Appendix A: Activity sheet for the Light Guidance condition

Recitation Activity: PhET Simulation

Explore the simulation with a partner. Record at least 10 observations below. Make sure to investigate all of the factors that affect the pH of a solution.

Appendix B: Activity sheet for the Moderate Guidance condition

Recitation Activity: PhET Simulation

I. Explore the simulation with a partner. Record some of your observations below.

II. Use the Introduction tab to compare **strong** and **weak** acid solutions.

1. Describe all the ways that strong and weak acid solutions are similar and different, and explain why that makes sense using evidence from the simulation.

2. Does the pH of an acid solution measure the strength of the acid? Explain your reasoning.

III. Use the Custom Solution tab to explore acid **concentration** and **strength**.

1. Describe all the ways that the initial acid concentration affects the solution and the measured pH, and explain why that makes sense using evidence from the simulation.

2. Describe all the ways that the acid strength affects the solution and the measured pH, and explain why that makes sense using evidence from the simulation.

3. Reconsider your answer to the question: "Does the pH of an acid solution measure the strength of the acid?" Use evidence from the simulation to support your answer.

Appendix C: Activity sheet for the Heavy Guidance condition

Recitation Activity: PhET Simulation

Part I: Strong and Weak Acids

1. Work on this activity with a partner.
2. Open the simulation on your computer.
3. Make sure you are on the "Introduction" tab. You should see a beaker of water with a magnifying glass and a control panel on the right side of the screen.
4. In the "Solutions" section of the control panel, select "Strong Acid."
5. Record the equation. **Strong Acid Equation:**

6. In the "Views" section of the control panel, make sure "Molecules" is selected.
7. Describe the "Molecules" view in the box below.
8. In the "Views" section of the control panel, select "Equilibrium Concentration."
9. Describe the "Equilibrium Concentration" view in the box below.

Molecules View: Strong Acid

Equilibrium Concentration View: Strong Acid

10. Dip the pH meter into the solution.
11. Record the pH. **Strong Acid pH** =

12. In the “Solutions” section of the control panel, select “Weak Acid.”
13. Record the equation. **Weak Acid Equation:**

14. In the “Views” section of the control panel, make sure “Molecules” is selected.
15. Describe the “Molecules” view in the box below.
16. In the “Views” section of the control panel, select “Equilibrium Concentration.”
17. Describe the “Equilibrium Concentration” view in the box below.

Molecules View: Weak Acid

Equilibrium Concentration View: Weak Acid

18. Dip the pH meter into the solution.
19. Record the pH. **Weak Acid pH** =

20. List two ways that strong and weak acid solutions are different.

Part II: Concentration and Strength

1. Click on the "Custom Solution" tab near the top of the screen. You should see sliders in the control panel on the right side of the screen.
2. In the "Solution" section of the control panel, make sure "Acid" is selected.
3. Change the "Strength" option to "strong."
4. In the "Views" section of the control panel, select "Equilibrium Concentration."
5. Set the "Initial Concentration" to 0.004 mol/L.
6. Use the "Equilibrium Concentration" view to record the concentrations of [HA], [A-], and [H_3O+] in the table below.
7. Dip the pH meter into solution and record pH in the table below.
8. Set the "Initial Concentration" to 0.030 mol/L and repeat steps 6 and 7.
9. Set the "Initial Concentration" to 0.200 mol/L and repeat steps 6 and 7 to complete the table.

Strong Acids

Initial Concentration (mol/L)	[HA] (mol/L)	[A-] (mol/L)	[H_3O+] (mol/L)	pH
0.004				
0.030				
0.200				

10. Based on the data you gathered, describe how the initial concentration of a strong acid affects the solution pH.

11. Change the “Strength” option to “weak.” You should see a slider appear in the “Strength” part of the control panel.
12. Make sure the “Strength” slider is set to the 1/4 point, closer to the weaker side of the slider. It is OK for this value to be approximate.
13. Set the “Initial Concentration” to 0.030 mol/L.
14. Use the “Equilibrium Concentration” view to record the concentrations of [HA], [A-], and [H_3O+] in the table below.
15. Dip the pH meter into solution and record pH in the table below.
16. Move the “Strength” slider to the 1/2 point and repeat steps 14 and 15.
17. Move the “Strength” slider to the 3/4 point, closer to the stronger side of the slider, and repeat steps 14 and 15 to complete the table.

Weak Acids

Strength (approximately)	[HA] (mol/L)	[A-] (mol/L)	[H_3O+] (mol/L)	pH
1/4 point				
1/2 point				
3/4 point				

18. Based on the data you gathered, describe how the strength of a weak acid affects the solution pH.

19. List two ways that a weak acid solution can have the same pH as a strong acid solution.

20. Close the simulation and wait for TA instruction.

Appendix D: Statistical Analyses of Simulation Features Used and Drawn

Statistical Analysis of Simulation Features Used

Student click data for the simulation features used were tested for normality using the Shapiro-Wilk test (Shapiro and Wilk, 1965), which indicated that the data were not normally distributed. Non-parametric statistical analyses using contingency tables were used to evaluate the significance of the differences between groups for number of features used for three feature categories: "All Features", for $N_F = 18$ for all levels of guidance; "Exploratory Features", where N_F varied between groups (LG=18, MG=12, HG=10); and "Prompted Features", where N_F again varied between groups (LG=0, MG=6, HG=8). For the feature categories where N_F was not equal between groups, the number of features was normalized as a ratio of number used to number possible and groups were compared by bins at increments of 0.1.

All Features

Table 1. Contingency table showing observed counts (O) and calculated expected values (E) for number of overall features used in the Acid-Base Solutions simulation. The total number of features is denoted by N_F (maximum: 18). The number of student groups that used N_F features appears in the column O_{LG} for the Light Guidance group, O_{MG} for the Medium Guidance group, and O_{HG} for the Heavy Guidance group. The sum of these columns appears in column O_T. The expected number of student groups with N_F features used appears in column E_{LG} for Light Guidance, E_{MG} for Medium Guidance, and E_{HG} for Heavy Guidance. The sum of these columns appears in column E_T.

N_F	O_{LG}	O_{MG}	O_{HG}	O_T
8	2	1	22	25
9	0	2	4	6
10	1	0	2	3
11	0	2	0	2
12	1	5	1	7
13	2	6	3	11
14	2	5	1	8
15	5	3	0	8
16	4	6	0	10
17	12	4	0	16
18	11	6	0	17
n=	40	40	33	113

N_F	E_{LG}	E_{MG}	E_{HG}	E_T
8	8.850	8.850	7.301	25
9	2.124	2.124	1.752	6
10	1.062	1.062	0.876	3
11	0.708	0.708	0.584	2
12	2.478	2.478	2.044	7
13	3.894	3.894	3.212	11
14	2.832	2.832	2.336	8
15	2.832	2.832	2.336	8
16	3.540	3.540	2.920	10
17	5.664	5.664	4.673	16
18	6.018	6.018	4.965	17

If the level of guidance had no effect on how many of the 18 features were used, we expect that the fraction of events in a given row is the same regardless of guidance level. A chi-squared analysis with the expectation values gives a chi-squared statistic of 91.79 with a reduced chi-square of 4.590. The critical value, for which we find our reduced statistic to be above, is $X^2_{crit}/\nu = 2.375$. The *p*-value for our observed reduced chi-square statistic is less than 0.0005, indicating that the level of guidance affected the total number of features students used.

Exploratory Features

Table 2. Contingency table showing observed feature use ratio (O) and calculated expected values (E) for number of "Exploratory" features used in the Acid-Base Solutions simulation. The feature use ratio is denoted by R_F (range of 0-1). The number of student groups that used R_F features appears in the column O_{LG} for the Light Guidance group, O_{MG} for the Medium Guidance group, and O_{HG} for the Heavy Guidance group. The sum of these columns appears in column O_T. The expected number of student groups with R_F features used appears in column E_{LG} for Light Guidance, E_{MG} for Medium Guidance, and E_{HG} for Heavy Guidance. The sum of these columns appears in column E_T.

R_F	O_{LG}	O_{MG}	O_{HG}	O_T		R_F	E_{LG}	E_{MG}	E_{HG}	E_T
0	0	0	22	22		0	7.788	7.788	6.425	22
0.1	0	0	4	4		0.1	1.416	1.416	1.168	4
0.2	0	0	2	2		0.2	0.708	0.708	0.584	2
0.3	0	2	0	2		0.3	0.708	0.708	0.584	2
0.4	0	0	1	1		0.4	0.354	0.354	0.292	1
0.5	2	5	3	10		0.5	3.540	3.540	2.920	10
0.6	1	5	1	7		0.6	2.478	2.478	2.044	7
0.7	1	9	0	10		0.7	3.540	3.540	2.920	10
0.8	4	2	0	6		0.8	2.124	2.124	1.752	6
0.9	9	6	0	15		0.9	5.310	5.310	4.381	15
1	23	11	0	34		1	12.035	12.035	9.929	34
n=	40	40	33	113						

If the level of guidance had no effect on the ratio (and relative number) of "Exploratory" features used, we expect that the fraction of events in a given row is the same regardless of guidance level. A chi-squared analysis with the expectation values gives a chi-squared statistic of 122.8 with a reduced chi-square of 6.142. The critical value, for which we find our reduced statistic to be above, is $X^2_{crit}/\nu = 2.375$. The *p*-value for our observed reduced chi-square statistic is less than 0.0005, indicating that the level of guidance affected the number of "Exploratory" features students used.

Prompted Features

Table 3. Contingency table showing observed feature use ratio (O) and calculated expected values (E) for number of "Prompted" features used in the Acid-Base Solutions simulation. The feature use ratio is denoted by R_F (range of 0-1; R_F bins with a count of 0 are not shown). The number of student groups that used R_F features appears in the column O_{MG} for the Medium Guidance group, and O_{HG} for the Heavy Guidance group. (Note that the LG group did not have any "Prompted" features.) The sum of these columns appears in column O_T. The expected number of student groups with R_F features used appears in column E_{MG} for Medium Guidance, and E_{HG} for Heavy Guidance. The sum of these columns appears in column E_T.

R_F	O_{MG}	O_{HG}	O_T		R_F	E_{MG}	E_{HG}	E_T
0.7	1	0	1		0.7	0.55	0.45	1
0.9	12	0	12		0.9	6.58	5.42	12
1	27	33	60		1	32.88	27.12	60
n=	40	33	73					

If the level of guidance had no effect on the ratio (and relative number) of "Prompted" features used, we expect that the fraction of events in a given row is the same regardless of guidance level. A chi-squared analysis with the expectation values gives a chi-squared statistic of 13.05 with a reduced chi-square of 3.262 The critical value, for which we find our reduced statistic to be above, is $X^2_{crit}/\nu = 2.918$. The *p*-value for our observed reduced chi-square statistic is less than 0.02, indicating that the level of guidance affected the number of "Prompted" features students used.

Statistical Analysis of Features Drawn in the Simulation Recreation Task

Student drawing data were tested for normality (Shapiro and Wilk, 1965). The Shapiro-Wilk test indicated that the coded results from student drawings were not normally distributed for all groups. Similarly to the simulation event data, non-parametric statistical analyses using contingency tables were utilized to evaluate the significance of the differences between groups based on the number of features students drew.

Drawn Features

Table 5. Contingency table showing observed counts (O) and calculated expected values (E) for the number of simulation features that students drew in the simulation recreation task. The total number of features is denoted by N_F (maximum possible was 17, maximum coded in any one student drawing was 16). The number of student groups that drew N_F features appears in the column O_{LG} for the Light Guidance group, O_{MG} for the Medium Guidance group, and O_{HG} for the Heavy Guidance group. The sum of these columns appears in column O_T. The expected number of student groups with N_F features drawn appears in column E_{LG} for Light Guidance, E_{MG} for Medium Guidance, and E_{HG} for Heavy Guidance. The sum of these columns appears in column E_T.

If the level of guidance had no effect on how many of the 17 possible features were drawn, we expect that the fraction of events in a given row is the same regardless of guidance level. A chi-squared analysis with the expectation values gives a chi-squared statistic of 44.92 with a reduced chi-square of 1.497. The critical value, for which we find our reduced statistic to be above, is $X^2_{crit}/\nu = 1.459$. The *p*-value for our observed reduced chi-square statistic is less than 0.05, indicating that the level of guidance affected the total number of features students drew the week following the simulation activity.

N_F	O_{LG}	O_{MG}	O_{HG}	O_T
1	1	1	0	2
2	1	1	0	2
3	2	0	0	2
4	2	4	3	9
5	4	5	4	13
6	5	7	7	19
7	3	11	8	22
8	8	6	14	28
9	9	7	8	24
10	3	13	4	20
11	10	6	5	21
12	7	4	0	11
13	4	1	0	5
14	4	2	0	6
15	2	0	1	3
16	1	0	0	1
n=	66	68	54	188

N_F	E_{LG}	E_{MG}	E_{HG}	E_T
1	0.702	0.723	0.574	2
2	0.702	0.723	0.574	2
3	0.702	0.723	0.574	2
4	3.160	3.255	2.585	9
5	4.564	4.702	3.734	13
6	6.670	6.872	5.457	19
7	7.723	7.957	6.319	22
8	9.830	10.128	8.043	28
9	8.426	8.681	6.894	24
10	7.021	7.234	5.745	20
11	7.372	7.596	6.032	21
12	3.862	3.979	3.160	11
13	1.755	1.809	1.436	5
14	2.106	2.170	1.723	6
15	1.053	1.085	0.862	3
16	0.351	0.362	0.287	1

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