post-questionnaire (N = 10).

Question 1 assessed familiarity with the definition of the equilibrium constant as a function of product and reactant concentrations. The two incorrect responses were both A, which neglects inclusion of the stoichiometric coefficient (molecularity) as an exponent in the formula for K . In the post-questionnaire, all students answered the question correctly.

Question 2 assessed an understanding of the relationship between the magnitude of K and the relative proportions of reactants and products. All students correctly answered the question on both questionnaires.

Question 3 assessed familiarity with the concept of an equilibrium “lying to the left” or “lying to the right” and the relationship of this notion with a numerical value of an equilibrium constant. All students correctly answered the question on both questionnaires.

Question 4 assessed whether students were able to execute symbolic algebra using chemical equations to successfully combine thermodynamic functions (Gibbs free energy of reaction). In the pre-questionnaire, 77% of students obtained the correct answer. The incorrect answers were divided across B ($N = 2$) and C ($N = 1$). Either of these incorrect answers are obtained if the student does not correctly apply the concept that ΔG_{rxn} for the forward reaction is equal to $-\Delta G_{\text{rxn}}$ for the reverse reaction. In the post-questionnaire, the 90% of respondents answered correctly and one incorrect answer of C remained.

Question 5 assessed whether the student understood that the equilibrium reached by a system does not depend on the order in which the elements of that system are combined. In the pre-questionnaire, 77% of respondents answered correctly. The remaining students ($N = 3$) chose answer D, indicating that they believed that the species formed first in the multistep reaction would predominate. In the post-questionnaire, 80% of students answered correctly and, again, the only incorrect answer chosen ($N = 2$) was D.

Question 6 assessed whether students understood that the equilibrium constant for a reaction does not change if additional reagents are added or removed. In the pre-questionnaire, responses were almost evenly divided among the three possible answers: 38.5% A ($N = 5$), 38.5% B ($N = 5$) and 21% C ($N = 3$). In the post-questionnaire, the proportion of correct answers rose to 50%, but the remaining responses were still split between A ($N = 2$) and C ($N = 3$).

Finally, the students were also invited to provide narrative feedback in the post-questionnaire about whether the treatment of FLP chemistry used in the course helped them to better understand fundamental aspects of chemical thermodynamics. The majority of respondents (70%) gave an affirmative (“yes”) response and indicated that they found the FLP material helpful in understanding thermodynamic concepts. The responses of the remaining 30% were categorized as “*somewhat*.” No respondents gave an answer corresponding to “*no*.” The narrative feedback also provided the participants an opportunity to qualify their answers. Positive comments from among the 70% whose answers were categorized as “yes”, included: “Yes. I feel like it tied together multiple concepts nicely.”; “It was very interesting and useful.”; “I did find it helped me better understand the concepts.”; “Yes, absolutely!” Responses from those whose answers were classified as “*somewhat*” included: “I think so, but am not 100% sure”; “I thought so. But looks like I was wrong.”; “It helped a bit. ... It has always been a challenging subject for me.”

DISCUSSION

The present-day maturity of FLP chemistry signals that it is ready to be incorporated into mainstream undergraduate education. Although FLP chemistry can be easily included as an “additional topic” or an example of a research application of main-group chemistry, recent developments in FLP research, which have highlighted the explicit thermodynamic connections between the chemistry of FLPs and classical Lewis adducts, suggest that alternative presentations are possible. With regards to course design and instruction, the incorporation of FLP chemistry as a natural progression from Lewis acid-base chemistry was facile. The links between FLP chemistry and conventional Lewis acid-base chemistry also facilitate the development of assessments that target higher-level cognitive domain objectives. Effective chemical learning requires that student learning be assessed across the entire

landscape of the cognitive domain [30]. Questions like those provided as examples in the Results section allow the student to understand, apply, analyze, and evaluate as they explore the extrapolation of classical Lewis acid-base chemistry to FLP chemistry. The response of this initial cohort of UC Santa Cruz students to the material has been positive, a reception that is reflected in the narrative responses collected in the post-questionnaire.

The data collected from the questionnaire also provides preliminary insight into whether teaching the FLP concept can help to cement an understanding of fundamental thermodynamic concepts. Figure 2 shows that for all questions the proportion of correct answers was greater after the coverage of the FLP material, but the sample size is too small to meaningfully quantify the statistical significance of this difference. A comparison of the responses from the pre- and post-questionnaires reveals that certain simple concepts were well-established even before the start of the course. For example, 100% of students responded correctly on both questionnaires to questions about the relationship between equilibrium constants and concentrations (Question 2), and the use of an equilibrium constant to represent the extent of a reaction (Question 3). Although a few students gave incorrect answers for the definition of an equilibrium constant (Question 1) on the pre-questionnaire, all respondents gave the correct answer in the post-questionnaire. Given the semantic nature of the knowledge probed with Question 1, the improvement likely stems from student re-exposure to topics that they have not used recently. Indeed, one of the narrative responses on the post-questionnaire included the following statement: “Although it had been a while since I took thermodynamics so I thought it helped jog my memory a little bit.” The improvement observed in the performance on Question 4 is not surprising given that the FLP material was explicitly used to construct assessments where students were required to use thermodynamic cycles to obtain values of ΔH or ΔG for a reaction (see Examples 1 and 2 in Results).

The less dramatic improvement in Questions 5 and 6 suggest that the concepts assessed in these questions were not heavily reinforced during the course. In future sessions, lectures and assessments will be altered to ensure that these concepts are indeed covered more explicitly. Fortunately, FLP chemistry provides a convenient palette from which to create questions that probe the notion that chemical systems in dynamic equilibrium will respond to variations in concentration so as to reestablish equilibrium (Question 5) and the constancy of the equilibrium constant during fluctuations in concentrations (Question 6).

Finally, it is crucial to note that this preliminary study was only a pilot project and analysis of the data is subject to a number of important limitations. Most importantly, the sample population, although representative of the typical enrollment in this course, is very small. The impact of the small sample size is further amplified by the decreased rate of response to the post-questionnaire. Also, we note that the pre-post study design was selected to see whether a course incorporating FLP material could help to solidify thermodynamic concepts; it was not designed to confirm that the FLP material is specifically responsible for the improvement in understanding. The latter would require a control group receiving a level of instruction that is identical except for the inclusion of the FLP material.

CONCLUSIONS

The FLP concept has unquestionably helped drive innovation in the chemical sciences. Although this concept continues to drive such innovation at the frontiers of chemical research, it has now matured sufficiently to be included within the core material of the undergraduate inorganic chemistry curriculum. The pilot experience of incorporating this material into the undergraduate curriculum at UC Santa Cruz was successful: the FLP material could be readily incorporated into the core material in addition to being an “advance topic” example of cutting-edge research. The students were receptive to

the material, engaged during lecture and discussion, and able to tackle FLP-based exam questions. The secondary goal of this study was to investigate whether the FLP material helped the students to solidify thermodynamic concepts that they had learned earlier in their educational careers. The preliminary quantitative data suggest that this is indeed the case, but the small sample size should be borne in mind. The qualitative narrative feedback is highly encouraging and indicates that the students did indeed find that their understanding of thermodynamic concepts was enhanced by the FLP material. These data will be used to inform the design of subsequent iterations of the main-group inorganic chemistry course at UC Santa Cruz and may also be of interest to instructors at other universities.

NOTES

An answer key to the examples can be requested from the corresponding author.

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APPENDIX 1

CHEM 151B - Post Questionnaire

The following 6 multiple-choice questions are designed to capture the class' general level of comfort with certain fundamental thermodynamic concepts. In our class this quarter, I will be evaluating whether or not some of the concepts that we are covering can serve as valuable pedagogical tools to solidify foundational thermodynamic concepts. These questions *will not be used as an assessment of your individual understanding* of the material. Another questionnaire will be administered later in the quarter.

1) What is the expression for the equilibrium constant of this reaction?



- A) $\frac{[B][C]}{[A]}$
- B) $\frac{[B] + [C]}{[A]}$
- C) $\frac{[A]^2}{[B][C]}$
- D) $\frac{[B][C]}{[A]^2}$

- ☐ A
- ☐ B
- ☐ C
- ☐ D

2) If the equilibrium constant for the reaction below is 10^{-5} , which has a greater concentration, A or B?



- ☐ A
- ☐ B

3) If the equilibrium constant were instead 10^5 , would the equilibrium "lie to the left" or "lie to the right"?



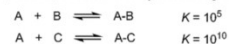
- ☐ Lie to the left
- ☐ Lie to the right

4) Consider the following set of reactions with their associated molar Gibbs free energies and calculate the missing ΔG° for the reaction of E to B.



- ☐ 214 kJ/mol
- ☐ 48
- ☐ -214 kJ/mol
- ☐ -48 kJ/mol

5) Consider three chemicals: acid A, base B, and base C. They can undergo the following reactions:



Compare the amount of A-B formed to A-C formed if:

Situation 1: A is combined with B and then C is added

Situation 2: A is combined with C and then B is added

In both situations, the reaction of the first two chemicals is allowed to reach equilibrium before the next is added and then final mixture is then allowed to reach equilibrium.

Situation 1

Situation 2

- | | |
|--------------------|-----------------|
| A) $[A-B] > [A-C]$ | $[A-B] > [A-C]$ |
| B) $[A-B] < [A-C]$ | $[A-B] < [A-C]$ |
| C) $[A-B] = [A-C]$ | $[A-B] = [A-C]$ |
| D) $[A-B] > [A-C]$ | $[A-B] < [A-C]$ |
| E) $[A-B] < [A-C]$ | $[A-B] > [A-C]$ |

- ☐ A
- ☐ B
- ☐ C
- ☐ D

6) The reaction below describes the combination of A and B to give C, a desired synthetic product. C can be readily isolated from reaction mixtures containing A and B. To drive the reaction to completion, a large excess of A was added to the reaction. What happens to K when the additional A is added?



- ☐ K increases
- ☐ K stays the same
- ☐ K decreases

Did you find that use of the Frustrated Lewis Pair chemistry in our discussion of main group chemistry helped you to better understand certain concepts in fundamental chemical thermodynamics? Any feedback you can give about how or why would be greatly appreciated.

Your answer

Submit

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