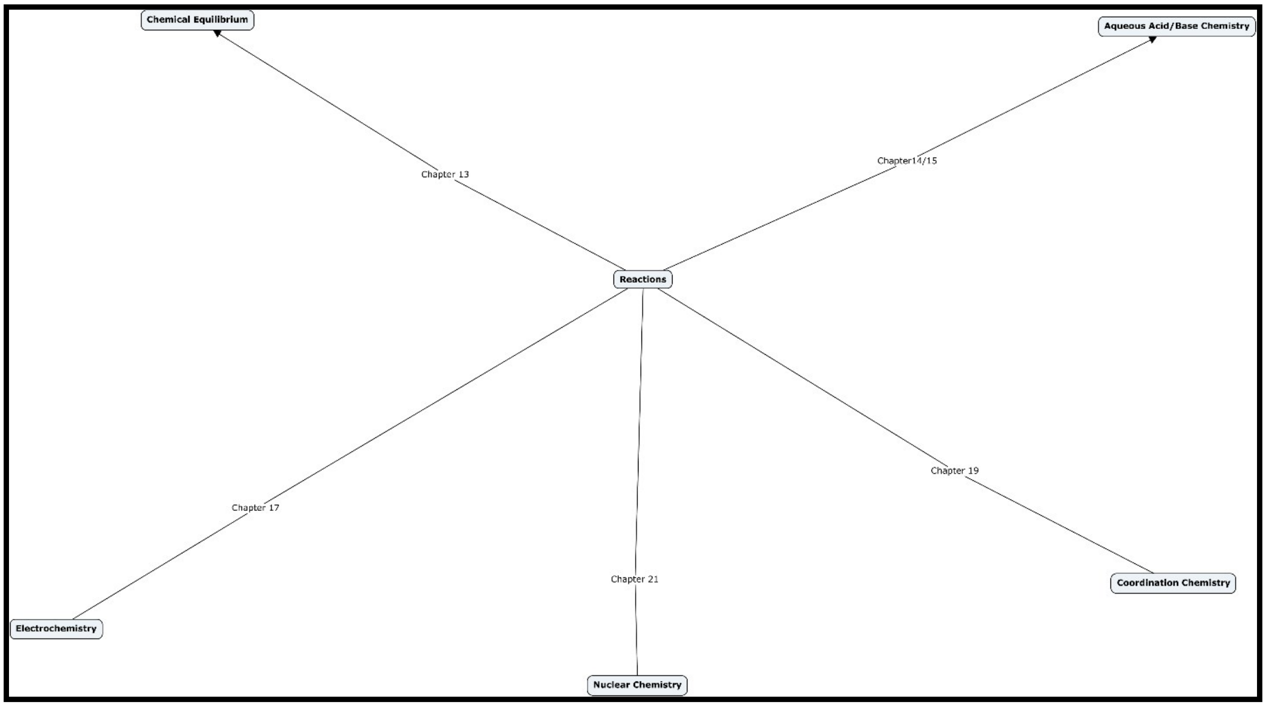
Appendix 1: Concept Map provided as outline for Spring 2018 implementation



Appendix 2: Instructor notes and concept inventory.

A. Instructor Notes

Overview

Studies of previous concept map implementation require significant training for both instructors and TAs for successful learning. This is an instructor's guide for the streamlined implementation of the concept map assignment. The primary objectives for this technique are:

1) Improved conceptual understanding of course material.
2) Student appreciation of chemistry concepts and how they relate to material inside and outside of the course.

Concept Map implementation

Students should be provided with instruction of how to use and develop concept maps. For our implementation, the Cmap program was utilized and an instructional video was provided to show students the basic tools of the program. Cmap is a free program which can be downloaded at **https://cmap.ihmc.us/**. Students should be provided an example of how to develop a concept map. This can be completed as an in class-activity or online assessment. Emphasis should be placed on students feeling comfortable developing a map and using their own words for connecting concepts rather than specific connections provided by the instructor. Informing students that there is no one correct way to link a concept from one to another is important to not prevent unique individual thinking. Providing an example of how to incorrectly link a concept may provide students with an example of the types of errors they should avoid. It may be of benefit to use a non-chemistry topic to facilitate this understanding of concept map development. Students should also be encouraged to not feel limited to material discussed in only the chemistry course as they are most likely taking other STEM related subjects. Students can and should feel free to add connections between these STEM subjects and chemistry to help students build a broader map of how the STEM fields connect. Collection of the concept maps in our implementation was done through ilearn (blackboard) recitation sections. The student saved the concept maps as .pdf files and uploaded these to weekly discussion folders. Set-up of this can be completed by the instructor or TA depending on who will be reviewing the concept maps for review and grading.

Concept Map Assignment and Grading

The concept map assignment should run the length of the course. Students should be encouraged to develop concept maps weekly as both study material and as review of the weekly material. As students develop this concept map, it is important to stress that the action of building a concept map is a form of studying and a great study tool for midterms or quizzes throughout the course. By the end of the course students should have a complete comprehensive map which is a great study tool for the concepts on the final exam. Students and TAs can have been shown to have significant pushback on the concept map assignment. Additionally, a subjective grading scheme is likely to deter students from completing concept maps as they may not know what to do to receive points. As such, less pushback was observed if the concept map assignment if it is given as an extra credit assignment. This approach provides students with an incentive to complete the assignment for both their grade and improved conceptual understanding.

For TAs, it is important that the TAs are proficient in understanding how to develop concept maps. This should not require more than an hour of discussion of what the concept maps are and how students will be developing them. Provide the TAs with a completed concept map so they can reference important connections but be sure the emphasize that there are other possible correct answers. The TAs can use these concept maps to review student concept maps to determine which concepts may be important for further discussion in subsequent recitations or lectures.

If assessment of these concepts is desired, a less subjective method should be implemented. One such example would be the use of close-ended questions about the concepts for the week. The completion of the concept map should be tied to the questions in this assessment to encourage completion of the concept mapping assignment.

In-class review and discussion

The concept map assignment is designed for easy implementation into current and existing instructors teaching styles. Following review of the concept maps that are turned in each week, concepts which students are having a particularly difficult time determining connections for will become apparent. Once these concepts are identified, these concepts should be discussed further. This can be accomplished in either the subsequent lecture or is TA led recitation sections. The TA/instructor should not provide students with the answer but pose questions which will lead to student discussion and deepen understanding of the concepts. After a few weeks of concept map development by the students, or after the first exam, students should be shown an instructor completed concept map (completed by instructor is preferred). This will reinforce where they should be with their concept maps and provide students once more with confidence that what they are working on is correct or the areas they need to improve. This does not have to be completed over an entire class period, but rather a short 5 to 10-minute discussion as to provide confidence to the students in their concept mapping skills.

B. Concept Inventory

1. In a galvanic cell in which the following spontaneous reaction takes place, what process occurs at the cathode?

$3\ Ce^{4+}(aq) + Cr(s) \rightarrow 3\ Ce^{3+}(aq) + Cr^{3+}(aq)$

(a) Reduction of $Cr^{3+}(aq)$
(b) Reduction of $Ce^{4+}(aq)$
(c) Reduction of Cr(s)
(d) Reduction of $Ce^{3+}(aq)$

2. At 445°C, K_c for the following reaction is 0.020.

$$2HI(g) \rightleftharpoons H_2(g) + I_2(g)$$

A mixture of H_2, I_2, and HI in a vessel at 445°C has the following concentrations: [HI] = 2.0 M, $[H_2]$ = 0.50 M and $[I_2]$ = 0.10 M. Which one of the following statements concerning the reaction quotient, Q_c, is **TRUE** for the above system?

(a) $Q_c = K_c$; the system is at equilibrium.
(b) Q_c is less than K_c; more H_2 and I_2 will be produced.
(c) Q_c is less than K_c; more HI will be produced.
(d) Q_c is greater than K_c; more H_2 and I_2 will be produced.
(e) Q_c is greater than K_c; more HI will be produced.

3. For a specific reaction, which of the following statements can be made about K_c, the equilibrium constant?

(a) It always remains the same at different reaction conditions unless the temperature is changed.
(b) It changes with changes in pressure.
(c) It increases if the concentration of one of the products is increased.
(d) It increases if the concentration of one of the reactants is increased.
(e) It may be changed by the addition of a catalyst.

4. Consider the equilibrium system:

$$2ICl(s) \rightleftharpoons I_2(s) + Cl_2(g)$$

Which of the following changes will increase the total amount of of Cl_2 that can be produced?
(a) removing some of the $I_2(s)$
(b) adding more ICl(s)
(c) removing the Cl_2 as it is formed
(d) decreasing the volume of the container

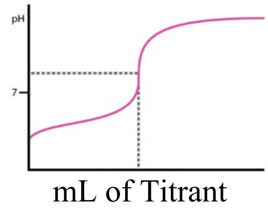
5. Which of the following would you predict to be the strongest acid?
(a) H_2SO_3; K_a=1.54 x 10^{-2}
(b) HNO_2; K_a =4.0 x 10^{-4}
(c)CH_3COOH; K_a =1.76 x 10^{-5}
(d) HF; K_a =7.2 x 10^{-4}
(e) HIO_3; K_a =1.6 x 10^{-1}

6. Which of the following solutions has the lowest pH at 25°C?
(a) 0.2 M sodium hydroxide K_a =1 x 10^{-13}
(b) 0.2 M hypochlorous acid K_a =2.9 x 10^{-8}
(c) 0.2 M ammonia K_a =5.8 x 10^{-10}
(d) 0.2 M benzoic acid K_a =6.3 x 10^{-5}
(e) pure water K_a =1 x 10^{-7}

7. Which of the following statements would be **TRUE** if an aqueous base was added to pure water? The self-dissociation constant for water is provided: $K_w = [OH^-][H_3O^+]$
(a) The self-dislocation constant for water (K_w) would decrease.
(b) The concentration of H_3O^+ would decrease.
(c) The concentration of OH^- would decrease.
(d) There would be no change in the concentration of H_3O^+ or OH^-.

8. Consider a 1.0 L solution which is 0.10 M in CH_3COOH and 0.20 M in $NaCH_3COO$. Which of the following statements is **TRUE**?
(a) If a small amount of NaOH is added, the pH decreases very slightly.
(b) If NaOH is added, the OH^- ions react with the CH_3COO^- ions.
(c) If less than 0.10 moles of HCl added the pH will change slightly.
(d) If HCl is added, the H^+ ions react with CH_3COOH ions.
(e) If more CH_3COOH is added, the pH increases.

9. The following titration curve is the kind of curve expected for the titration of a ____ acid with a ____ base.

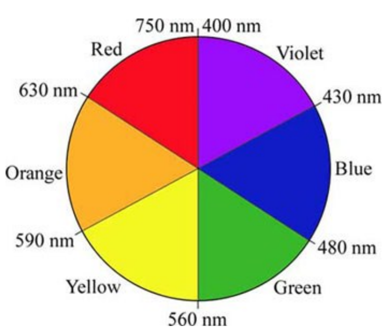


(a) strong, strong
(b) weak, strong
(c) strong, weak
(d) weak, weak

10. If you use x to represent the molar concentration of silver(I) and y to represent the molar concentration of sulfide, the solubility product expression for solid silver(I) sulfide (Ag_2S) is formulated as:
(a) xy
(b) x^2y
(c) xy^2
(d) x^2y^2
(e) xy^3

11. In coordination chemistry, the donor atom of a ligand is
(a) a Lewis acid.
(b) the counter ion
(c) the central metal atom/ion.
(d) the atom in the ligand that shares an electron pair with the metal.
(e) the atom in the ligand that accepts an electron pair from the metal.

12. (Crystal Field Theory) Consider the violet-colored compound, $[Cr(OH_2)_6]Cl_3$ and the yellow compound, $[Cr(NH_3)_6]Cl_3$. Which of the following statements is **TRUE**?



(a) Δ_{oct} for $[Cr(OH_2)_6]^{3+}$ is greater than Δ_{oct} for $[Cr(NH_3)_6]^{3+}$.
(b) Δ_{oct} for $[Cr(NH_3)_6]^{3+}$ is related directly to the energy of violet light.
(c) Δ_{oct} for $[Cr(OH_2)_6]^{3+}$ is related directly to the energy of violet light.
(d) A solution of $[Cr(OH_2)_6]Cl_3$ absorbs light with an approximate wavelength range of 400 - 430 nm.

13. What is the oxidation number of the central metal atom in the coordination compound $[Pt(NH_3)_3Cl]Cl$?

(a) -1
(b) 0
(c) +1
(d) +2
(e) +3

14. Which of the following describes what occurs in the fission process?

(a) A heavy nucleus is fragmented into lighter ones.
(b) A neutron is split into a neutron and proton.
(c) Two light nuclei are combined into a heavier one.
(d) A proton is split into three quarks.
(e) A particle and anti-particle appear in an area of high energy density.

15. Consider the case of a radioactive element X which decays by electron (beta) emission with a half-life of 4 days to a stable nuclide of element Z. Which of the following statements is **CORRECT**?

$${}^{a}_{b}X \rightarrow {}^{a}_{b+1}Z + \text{beta particle} \qquad (a = \text{mass number}; b = \text{atomic number})$$

(a) After 8 days the sample will consist of one-fourth element Z and three-fourths element X by mass.
(b) 2.0 g of element X would be required to produce 1.0 g of element Z after 8 days.
(c) There would be equal masses of X and Z after 8 days.
(d) After 8 days there would be 0 g of element X present.

16. What is the other product produced in the following nuclear reaction?

$${}^{238}U \rightarrow {}^{234}Th + \_\_\_\_\_\_\_\_\_\_$$

(a) a helium-4 nucleus
(b) an electron
(c) a gamma particle
(d) a positron particle

Appendix 3: Item analysis for concept inventory.

Question	Mean	Std. Deviation	N
Q1	0.855	0.352	242
Q2	0.620	0.486	242
Q3	0.529	0.500	242
Q4	0.479	0.501	242
Q5	0.393	0.489	242
Q6	0.719	0.450	242
Q7	0.851	0.357	242
Q8	0.719	0.450	242
Q9	0.603	0.490	242
Q10	0.500	0.501	242
Q11	0.715	0.452	242
Q12	0.401	0.491	242
Q13	0.822	0.383	242
Q14	0.851	0.357	242
Q15	0.674	0.470	242
Q16	0.773	0.420	242

Appendix 4: Item-total correlation for concept inventory.

Question	Corrected Item-Total Correlation	Cronbach's Alpha if Item Deleted
Q1	0.365	0.614
Q2	0.319	0.616
Q3	0.373	0.607
Q4	0.241	0.628
Q5	0.065	0.654
Q6	0.236	0628
Q7	0.128	0.641
Q8	0.243	0.627
Q9	0.144	0.643
Q10	0.110	0.648
Q11	0.232	0.629
Q12	0.206	0.633
Q13	0.368	0.612
Q14	0.310	0.620
Q15	0.384	0.606
Q16	0.407	0.605

Appendix 5: Stratified alpha reliability coefficient for concept inventory.

Stratified Alpha (α_s) = 1-[Σ(variance of each item)(1- α_i)]/(variance of all items)
0.661 (n = 16; variance of all test items = 8.13)
Test Item Concept Dimensions (α and variance of each dimension)
Items 1, 13 (Electrochemistry); α_i = 0.344; variance = 0.327
Items 2-4, 10 (Equilibrium); α_i = 0.285; variance = 1.26
Items 5-9 (Acid-base Chemistry); α_i = 0.454; variance = 1.59
Items 11-12 (Coordination Chemistry); α_i = 0.429; variance = 0.567
Items 14-16 (Nuclear Chemistry); α_i = 0.348; variance = 0.683

Appendix 6: ANOVA analyses; comparison of concept map inventory pre-test scores, math SAT scores, and high school GPA between selected groups.

Concept Map Treatment vs. Journal Control	***F***	***p***	**Partial *η2* effect size**
Concept Inventory Pre-test Dependent Variable	2.73	0.100	0.0120
SAT Math Dependent Variable	6.68	< 0.05	0.0320
High School GPA Dependent Variable	0.753	0.386	0.00300

Appendix 7: Correlations of independent variables included in the multiple regression analysis in which the impact of the concept inventory post-test performance of the concept map treatment group was compared ot the journal control group (analysis shown in Table 5 of the main manuscript).

Correlations						
		Posttest	Class	HighschoolGPA	SATmath	Pretest
Pearson Correlation	Posttest	1.00	0.143	0.00800	0.499	0.317
	Class	0.143	1.00	0.102	0.198	0.0840
	HighschoolGPA	0.00800	0.102	1.00	-0.0630	0.0820
	SATmath	0.499	0.198	-0.0630	1.00	0.282
	Pretest	0.317	0.0840	0.0820	0.282	1.00
Sig. (1-tailed)	Posttest	n/a	0.0230	0.457	0.000	0.000
	Class	0.023		0.0780	0.00300	0.123
	HighschoolGPA	0.457	0.0780	n/a	0.190	0.127
	SATmath	0.000	0.00300	0.190	n/a	0.000
	Pretest	0.000	0.123	0.127	0.000	n/a

Appendix 8: Multiple regression analysis carried out for post-hoc power analysis, in which the class treatment independent variable was removed.[a] The difference in R^2 compared to the full model was used to estimate the f^2 effect size index; f^2 = change in $R^2/(1-R^2)$. The function of the effect size index and the non-centrality parameter (λ) was used to estimate the power from Cohen's power tables at $\alpha = 0.05$ (Table 9.3.2, Cohen, 1988); $\lambda = (u + v + 1)$, where u = # independent variables in the model and v = degrees of freedom ($v = N - u - w - 1$); N = sample size and w = #independent variables in the model without the treatment independent variable. $f^2 = (0.285\text{-}0.284)/(1\text{-}0.285) = 0.0014$; $v = 115 - 4 - 3 - 1 = 107$; $\lambda = (4 + 107 + 1) = 0.16$; therefore if $u = 4$, $\lambda = 0.16$, and $v = 97$ the power is estimated to be ≈ 0.05 (if $\lambda < 2$, the power is estimated to equal α at all values of u).

	Unstandardized Coefficients		**Standardized Coefficients**		
	b	**Std. Error**	***Beta***	***t***	***p***
Constant	-1.27	2.89		-0.439	0.661
High School GPA	0.221	0.668	0.0200	0.331	0.741
SAT Math	0.016	0.002	0.447	6.97	< 0.001
Concept inventory pre-test	0.236	0.080	0.190	2.96	< 0.05

[a]$R = 0.533$; $R^2 = 0.284$; adjusted $R^2 = 0.272$; Standard error of the estimate = 2.46

Appendix 9: Multiple regression analysis carried out for post-hoc power analysis, in which the concept map rubric score independent variable was removed.[a] The difference in R^2 compared to the full model was used to estimate the f^2 effect size index; f^2 = change in $R^2/(1-R^2)$. The function of the effect size index and the non-centrality parameter (λ) was used to estimate the power from Cohen's power tables at $\alpha = 0.05$ (Table 9.3.2, Cohen, 1988); $\lambda = (u + v + 1)$, where u = # independent variables in the model and v = degrees of freedom ($v = N - u - w - 1$); N = sample size and w = #independent variables in the model without the rubric score independent variable. $f^2 = (0.344-0.324)/(1-0.344) = 0.031$; $v = 100 - 4 - 3 - 1 = 92$; $\lambda = (4 + 92 + 1) = 2.98$; therefore if u = 4, $\lambda = 2.98$, and v = 92 the power is estimated to be ≈ 0.24 at $\alpha = 0.05$.

	Unstandardized Coefficients		**Standardized Coefficients**		
	b	**Std. Error**	***Beta***	***t***	***p***
Constant	-0.978	4.339		-0.225	0.822
High School GPA	0.436	1.014	0.0420	0.430	0.668
SAT Math	0.015	0.003	0.465	4.52	< 0.001
Concept inventory pre-test	0.212	0.107	0.205	1.99	0.0510

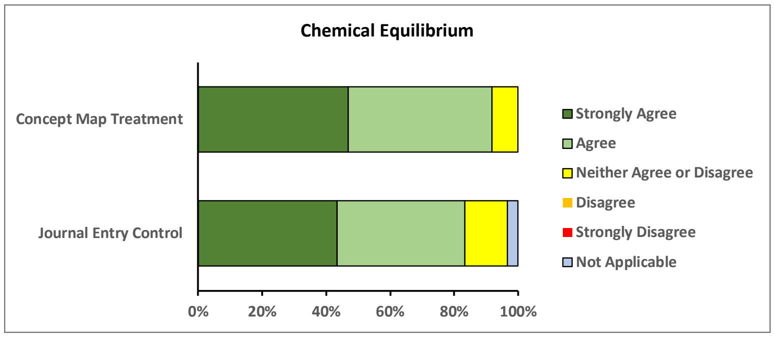
[a]R = 0.569; $R^2 = 0.324$; adjusted $R^2 = 0.296$; Standard error of the estimate = 2.23

Appendix 10: Summaries of Liker-scale averages and standard deviations for pre- and post-SALG questions analyzed for the concept map treatment and journal entry control groups.

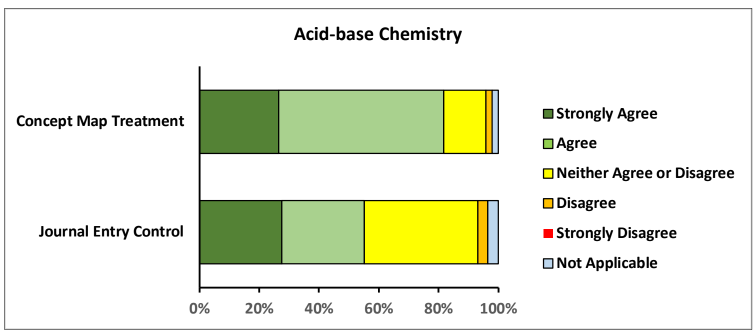
Question	Concept pre-SALG	Concept post-SALG	Journal pre-SALG	Journal post-SALG
1. Chemical Equilibrium.	4.0 +/ - 1.0	4.4 +/- 0.6	3.9 +/- 1.0	4.3 +/- 0.7
2. Acid Base Chemistry.	3.6 +/- 1.0	4.1 +/- 0.7	3.3 +/- 0.9	3.8 +/- 0.9
3. How ideas we will explore in this class relate to ideas I have encountered in other classes within this subject area.	4.0 +/- 0.8	4.2 +/- 0.8	4.0 +/- 1.0	3.9 +/- 0.9
4. How ideas we will explore in this class relate to ideas I have encountered in classes outside of this subject area.	3.6 +/- 0.9	4.1 +/- 1.0	3.6 +/- 1.0	4.1 +/- 0.9
5. How studying this subject helps people address real world issues.	4.0 +/- 1.0	4.3 +/- 0.7	4.0 +/- 1.3	4.2 +/- 0.9
6. Connecting key ideas I learn in my classes with other knowledge.	4.1 +/- 0.9	4.0 +/- 0.8	4.0 +/- 1.0	3.8 +/- 0.9
7. Applying what I learn in classes to other situations.	4.1 +/- 0.9	3.8 +/- 0.9	4.0 +/- 1.0	3.8 +/- 1.0
8. Using systematic reasoning in my approach to problems.	4.5 +/- 0.9	3.9 +/- 0.9	4.3 +/- 0.9	3.8 +/- 1.0
9. Feel(ing) comfortable working with complex ideas.	4.2 +/- 0.9	3.9 +/- 1.0	4.1 +/- 1.0	4.0 +/- 0.9

Appendix 11: Post-SALG responses to SALG questions: A) #1; B) #2; C) #7; D) #8; E) #9. Post-SALG sample sizes: treatment = 49, control = 30.

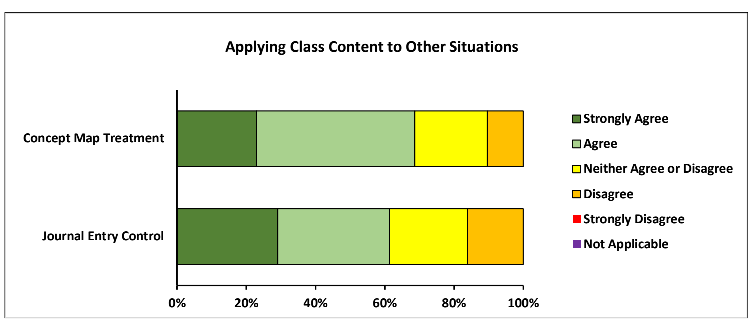
A



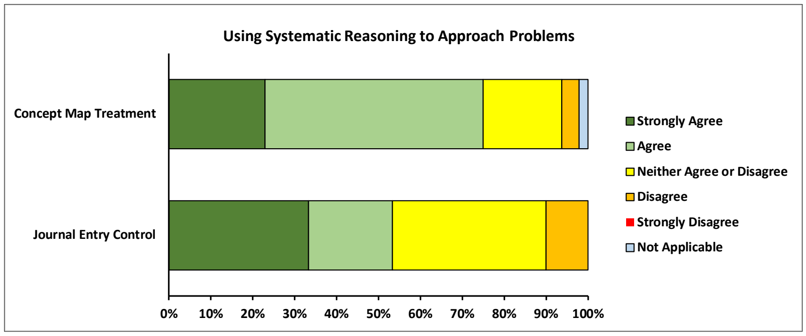
B



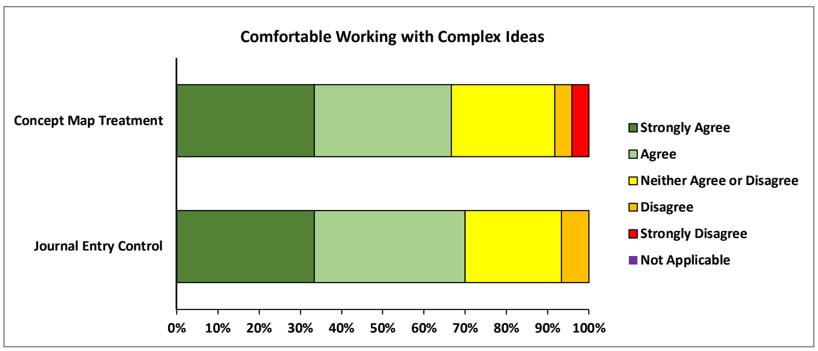
C



D


Using Systematic Reasoning to Approach Problems
Concept Map Treatment
Journal Entry Control
0%
10%
20%
30%
40%
50%
60%
70%
80%
90%
100%
Strongly Agree
Agree
Neither Agree or Disagree
Disagree
Strongly Disagree
Not Applicable

E


Comfortable Working with Complex Ideas
Concept Map Treatment
Journal Entry Control
0%
10%
20%
30%
40%
50%
60%
70%
80%
90%
100%
Strongly Agree
Agree
Neither Agree or Disagree
Disagree
Strongly Disagree
Not Applicable

Appendix 12: The percentage of students who made gains from pre- to post-SALG plotter versus the number of questions in which gains were made (out of a total of 9 questions. The number of respondents for both the pre- and post-SALG was: treatment = 36; control = 18.