Supplemental Material

CBE—Life Sciences Education

Gauthier *et al.*

Supplementary Materials

Molecular Concepts Adaptive Assessment (MCAA) characterizes undergraduate misconceptions about molecular emergence

Authors: Andrea Gauthier, Stuart Jantzen, Gaël McGill, Jodie Jenkinson

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EXPERIMENT 1

Focus group discussion guide

"Were there any questions from the first half (science literacy) that you had problems with?" (display questions)

"From the second half (the molecular questions), what are your general impressions or thoughts?"

"How would you describe a molecule? What falls under the category of molecule?"

"What is meant by the term 'random' movement? What is meant by the term 'directed' movement?"

"To what extent and under what conditions is the movement of a molecule directed (rather than random)?"

"How did you feel about providing your confidence on responses? Was that difficult to do?"

Walk through subset of questions and have students discuss their opinions on each one.

When a question subset is displayed: "Depending on how you answered certain questions, you may have seen other questions specific to that response (e.g. if you saw the question 'A molecule knows the location of its receptor' and answered True, then you would see 'How does a molecule know the location of its receptor')."

***NOTE**: Focus group transcripts are provided at the end of this document due to their length.*

Effect size interpretation guide

Table 1. Interpretation guide for effect sizes used in this study.

			Typical interpretation of effect		
Metric	**Symbol**	**Data type/analysis**	**Small**	**Medium**	**Large**
Eta-squared[1]	η^2	Between-subjects comparisons of non-parametric continuous data	0.01	0.06	0.14
Phi[2]	Φ	Between-subjects comparisons of categorical data	0.1	0.3	0.5
Partial eta-square[1]	η_p^2	Between-subjects comparisons of parametric continuous data within analyses of variance	0.01	0.06	0.14
Correlation coefficient[1]	r_{cc}	Within-subjects (repeated measures) comparisons of non-parametric continuous data	0.1	0.3	0.5
Odds ratio[5]	OR	Within-subjects (repeated measures) comparisons of categorical data	1.5	3.5	9.0

1. (Cohen, 1973, 1988)
2. (Fern & Monroe, 1996; Rosenthal, 1994)
3. (Fleiss, 1994; Kline, 2004)

Holm's Sequential Bonferroni Procedure - E1

Table 2. Holm-Bonferroni (HB) adjusted alphas for 16 comparisons.

Rank	HB-α	Rank	HB-α
1	0.003	9	0.006
2	0.003	10	0.007
3	0.004	11	0.008
4	0.004	12	0.010
5	0.004	13	0.013
6	0.005	14	0.017
7	0.005	15	0.025
8	0.006	16	0.050

Holm-Bonferroni α = Target α / (k - rank +1), where Target α = .050 and k = the number of comparisons

Science literacy

Table 3. Comparison of science literacy scores between first-, second-, and third-year students (Kruskal-Wallis test). Measured at baseline (time of pre-test).

	Mean test score (SD)				
Test	**1st-year**	**2nd-year**	**3rd-year**	**χ^2(df = 2)**	***p***
Science literacy	8.67 (1.29)	9.05 (1.10)	9.17 (1.01)	22.08	< .005 *

* Significance indicated α = .050

Table 4. Post-hoc pairwise comparisons of science literacy test scores between first-, second-, and third-year students (Mann-Whitney U tests), for identified significant tests in **Table 3**.

Test	Pairwise comparison	U	*Z*	*p*	Eta^2	Rank (HB-α)
Science literacy	1st-year vs. 2nd-year	48285.5	-4.16	< .001 *	0.03	1 (.017) *
	1st-year vs. 3rd-year	11772.0	-3.23	.001 *	0.02	2 (.025) *
	2nd-year vs. 3rd-year	9474.5	-0.70	.485	-	-

* Significance indicated at HB-α (based on 3 comparisons at target α = .050)

MCAA results for each answer from Experiment 1

Differences in responses by educational level

Table 5. Pearson Chi-square tests investigating proportional differences in answers between educational levels (first-, second-, and third-year Biology courses) for each MCAA statement in E1.

ID		1st-year: n (%)	2nd-year: n (%)	3rd-year: n (%)	χ^2(df)	*p* (Φ)	Rank (HB-α)
A	✓ Does not hold misconception	63 (14.9%)	47 (17.0%)	20 (27.8%)	7.350 (2)	.025 (0.098)	4 (.004)
	✗ Holds misconception	361 (85.1%)	230 (83.0%)	52 (72.2%)			
B	To bind with a specific molecule of one type of receptor	245 (67.9%)	170 (73.9%)	29 (55.8%)	8.211 (4)	.084	-
	To bind with any molecule of one type of receptor	95 (26.3%)	53 (23.0%)	19 (36.5%)	[11.1% of cells have expected count < 5]		
	To bind with any molecule of a variety of receptor types	21 (5.8%)	7 (3.0%)	4 (7.7%)			
C	✓ Does not hold misconception	114 (31.6%)	73 (31.7%)	31 (59.6%)	16.692 (2)	< .001 * (0.161)	1 (.003) *
	✗ Holds misconception	247 (68.4%)	157 (68.3%)	21 (40.4%)			
D	✓ Does not hold misconception	140 (38.8%)	87 (37.8%)	30 (57.7%)	7.460 (2)	.024 (0.108)	3 (.004)
	✗ Holds misconception	221 (61.2%)	143 (62.2%)	22 (42.3%)			
E	It can sense the receptor from a distance	23 (10.4%)	14 (9.8%)	0 (0.0%)	7.076 (4)	.132	-
	It has "hard-wired" knowledge	43 (19.5%)	18 (12.6%)	2 (9.1%)	[22.2% of cells have expected count < 5]		
	Through interactions when it is close to the receptor	155 (70.1%)	111 (77.6%)	20 (90.9%)			
F	✓ Does not hold misconception	274 (64.6%)	196 (70.8%)	55 (76.4%)	5.510 (2)	.064	-
	✗ Holds misconception	150 (35.4%)	81 (29.2%)	17 (23.6%)			
G	✓ Does not hold misconception	220 (80.3%)	166 (84.7%)	47 (85.5%)	1.909 (2)	.385	-
	✗ Holds misconception	54 (19.7%)	30 (15.3%)	8 (14.5%)			
H	✗ They repel each other	32 (14.5%)	13 (7.8%)	1 (2.1%)	9.199 (4)	.056	-
	✗ They move into less crowded areas	94 (42.7%)	73 (44.0%)	20 (42.6%)	[11.1% of cells have expected count < 5]		
	✓ Entropy increases as they spread out	94 (42.7%)	80 (76.7%)	26 (55.3%)			
I	✓ Does not hold misconception	64 (42.7%)	42 (51.9%)	8 (47.1%)	1.795 (2)	.408	-

	✗ Holds misconception	86 (57.3%)	39 (48.1%)	9 (52.9%)			
J	✓ Does not hold misconception	29 (19.3%)	13 (16.0%)	8 (47.1%)	8.556 (2)	.014 (0.186)	2 (.003)
	✗ Holds misconception	121 (80.7%)	68 (84.0%)	9 (52.9%)	[16.7% of cells have expected count < 5]		
K	✗ The extracellular molecule propels itself	42 (28.0%)	22 (27.2%)	0 (0.0%)	9.171 (4)	.057	-
	✗ The extracellular molecule is released with the correct initial trajectory	50 (33.3%)	22 (27.2%)	5 (29.4%)	[11.1% of cells have expected count < 5]		
	✓ The extracellular molecule collides with other molecules	58 (38.7%)	37 (45.7%)	12 (70.6%)			
L	✗ High proportion of empty space - collisions are infrequent	108 (25.5%)	57 (20.6%)	12 (16.7%)	6.357 (4)	.174	-
	✗ Low proportion of empty space - collisions are frequent	222 (52.4%)	165 (59.6%)	40 (55.6%)			
	✓ Virtually no empty space - collisions are virtually constant	94 (22.2%)	55 (19.9%)	20 (27.8%)			
M	✓ Does not hold misconception	59 (17.9%)	30 (13.5%)	9 (17.3%)	1.910 (2)	.385	-
	✗ Holds misconception	271 (82.1%)	192 (86.5%)	43 (82.7%)			
N	✓ Does not hold misconception	127 (83.0%)	69 (81.2%)	24 (82.8%)	0.129 (2)	.937	-
	✗ Holds misconception	26 (17.0%)	16 (18.8%)	5 (17.2%)			
O	✓ Does not hold misconception	218 (51.4%)	134 (48.4%)	32 (44.4%)	1.489 (2)	.475	-
	✗ Holds misconception	206 (48.6%)	143 (51.6%)	40 (55.6%)			
P	✓ Does not hold misconception	196 (46.2%)	144 (52.0%)	43 (59.7%)	5.511 (2)	.064	-
	✗ Holds misconception	228 (53.8%)	133 (48.0%)	29 (40.3%)			

* Significance indicated at HB-α (based on 16 comparisons at target α = .050)
NOTE: Pearson chi-square results may be invalid where more than 20% of the cells in the cross-tabulation have expected cell counts of less than 5 observations. In tests where all cells had counts greater than 5, no extra information is given.

Table 6. Post-hoc pairwise comparisons between educational levels for significant results in **Table 5**, E1.

Statement ID	Pairwise comparison	χ^2(df)	*p*	Φ	Rank (HB-α)
C[1]	1st-year vs. 2nd-year	0.002 (1)	.967	-	-
	1st-year vs. 3rd-year	15.682 (1)	< .001 *	-0.195	1 (.001) *
	2nd-year vs. 3rd-year	14.158 (1)	< .001 *	-0.224	2 (.002) *

* Significance indicated at HB-α

1. HB-α calculated for 3 comparisons based on original rank of 1 (.003) for Statement C from **Table 5**.

Additional characterization for multiple-choice statements

Table 7. Chi-square goodness-of-fit analysis in multiple-choice statements B, D, H, J and N to identify if differences exist in answer frequency between options (E1).

ID	N		Observed n (%)	Expected n	χ^2(df)	*p*	Φ	Rank (HB-α)
B	643	To bind with a specific molecule of one type of receptor	444 (69.0%)	214.3	411.661 (2)	< .001 *	0.800	1 (.003) *
		To bind with any molecule of one type of receptor	167 (26.0%)	214.3				
		To bind with any molecule of a variety of receptor types	32 (5.0%)	214.3				
E	386	It can sense the receptor from a distance	37 (9.6%)	128.7	291.207 (2)	< .001*	0.869	2 (.003) *
		It has "hard-wired" knowledge	63 (16.3%)	128.7				
		Through interactions when it is close to the receptor	286 (74.1%)	128.7				
H	233	They repel each other	46 (19.7%)	116.5	85.326 (1)	< .001*	0.605	4 (.004) *
		They move into less crowded areas	187 (80.3%)	116.5				
K	141	The extracellular molecule propels itself	64 (45.4%)	70.5	1.199 (1)	.274	-	-
		The extracellular molecule is released with the correct initial trajectory	77 (54.6%)	70.5				
L	604	High proportion of empty space - collisions are infrequent	177 (29.3%)	302.0	103.477 (1)	< .001*	0.414	3 (.004) *
		Low proportion of empty space - collisions are frequent	427 (70.7%)	302.0				

* Significance indicated at HB-α (based on 16 comparisons at target α = .050)

Table 8. Post-hoc pairwise comparisons (Pearson Chi-square) on significant tests in **Table 7**, to identify which choice represents the more prevalent misconception (E1).

Statement ID	Pairwise comparison	χ^2(df)	*p*	Φ	Rank (HB-α)
B[1]	Specific - One type	125.579 (1)	< .001 *	0.453	2 (.002) *
	Specific - Variety	356.605 (1)	< .001 *	0.866	1 (.001) *
	One type - Variety	91.583 (1)	< .001 *	0.687	3 (.003) *
E[2]	Sense - Hard-wired	6.760 (1)	.009	-	-
	Sense - Interactions	191.954 (1)	< .001 *	0.771	1 (.001) *
	Hard-wired - Interactions	142.490 (1)	< .001 *	0.639	2 (.002) *

* Significance indicated at HB-α

1. HB-α calculated for 3 comparisons based on original rank of 1 (.003) for Statement B from **Table 7**.
2. HB-α calculated for 3 comparisons based on original rank of 2 (.003) for Statement E from **Table 7**.

Note: Post-hoc pairwise comparisons not required for statements H and N, since only two options exist.

Re-design of the MCAA: Comparison

Table 9. Comparison between the revised phrasing of MCAA statements in Experiment 2 and original phrasing in Experiment 1.

	Experiment 2 - New phrasing		Experiment 1 - original (prototype) phrasing
A	An extracellular molecule tries to move toward a complementary receptor. (True or **False**)	A	An extracellular molecule attempts to move toward its receptor (i.e. it has a binding objective) (True or **False**)
B	Based on your previous answer and assuming there are several of the complementary receptors present, an extracellular molecule tries to move toward: I. one specific predetermined complementary receptor; II. any of the complementary receptors that are present; III. whichever complementary receptor is closest	B	How specific is the extracellular molecule's objective? I. To bind with a specific molecule of one type of receptor; II. To bind with any molecule of one type of receptor; III. To bind with any molecule of a variety of receptor types
C	An extracellular molecule knows the physical location of a complementary receptor. (True or **False**)	D	An extracellular molecule knows the location of its receptor. (True or **False**)
D	Based on your previous answer, how does an extracellular molecule know the location of a complementary receptor? I. It can sense the receptor from a distance; II. It has “hard-wired” knowledge; III. It receives a message from elsewhere (e.g. from nucleus); IV. It can sense the receptor when it is close to it	E	How does an extracellular molecule know the location of its receptor? I. It can sense the receptor from a distance; II. It has “hard-wired” knowledge; III. Through interactions when it is close to the receptor
E	What is the mechanism of an extracellular molecule's movement toward a complementary receptor? I. The extracellular molecule propels itself; II. The extracellular molecule is released from its source with the correct initial trajectory; III. The extracellular molecule uses other “helper” molecules to carry it closer; **IV. The extracellular molecule collides randomly with other molecules**	K	What is the mechanism of an extracellular molecule's movement to a receptor? I. The extracellular molecule propels itself; II. The extracellular molecule is released with the correct initial trajectory; **III. The extracellular molecule collides with other molecules**
F	An extracellular molecule can change direction on its own. (True or **False**)	F	An extracellular molecule can change trajectory on its own. (True or **False**)
G	If extracellular molecules move via random collisions, what determines the chance of a binding event occurring between one of these molecules and a complementary receptor? I. If the binding event is required for cell function, it will happen regardless of other factors; **II. The chance of the binding event occurring is determined by other factors, such as concentration and temperature**	G	If a group of molecules is released into an extracellular space (i.e. through exocytosis), they are certain to spread out over time. (**True** or False)
H	In general, a large molecule (e.g. protein) has a more direct path of motion, whereas a small molecule (e.g. carbon dioxide or water) has a more random path of motion. (True or **False**)	I	A molecule that is critical to cell function moves more directly than a less critical molecule. (True or **False**)
I	A molecule’s path of motion is more direct when it has been activated (e.g. by phosphorylation), whereas its path of motion is more random when it is inactive. (True or **False**)	J	A molecule moves more directly when it has been activated (e.g. by phosphorylation) than when it is inactive. (True or **False**)
J	Inside a cell, macromolecules (e.g. proteins) are densely crowded, so much so that the average distance between two macromolecules is typically less than the width of a single macromolecule. (**True** or False)	L	How much empty space is in an intracellular environment? I. High proportion of empty space - collisions are infrequent; II. Low proportion of empty space - collisions are frequent;

III. **Virtually no empty space - collisions are virtually constant**

K Inside a cell, water and other molecules are all in contact with each other; therefore, empty space does not dictate the direction of diffusion. (**True** or False)

L In the case of simple diffusion across a permeable membrane, once solute molecules reach an equilibrium, they cease to cross the membrane. (True or **False**)

M A drop of dye is placed in some water. The water, acting as a solvent, diffuses into the dye in the same way as the dye, acting as a solute, diffuses into the water. (**True** or False)

M Inside cells, diffusion occurs when molecules move from areas crowded with various molecules to areas with more empty space. (True or **False**)

P In the case of simple diffusion across a permeable membrane, once solute molecules reach an equilibrium, they cease to cross the membrane. (True or **False**)

O In the case of simple diffusion at the molecular level, solvent and solute molecules have equivalent roles. (**True** or False)

Excluded pilot statements

C All types of molecules have an objective. (True or **False**)

H Why will these extracellular molecules spread out over time?

I. They repel each other
II. They move into less crowded areas
III. **Entropy increases as they spread out**

N Water molecules have a significant influence on the movement of a macromolecule. (**True** or False)

EXPERIMENT 2

Holm's Sequential Bonferroni Procedure - E2

Table 10. Holm-Bonferroni (HB) adjusted alphas for multiple comparisons.

13 Comparisons				11 Comparisons			
Rank	**HB-α**	**Rank**	**HB-α**	**Rank**	**HB-α**	**Rank**	**HB-α**
1	.004	8	.008	1	.005	8	.013
2	.004	9	.010	2	.005	9	.017
3	.005	10	.013	3	.006	10	.025
4	.005	11	.017	4	.006	11	.050
5	.006	12	.025	5	.007	-	-
6	.006	13	.050	6	.008	-	-
7	.007	-	-	7	.010	-	-

Holm-Bonferroni α = Target α / (k - rank +1), where Target α = .050 and k = the number of comparisons

Science literacy and bioliteracy

Science literacy comparison between E1 and E2

Table 11. Detailed comparison of science literacy scores between E1 and E2 at each educational level (first-, second-, and third-year students)

	E1 Mean (SD)	**E2 Mean (SD)**	**U**	**Z**	**p**	**Rank (HB-α)**
First-years	8.67 (1.29)	8.59 (1.32)	178379.50	-0.961	.337	-
Second-years	9.05 (1.10)	8.82 (1.30)	31364.00	-2.052	.040	1 (.017)
Third-years	9.17 (1.01)	8.92 (1.24)	1629.00	-0.951	.341	-

* Significance indicated at HB-α (based on 3 comparisons at target α = .050)

Comparison of science literacy and bioliteracy across biology-course levels

Table 12. Comparison of science literacy and bioliteracy test scores between first-, second-, and third-year students (Kruskal-Wallis tests). Measured at baseline (time of pre-test).

	Mean test score (SD)				
Test	**1st-year**	**2nd-year**	**3rd-year**	**χ^2(df = 2)**	***p***
Science literacy	8.59 (1.32)	8.82 (1.30)	8.92 (1.24)	10.74	.005 *
Bioliteracy	4.60 (1.80)	5.06 (1.70)	5.90 (1.85)	37.61	< .001 *

* Significance indicated α = .050

Table 13. Post-hoc pairwise comparisons of science literacy and bioliteracy test scores between first-, second-, and third-year students (Mann-Whitney U tests), for identified significant tests in **Table 12**.

Test	Pairwise comparison	U	*Z*	*p*	Eta^2	Rank (HB-α)
Science literacy	1st-year vs. 2nd-year	96673.5	-2.85	.004 *	< 0.01	1 (.017) *
	1st-year vs. 3rd-year	18348.5	-1.92	.055	-	-
	2nd-year vs. 3rd-year	5978.0	-0.55	.579	-	-
Bioliteracy	1st-year vs. 2nd-year	89770.0	-4.34	< .001 *	0.02	2 (.025) *
	1st-year vs. 3rd-year	13200.5	-4.73	< .001 *	0.02	1 (.017) *
	2nd-year vs. 3rd-year	4759.0	-2.74	.006 *	0.03	3 (.050) *

* Significance indicated at HB-α (based on 3 comparisons at target α = .050)

Q1. How does the overall frequency of misconceptions held by students change over time?

Between introductory, intermediate, and advanced courses

Table 14. ANOVA investigating the effect of educational level (first-, second-, or third-year undergraduate) on total molecular misconceptions held by the students in Experiment 2, while controlling for year of distribution (2015/2016).

Variable	df	F	Sig	Partial eta^2	Obs. power
Intercept	1, 1164	2271.710	< .001	0.661	1.000
Educational level	2, 1164	2.136	.119	0.004	0.439
Year of distribution	1, 1164	3.344	.068	0.004	0.447
Educational level * Year of distribution	2, 1164	1.383	.251	0.002	0.298

R-Squared = 0.008, R-Squared adjusted = 0.004
Levene's test: F(5, 1164) = 1.41, *p* = .218

Over the course of a semester

Table 15. Pre-test misconceptions in those who did and did not complete the post-test.

Pre-test misconceptions	n	Min, Max	Mean	SD
Did not complete post-test	224	1, 10	5.97	2.13
Completed post-test	881	0, 11	5.92	2.25

SD = Standard Deviation

Table 16. Univariate ANOVA verifying that those who did and did not complete the post-test MCAA in E2 represent a population of students with similar misconceptions.

Variable	df	F	Sig	Partial eta^2	Obs. power
Completed	1, 1103	.095	.757	< 0.001	0.061

R-Squared < 0.001, R-Squared adjusted = -0.001
Levene's test: F(1, 1103) = 1.24, p = .265

Over the course of three consecutive years

Table 17. Repeated measures ANOVA investigating change in misconceptions over the course of three consecutive years in Experiment 2 (2015, 2016, and 2017) and how this change might be influenced by educational level (first- or second-year undergraduate).

Variable	df	F	Sig	Partial eta^2	Obs. power
Change	2, 52	1.242	.297	0.046	0.259
Change * Educational level	2, 52	0.374	.690	0.014	0.107

R-Squared < 0.001, R-Squared adjusted = -0.001
Box's M test: Box's M = 4.86, F(6, 745.78) = 0.65, p = .692
Mauchly's test of Sphericity: W = 0.91, $\chi^2(2)$ = 2.29, p = .318
Levene's test 2015: F(1, 26) = 0.67, p = .419; 2016: F(1, 26) = 0.47, p = .497; 2017: F(1, 26) = 0.93, p = .345

Table 18. Pre-test misconceptions in 2015 in those who did and did not persist through to the 2017 distribution of the MCAA.

Pre-test misconceptions	n	Min, Max	Mean	SD
Did not persist through to 2017	629	0, 11	5.83	2.31
Persisted through to 2017	28	2, 10	5.86	2.29

SD = Standard Deviation

Table 19. Univariate ANOVA verifying that those who did and did persist from 2015 to 2017 in E2 represent a population of students with similar misconceptions.

Variable	df	F	Sig	Partial eta^2	Obs. power
Persisted through to 2017	1, 655	< 0.01	.960	0.000	0.050

R-Squared < 0.001, R-Squared adjusted = -0.002
Levene's test: F(1, 655) = 0.06, p = .815

Q2. How did students respond to each MCAA item, and which misconceptions change over time?

Between introductory, intermediate, and advanced courses

Table 20. Chi-square tests investigating proportional differences in answers between educational levels (first-, second-, and third-year Biology courses) for each MCAA statement in E2.

ID		**1st-year: n (%)**	**2nd-year: n (%)**	**3rd-year: n (%)**	**χ^2(df)**	***p* (Φ)**	**Rank (HB-α)**
A	✓ Does not hold misconception	178 (20.5%)	54 (21.5%)	13 (26.0%)	0.933 (2)	.627	-
	✗ Holds misconception	691 (79.5%)	197 (78.5%)	37 (74.0%)			
B	Any of the complementary receptors that are present	135 (19.5%)	41 (20.8%)	8 (21.6%)	5.385 (4)	.250	-
	Whichever complementary receptor is closest	159 (23.0%)	44 (22.3%)	14 (37.8%)			
	One specific predetermined complementary receptor	397 (57.5%)	112 (56.9%)	15 (40.5%)			
C	✓ Does not hold misconception	458 (52.7%)	129 (51.4%)	39 (78.0%)	12.733 (2)	.002 * (0.104)	1 (.004) *
	✗ Holds misconception	411 (47.3%)	122 (48.5%)	11 (22.0%)			
D	It can sense the receptor when it is close to it	106 (25.8%)	29 (23.8%)	4 (36.4%)	8.793 (6)	.186	-
	It can sense the receptor from a distance	32 (7.8%)	11 (9.0%)	3 (27.4%)	[25% of cells have expected count < 5]		
	It has “hard-wired” knowledge	39 (9.5%)	16 (13.1%)	0 (0.0%)			
	It receives a message from elsewhere (e.g. from nucleus)	234 (56.9%)	66 (54.1%)	4 (36.4%)			
E	✓ The extracellular molecule collides randomly with other molecules	241 (27.7%)	63 (25.1%)	17 (34.0%)	4.502 (6)	.609	-
	✗ The extracellular molecule propels itself	118 (13.6%)	36 (14.3%)	4 (8.0%)			
	✗ The extracellular molecule is released from its source with the correct initial trajectory	146 (16.8%)	41 (16.3%)	5 (10.0%)			
	✗ The extracellular molecule uses other “helper”	364 (41.9%)	111 (44.2%)	24 (48.0%)			

	molecules to carry it closer						
F	✓ Does not hold misconception	402 (64.0%)	110 (58.5%)	22 (66.7%)	2.086 (2)	.352	-
	✗ Holds misconception	226 (36.0%)	78 (41.5%)	11 (33.3%)			
G	✓ Does not hold misconception	197 (81.7%)	59 (93.7%)	16 (94.1%)	6.697 (2) [16.7% of cells have expected count < 5]	.035 (0.144)	2 (.004)
	✗ Holds misconception	44 (18.3%)	4 (6.3%)	1 (2.6%)			
H	✓ Does not hold misconception	263 (41.9%)	74 (39.4%)	11 (33.3%)	1.211 (2)	.546	-
	✗ Holds misconception	365 (58.1%)	114 (60.6%	22 (66.7%)			
I	✓ Does not hold misconception	146 (21.2%)	54 (28.7%)	10 (30.3%)	2.901 (2)	.234	-
	✗ Holds misconception	482 (76.8%)	134 (71.3%)	23 (69.7%)			
J	✓ Does not hold misconception	452 (52.0%)	133 (53.0%)	25 (50.0%)	0.170 (2)	.919	-
	✗ Holds misconception	417 (48.0%)	118 (47.0%)	25 (50.0%)			
K	✓ Does not hold misconception	417 (48.0%)	135 (53.8%)	30 (60.0%)	4.817 (2)	.090	-
	✗ Holds misconception	452 (52.0%)	116 (46.2%)	20 (40.0%)			
L	✓ Does not hold misconception	363 (41.8%)	122 (48.6%)	25 (50.0%)	4.571 (2)	.102	-
	✗ Holds misconception	506 (58.2%)	129 (51.4%)	25 (50.0%)			
M	✓ Does not hold misconception	502 (57.8%)	133 (53.0%)	32 (64.0%)	2.857 (2)	.240	-
	✗ Holds misconception	367 (42.2%)	118 (47.0%)	18 (36.0%)			

* Significance indicated at HB-α (based on 13 comparisons at target α = .050)
NOTE: Pearson chi-square results may be invalid where more than 20% of the cells in the cross-tabulation have expected cell counts of less than 5 observations. In tests where all cells had counts greater than 5, no extra information is given.

Table 21. Post-hoc pairwise comparisons between educational levels for significant results in Between introductory, intermediate, and advanced courses

Table 20.

Statement ID	Pairwise comparison	χ^2(df)	*p*	Φ	Rank (BF-α)
C[1]	1st-year vs. 2nd-year	0.134 (1)	.714	-	-
	1st-year vs. 3rd-year	12.18 (1)	< .001 *	-0.115	1 (.001) *
	2nd-year vs. 3rd-year	11.967 (1)	< .001 *	-0.199	2 (.002) *

* Significance indicated at HB-α

1. HB-α calculated for 3 comparisons based on original rank of 1 (.004) for Statement C from Table 11.

Additional characterization for multiple-choice statements

Table 22. Chi-square goodness-of-fit analysis in multiple-choice statements B, D, and E to identify if differences exist in answer frequency between options (E2).

ID	N		Observed n (%)	Expected n	χ^2(df)	*p*	Rank (BF-α)
B	925	One specific predetermined complementary receptor	524 (56.6%)	308.3	228.041 (2)	< .001 *	3 (.005) *
		Whichever complementary receptor is closest	217 (23.5%)	308.3			
		Any of the complementary receptors that are present	184 (19.9%)	308.3			
D	544	It can sense the receptor when it is close to it	139 (25.6%)	136.0	315.397 (3)	< .001 *	1 (.004) *
		It can sense the receptor from a distance	46 (8.5%)	136.0			
		It has “hard-wired” knowledge	55 (10.1%)	136.0			
		It receives a message from elsewhere (e.g. from nucleus)	304 (55.9%)	136.0			
E	849	The extracellular molecule propels itself	158 (18.6%)	283.0	249.336 (2)	< .001 *	2 (.004) *
		The extracellular molecule is released from its source with the correct initial trajectory	192 (22.6%)	283.0			
		The extracellular molecule uses other “helper” molecules to carry it closer	499 (58.8%)	283.0			

* Significance indicated at HB-α (based on 13 comparisons at target α = .050)

Table 23. Post-hoc pairwise comparisons (Pearson chi-square) on significant tests in **Table 22**, to identify which choice represents the more prevalent misconception (E2).

Statement ID	Pairwise comparison	χ^2(df)	*p*	Φ	Rank (HB-α)
B[1]	Specific - Closest	127.192 (1)	< .001 *	0.414	2 (.003) *
	Specific - Any	163.277 (1)	< .001 *	0.480	1 (.002) *
	Closest - Any	2.716 (1)	.099	-	-
D[2]	Close sense - Distant sense	43.085 (1)	< .001 *	0.479	5 (.002) *
	Close Sense - Hard-wired	22.780 (1)	< .001 *	0.330	4 (.001) *
	Close Sense - Message	49.893 (1)	< .001 *	0.330	3 (.001) *
	Distant Sense - Hard-wired	4.966 (1)	.026	-	-
	Distant Sense - Message	184.207 (1)	< .001 *	0.722	1 (.001) *
	Message - Hard-wired	146.406 (1)	< .001 *	0.626	2 (.001) *
E[3]	Self-propelled - Trajectory	3.303 (1)	.069	-	-
	Self-propelled - Carried	176.988 (1)	< .001 *	0.519	1 (.001) *
	Trajectory - Carried	136.395 (1)	< .001 *	0.444	2 (.002) *

* Significance indicated at HB-α

1. HB-α calculated for 3 comparisons based on original rank of 3 (.005) for Statement B from **Table 22**.
2. HB-α calculated for 6 comparisons based on original rank of 1 (.004) for Statement D from **Table 22**.
3. HB-α calculated for 3 comparisons based on original rank of 2 (.004) for Statement E from **Table 22**.

Change over the course of a semester

Table 24. Repeated measures McNemar tests on each MCAA misconception statement (pre-test to post-test comparison).

ID	N	Pre-test: n (%) Holds misc.	Post-test: n (%) Holds misc.	Change: n (%) Resolved misc.	χ^2(df)	*p*	OR (95% CI)	Rank (HB-α)
A	881	698 (79.2%)	680 (77.2%)	-18 (-2.0%)	1.246 (1)	.264	-	-
C	881	411 (46.7%)	390 (44.3%)	-21 (-2.4%)	1.475 (1)	.225	-	-
E	881	633 (71.9%)	598 (67.9%)	-35 (-4.0%)	5.543 (1)	.019	-	3 (.006)
F	505	202 (40.0%)	158 (31.3%)	-44 (-8.7%)	10.756 (1)	.001 *	1.464 (1.13, 1.89)	1 (.005) *
G	155	21 (13.5%)	27 (17.4%)	+6 (3.9%)	1.286 (1)	.257	-	-
H	505	299 (59.2%)	308 (61.0%)	+9 (1.8%)	0.415 (1)	.519	-	-
I	505	378 (74.9%)	371 (73.5%)	-7 (1.4%)	0.293 (1)	.588	-	-
J	881	409 (46.4%)	370 (42.0%)	-39 (-4.4%)	4.122 (1)	.042	-	4 (.006)
K	881	448 (50.9%)	455 (51.6%)	+7 (0.8%)	0.138 (1)	.710	-	-
L	881	487 (55.3%)	430 (48.8%)	-57 (-6.5%)	10.059 (1)	.002 *	1.297 (1.08, 1.56)	2 (.005) *
M	881	383 (43.5%)	357 (40.5%)	-26 (-3.0%)	2.000 (1)	.157	-	-

* Significance indicated at HB-α (based on 11 comparisons at target α = .050)

Q3. How strongly do students adhere to their misconceptions and does their confidence change over time?

Between introductory, intermediate, and advanced courses

Table 25. Comparison of confidence in *correct answers* between first-, second-, and third-year students (Kruskal-Wallis tests).

	Mean confidence (SD)					
ID	**1st-year**	**2nd-year**	**3rd-year**	**χ^2(df = 2)**	***p***	**Rank (HB-α)**
A	47.17 (31.28)	53.26 (29.11)	76.54 (21.77)	12.56	.002 *	8 (.013) *
C	52.26 (29.78)	59.15 (27.27)	80.90 (23.55)	34.81	< .001 *	1 (.005) *
E	52.30 (29.64)	62.35 (27.06)	84.18 (16.34)	22.42	< .001 *	3 (.006) *
F	47.59 (27.86)	51.95 (26.26)	72.50 (29.26)	15.07	.001 *	6 (.008) *
G	66.52 (29.94)	71.88 (23.76)	92.19 (11.10)	13.64	.001 *	7 (.010) *
H	47.79 (28.18)	55.99 (26.16)	77.64 (20.34)	15.44	< .001 *	5 (.007) *
I	41.39 (26.80)	47.54 (21.81)	72.70 (27.07)	11.92	.003 *	9 (.017) *
J	43.12 (27.38)	47.86 (23.80)	58.08 (25.39)	10.15	.006 *	11 (.050) *
K	50.38 (26.87)	53.38 (24.29)	67.03 (24.44)	10.51	.005 *	10 (.025) *
L	62.91 (31.50)	73.23 (27.19)	88.88 (15.62)	22.74	< .001 *	2 (.005) *
M	56.70 (26.81)	60.33 (26.84)	75.19 (24.07)	16.88	< .001 *	4 (.006) *
Total	**51.39 (24.29)**	**57.16 (20.55)**	**72.94 (21.10)**	**44.75**	**< .001 ***	**N/A**

NOTE: These analyses consider only students who responded correctly to the statement in question.

Eta-squared = $Z^2/(N-1)$; r effect size = $Z/\sqrt{N}$

* Significance indicated at HB-α (based on 11 comparisons at target α = .050)

Table 26. Comparison of confidence in *misconceptions* between first-, second-, and third-year students (Kruskal-Wallis tests).

	Mean % confidence (SD)					
ID	**1st-year**	**2nd-year**	**3rd-year**	**χ^2(df = 2)**	***p***	**Rank (HB-α)**
A	53.37 (27.70)	58.60 (26.92)	76.19 (22.16)	28.45	< .001 *	2 (.005) *
C	49.52 (27.70)	54.50 (25.14)	67.00 (19.17)	6.75	.034	7 (.010)
E	43.90 (27.57)	51.25 (25.62)	76.09 (23.26)	44.58	< .001 *	1 (.005) *
F	42.95 (27.70)	48.08 (25.08)	61.73 (15.63)	6.17	.046	8 (.013)
G	46.48 (25.19)	45.25 (28.70)	9.00 (-)	1.84	.399	-
H	50.51 (26.47)	59.69 (23.47)	63.50 (25.35)	14.21	.001 *	4 (.006) *
I	47.53 (27.22)	53.16 (23.67)	68.35 (23.63)	15.61	< .001 *	3 (.006) *
J	45.36 (27.94)	48.48 (26.69)	58.32 (22.61)	6.86	.032	6 (.008)
K	50.58 (28.51)	51.89 (27.20)	60.85 (23.52)	2.64	.267	-
L	63.56 (27.75)	69.72 (25.62)	73.52 (29.16)	8.35	.015	5 (.007)
M	55.67 (27.76)	58.06 (25.31)	66.56 (29.33)	3.04	.219	-
Total	**51.30 (22.71)**	**55.74 (19.57)**	**68.14 (20.19)**	**29.18**	**<.001 ***	**N/A**

NOTE: These analyses consider only students who responded with a misconception the statement in question.
Eta-squared = $Z^2/(N-1)$; r effect size = $Z/\sqrt{N}$
* Significance indicated at HB-α (based on 11 comparisons at target α = .050)

Table 27. Post-hoc pairwise comparison of confidence in correct answers for significant Kruskal-Wallis tests (Between introductory, intermediate, and advanced courses

Table 25).

Statement ID	Pairwise comparison	U	*Z*	*p*	Eta^2	Rank (HB-α)
A[1]	1st-year vs. 2nd-year	4245.00	-1.302	.193	-	-
	1st-year vs. 3rd-year	510.50	-3.366	.001 *	0.060	1 (.004) *
	2nd-year vs. 3rd-year	176.50	-2.778	.005 *	0.117	2 (.007) *
C[2]	1st-year vs. 2nd-year	25812.00	-2.196	.028	-	-
	1st-year vs. 3rd-year	4088.00	-5.636	< .001 *	0.064	1 (.002) *
	2nd-year vs. 3rd-year	1362.00	-4.345	< .001 *	0.113	2 (.003) *
E[3]	1st-year vs. 2nd-year	6243.00	-2.173	.030	-	-
	1st-year vs. 3rd-year	746.50	-4.382	< .001 *	0.075	1 (.002) *
	2nd-year vs. 3rd-year	267.00	-3.162	.002 *	0.127	2 (.003) *
F[4]	1st-year vs. 2nd-year	20343.50	-1.287	.198	-	-

	1st-year vs. 3rd-year	2329.50	-3.744	< .001 *	0.033	1 (.003) *
	2nd-year vs. 3rd-year	706.00	-3.080	.002 *	0.072	2 (.004) *
G[5]	1st-year vs. 2nd-year	5457.50	-0.712	.477	-	-
	1st-year vs. 3rd-year	748.00	-3.510	< .001 *	0.058	2 (.005) *
	2nd-year vs. 3rd-year	193.00	-3.623	< .001 *	0.177	1 (.003) *
H[6]	1st-year vs. 2nd-year	7919.00	-2.451	.014	-	-
	1st-year vs. 3rd-year	616.50	-3.231	.001 *	0.038	1 (.002) *
	2nd-year vs. 3rd-year	233.50	-2.404	.016	-	-
I[7]	1st-year vs. 2nd-year	3352.00	-1.627	.104	-	-
	1st-year vs. 3rd-year	299.00	-3.126	.002 *	0.063	1 (.006) *
	2nd-year vs. 3rd-year	127.00	-2.651	.008 *	0.112	2 (.009) *
J[8]	1st-year vs. 2nd-year	26576.00	-2.034	.042	-	2 (.025)
	1st-year vs. 3rd-year	3890.50	-2.625	.009 *	0.014	1 (.017) *
	2nd-year vs. 3rd-year	1295.00	-1.753	.080	-	-
K[9]	1st-year vs. 2nd-year	26862.50	-0.799	.424	-	-
	1st-year vs. 3rd-year	4089.50	-3.172	.002 *	0.023	1 (.008) *
	2nd-year vs. 3rd-year	1371.00	-2.766	.006 *	0.047	2 (.013) *
L[10]	1st-year vs. 2nd-year	18253.50	-2.916	.004	-	2 (.003)
	1st-year vs. 3rd-year	2332.50	-4.082	< .001 *	0.043	1 (.002) *
	2nd-year vs. 3rd-year	1025.50	-2.601	.009	-	-
M[11]	1st-year vs. 2nd-year	30470.00	-1.550	.121	-	-
	1st-year vs. 3rd-year	4711.00	-3.927	< .001 *	0.029	1 (.002) *
	2nd-year vs. 3rd-year	1399.00	-3.007	.003 *	0.055	2 (.003) *
Total[12]	**1st-year vs. 2nd-year**	**93543.00**	**-3.252**	**.001 ***	**0.009**	**3 (.050) ***
	1st-year vs. 3rd-year	**10678.50**	**-6.025**	**< .001 ***	**0.040**	**1 (.017) ***
	2nd-year vs. 3rd-year	**3498.50**	**-4.914**	**< .001 ***	**0.081**	**2 (.025) ***

* Significance indicated at HB-α

1. HB-α calculated for 3 comparisons based on original rank of 8 (.013) for Statement A from **Between introductory,** intermediate, and advanced courses
2. **Table 25**.
3. HB-α calculated for 3 comparisons based on original rank of 1 (.005) for Statement C from **Between introductory,** intermediate, and advanced courses
4. **Table 25**.
5. HB-α calculated for 3 comparisons based on original rank of 3 (.006) for Statement E from **Between introductory,** intermediate, and advanced courses
6. **Table 25**.

7. HB-α calculated for 3 comparisons based on original rank of 6 (.008) for Statement F from **Between introductory,** intermediate, and advanced courses
8. **Table 25**.
9. HB-α calculated for 3 comparisons based on original rank of 7 (.010) for Statement G from **Between introductory,** intermediate, and advanced courses
10. **Table 25**.
11. HB-α calculated for 3 comparisons based on original rank of 5 (.007) for Statement H from **Between introductory,** intermediate, and advanced courses
12. **Table 25**.
13. HB-α calculated for 3 comparisons based on original rank of 9 (.017) for Statement I from **Between introductory,** intermediate, and advanced courses
14. **Table 25**.
15. HB-α calculated for 3 comparisons based on original rank of 11 (.050) for Statement J from **Between introductory,** intermediate, and advanced courses
16. **Table 25**.
17. HB-α calculated for 3 comparisons based on original rank of 10 (.025) for Statement K from **Between introductory,** intermediate, and advanced courses
18. **Table 25**.
19. HB-α calculated for 3 comparisons based on original rank of 2 (.005) for Statement L from **Between introductory,** intermediate, and advanced courses
20. **Table 25**.
21. HB-α calculated for 3 comparisons based on original rank of 4 (.006) for Statement M from **Between introductory,** intermediate, and advanced courses
22. **Table 25**.
23. HB-α calculated for 3 comparisons based on alpha = .050.

Table 28. Post-hoc pairwise comparison of confidence in *misconceptions* for significant Kruskal-Wallis tests (**Table 26**).

Statement ID	Pairwise comparison	U	*Z*	*p*	Eta^2	Rank (HB-α)
A[1]	1st-year vs. 2nd-year	60172.00	-2.492	.013	-	-
	1st-year vs. 3rd-year	6684.00	-4.907	< .001 *	0.033	1 (.002) *
	2nd-year vs. 3rd-year	2337.50	-3.734	< .001 *	0.060	2 (.003) *
E[2]	1st-year vs. 2nd-year	49778.50	-3.268	.001 *	0.013	3 (.005) *
	1st-year vs. 3rd-year	3947.00	-6.007	< .001 *	0.055	1 (.002) *
	2nd-year vs. 3rd-year	1440.50	-4.190	< .001 *	0.080	2 (.003) *
H[3]	1st-year vs. 2nd-year	16580.50	-3.282	.001 *	0.023	1 (.002) *
	1st-year vs. 3rd-year	2888.00	-2.216	.027	-	-
	2nd-year vs. 3rd-year	1147.00	-0.634	.526	-	-
I[4]	1st-year vs. 2nd-year	28287.00	-2.201	.028	-	-
	1st-year vs. 3rd-year	31995.50	-3.432	.001 *	0.023	1 (.002) *
	2nd-year vs. 3rd-year	1020.50	-2.586	.010	-	-

Total [5]	1st-year vs. 2nd-year	95709.50	-2.883	.004 *	0.007	3 (.050) *
	1st-year vs. 3rd-year	12322.00	-4.753	< .001 *	0.025	1 (.017) *
	2nd-year vs. 3rd-year	3989.00	-3.708	< .001 *	0.046	2 (.025) *

* Significance indicated at HB-α

1. HB-α calculated for 3 comparisons based on original rank of 2 (.005) for Statement A from **Table 26**.
2. HB-α calculated for 3 comparisons based on original rank of 1 (.005) for Statement E from **Table 26**.
3. HB-α calculated for 3 comparisons based on original rank of 4 (.006) for Statement H from **Table 26**.
4. HB-α calculated for 3 comparisons based on original rank of 3 (.006) for Statement I from **Table 26**.
5. HB-α calculated for 3 comparisons based on alpha = .050.

Table 29. Within-subjects (Wilcoxin) comparison of confidence correctly- vs. incorrectly- (misconception) answered MCAA items, at each educational level.

		Mean confidence (SD)					
Edu. level	**N**	**Correct answers**	**Misconceptions**	**Z**	***p***	r_{cc}	**Rank (HB-α)**
1st-year	869	51.39 (24.29)	51.30 (22.71)	-0.548	.584		-
2nd-year	251	57.16 (20.55)	55.74 (19.57)	-1.493	.135	-	-
3rd-year	50	72.94 (21.10)	68.14 (20.19)	-2.174	.030	-	1 (.017)

NOTE: These analyses consider only students who responded correctly to the statement in question.

Correlation coefficient (r_{cc}) effect size = Z/√N

* Significance indicated at HB-α (based on 3 comparisons at target α = .050)

Over the course of a semester

Table 30. Pre-test to post-test change in average confidence on *correctly* answered MCAA items, stratified by educational level.

		Mean confidence (SD)					
Edu. level	**N**	**pre-test**	**post-test**	**Z**	***p***	**r_{cc}**	**Rank (HB-α)**
1st-year	685	51.70 (24.47)	53.29 (22.50)	-2.308	.021 *	-0.088	2 (.025) *
2nd-year	158	57.31 (20.46)	64.74 (18.17)	-4.971	< .001 *	-0.395	1 (.017) *
3rd-year	34	74.16 (21.14)	77.05 (15.82)	-1.563	.118	-	-

NOTE: Total N=877, which is less than the total sample who completed the post-test (N=881); this is because some individuals did not answer any statements correctly.

Correlation coefficient (r_{cc}) effect size = Z/√N

** Significance indicated at HB-α (based on 3 comparisons at target α = .050)*

Table 31. Pre-test to post-test change in average confidence on *incorrectly* answered MCAA items (i.e. confidence in misconceptions), stratified by educational level.

		Mean confidence (SD)					
Edu. level	**N**	**pre-test**	**post-test**	**Z**	***p***	**r_{cc}**	**Rank (HB-α)**
1st-year	679	51.54 (23.14)	52.71 (21.48)	-1.573	.116	-	-
2nd-year	157	56.14 (19.32)	64.23 (16.47)	-5.091	< .001 *	-0.406	1 (.017) *
3rd-year	31	71.19 (17.84)	74.62 (18.45)	-1.235	.217	-	-

NOTE: Total N=867, which is less than the total sample who completed the post-test (N=881); this is because some individuals did not respond with any misconceptions.

Correlation coefficient (r_{cc}) effect size = Z/√N

** Significance indicated at HB-α (based on 3 comparisons at target α = .050)*

Table 32. Confidence change from pre- to post-test in those *retained* specific misconceptions (i.e. responded with the misconception at both pre- and post-tests).

			Mean confidence (SD)					
ID	**Course**	**N**	**pre-test**	**post-test**	**Z**	***p***	**r_{cc}**	**Rank (HB-α)**
A	1st-year	436	52.42 (27.60)	56.35 (26.55)	-3.286	.001 *	-0.157	5 (.002) *
	2nd-year	100	59.78 (24.87)	71.52 (22.06)	-3.723	< .001 *	-0.372	2 (.002) *
	3rd-year	23	78.78 (21.65)	80.65 (19.63)	-0.483	.629	-	-
C	1st-year	199	51.17 (27.84)	49.78 (25.02)	-0.752	.452	-	-
	2nd-year	48	55.69 (27.13)	64.17 (21.77)	-2.371	.018	-	8 (.002)
	3rd-year	4	76.00 (17.05)	77.75 (8.02)	-0.365	.715	-	-
E	1st-year	388	43.91 (28.25)	48.03 (25.66)	-3.542	< .001 *	-0.180	3 (.002) *
	2nd-year	98	51.58 (23.38)	63.66 (21.56)	-4.221	< .001 *	-0.426	1 (.002) *

	3rd-year	19	74.79 (22.63)	75.68 (19.97)	-0.196	.844	-	-
F	1st-year	75	42.73 (26.64)	49.15 (25.22)	-1.941	.052	-	-
	2nd-year	10	43.90 (28.43)	51.00 (28.13)	-0.840	.401	-	-
	3rd-year	5	66.60 (18.05)	42.40 (17.57)	-1.753	.080	-	-
G	1st-year	9	55.89 (14.11)	67.33 (23.77)	-0.890	.373	-	-
	2nd-year	1	50.00 (-)	50.00 (-)	-	-	-	-
	3rd-year	0	-	-	-	-	-	-
H	1st-year	156	54.22 (27.11)	51.13 (25.70)	-1.414	.157	-	-
	2nd-year	40	54.00 (17.51)	61.58 (20.66)	-2.650	.008	-	6 (.002)
	3rd-year	10	70.60 (20.55)	75.70 (20.07)	-0.593	.553	-	-
I	1st-year	227	47.21 (26.85)	50.22 (25.90)	-1.456	.145	-	-
	2nd-year	52	54.37 (23.41)	63.04 (20.78)	-2.611	.009	-	7 (.002)
	3rd-year	12	71.50 (23.09)	74.83 (19.53)	-0.623	.533	-	-
J	1st-year	155	45.68 (27.65)	47.88 (26.28)	-1.296	.195	-	-
	2nd-year	43	46.44 (25.31)	53.84 (25.93)	-1.472	.141	-	-
	3rd-year	7	64.57 (22.68)	76.14 (16.83)	-1.693	.090	-	-
K	1st-year	223	54.30 (28.27)	52.64 (25.73)	-1.024	.306	-	-
	2nd-year	42	50.98 (29.09)	61.76 (24.72)	-1.913	.056	-	-
	3rd-year	9	72.00 (18.27)	67.44 (17.95)	-0.652	.515	-	-
L	1st-year	241	65.10 (27.97)	59.61 (26.38)	-3.528	< .001 *	-0.227	4 (.002) *
	2nd-year	49	70.57 (28.71)	71.78 (21.62)	-0.194	.846	-	-
	3rd-year	7	67.43 (33.82)	67.29 (25.01)	-0.271	.786	-	-
M	1st-year	154	55.97 (27.64)	56.60 (26.47)	-0.721	.471	-	-
	2nd-year	37	65.19 (24.04)	64.22 (22.68)	-0.627	.531	-	-
	3rd-year	10	79.30 (20.27)	72.20 (723.96)	-0.631	.528	-	-

Correlation coefficient (r_{cc}) effect size = Z/√N; Note being Z = $\sqrt{\chi^2}$

* Significance indicated at HB-α (based on 33 comparisons at target α = .050)

Q4. How did the rewording/restructuring of the MCAA influence students' responses?

Table 33. Chi-Square results investigating differences in frequency of misconceptions between Experiments 1 (E1) and 2 (E2) when wording and sequence of statements are redesigned.

	Final MCAA (E2)			Pilot MCAA (E1)					
ID	**N total**	**n (%) Holds misc.**	**ID**	**N total**	**n (%) Holds misc.**	**χ^2 (df)**	***p***	**ϕ**	**Rank (HB-α)**
A	1170	925 (79.1%)	A	773	643 (83.2%)	5.079 (1)	.024	-	7 (.010)
C	1170	544 (46.5%)	D	643	386 (60.0%)	30.429 (1)	< .001 *	-0.130	3 (.006) *
E	1170	849 (72.6%)	K	248	141 (56.9%)	23.963 (1)	< .001 *	0.130	4 (.006) *
F	849	315 (37.1%)	F	773	248 (32.1%)	4.499 (1)	.034	-	8 (.013)
G	321	49 (15.3%)	G	525	92 (17.5%)	0.732 (1)	.392	-	-
H	849	501 (59.0%)	I	248	134 (54.0%)	1.951 (1)	.162	-	-
I	849	639 (75.3%)	J	248	198 (79.8%)	2.220 (1)	.136	-	-
J	1170	560 (47.9%)	L	773	604 (78.1%)	177.617 (1)	< .001 *	-0.302	2 (.005) *
K	1170	588 (50.3%)	M	604	506 (83.8%)	189.329 (1)	< .001 *	-0.327	1 (.005) *
L	1170	660 (56.4%)	P	773	390 (50.5%)	6.652 (1)	.010	-	6 (.008)
M	1170	503 (43.0%)	O	773	389 (50.3%)	10.077 (1)	.002 *	-0.072	5 (.007) *

* Significance indicated at HB-α (based on 11 comparisons at target α = .050)

FOCUS GROUP CODED TRANSCRIPTS

Table 34. Focus group transcripts. Codes: 1 = misinterpretation of language, 2 = misconception identified by MCAA, 3 = misconception not identified by MCAA, 4 = correct understanding, 0 = general discussion

Participant	Focus Group 1: Statement / Question	Code
	We talked a lot in- in this survey about random movement or directed movement, and I wonder if I were to ask you what is meant by the term random, or what is meant by the term directed? Uh, what does that mean to you?	
4	I don't exactly know	1
3	for random I would say that there- like it doesn't have a direction, so it's kind of just- I don't know how to say it in like um, so random as in there's like, there's no like... destination I guess in a sense?...whereas like directed, it's complete opposite so there's, like the molecule is- or atom or whatever it may be is actually trying to get to a specific point?	0
2	randomized, um, I feel like it doesn't have a purpose...when it's directed, I feel like um, either the molecules are like binding to do something or they have a purpose to their movement, so it's in a certain fashion, they're trying to accomplish something	0
1	a random movement to me would seem more- it's unambiguous, non-predictable, uh it can go in any direction and at any time. And directed would be more of- it has a path to follow, like a reason to go to a certain uh- a certain place or area in space.	0
	To what extent and under what conditions is the movement of a molecule directed, rather than random?	
4	Um, I guess it would be when molecules interact with each other then? Um, then they actually have like something to do, so they- their movement, like whatever they do is kind of with a purpose	2
	Interactions, and where- where does the purpose come from?	
4	It would come from like... the attraction between the two molecules, like whether it has to like um- if you think of like reactions and stuff, right?	2
3	based on like different factors, like electronegativities for example, umm, and that kind of... that type of really basic um... idea actually kind of gives a reason for some molecules to move or atoms to move in the way that they move? It's like through positive and negative attraction, for example, or just covalent bonds	2
2	Yeah, I don't know how much like of molecule movement is actually like unpredictable, I think that like they mostly- it's mostly directed, um, based on umm, like intramolecular and um, intermolecular like uh interactions that they have, so I don't think a lot of it is like ambiguous	2
	So at what distance might a protein receptor be from its ligand for those forces that you talk about to be in place. Is it- is it there all the time, or is it just when the ligand be- is very close to the protein or...	
2	I think there's always going to be a little- I think there's always going to be a bond present? It's just the strength of the bond and it decreases over like distance and stuff?	2
1	whenever I would say there's a process or an end purpose	2

	let's say DNA, uh or DNA being uh transcribed and translated into protein, so you have the mRNA produced and then some- and that's carried outside of the cell and then you have a tRNA molecule and- and a ribosome coming together. The tRNA would bring amino acids to <the> ribosome so in that sense	2
1	the amino acid's being directed to the ribosome by tRNA for the overall purpose of synthesizing a protein.	
	An extracellular molecule attempts to move towards its receptor. Uh, do you want to sort of discuss your reasons for answering what you did, maybe? And you can also discuss the other questions that are on the screen there in the same... general idea	
	you have uh, let's say an amino acid going to the ribosome, the amino acid itself doesn't attempt to go to	3
1	the ribosome. You have another molecule assisting it to go there.	
	then you have other molecules that do on their own have enough affinity, let's say due to proximity, or just	2
1	the presence of them being- always being there, in which they would move to the receptor	
1	I would put it down as true, because I associate uh, like I said direction with uh purpose	2
	in this particular question, the first thing that comes to mind is the idea of the chemical synapse and like <*> and all that, so um, I can't remember exactly what the molecule was called, but um, the one that...it's the same idea with that just being able to find its receptor, like on its own, like it didn't really need that	2
3	much assistance, if any, to find that receptor on the other side, so uh, I would say it's true in that sense.	
	If you answered true for that, how specific is that molecule's objective?...Is it... attempting to move towards one specific molecule or equally likely for any of- of that receptor? Or maybe there's a few different types of receptors that it- that it might bind to	
	For the most part, well when I think of uh binding, I would say that it has to be quite specific, because of the complexity of everything going on. You don't want a molecule to be uh ambiguous in its binding. However you do have times where uh you have so many multiple pathways that overlap with one another,	1
1	and so that one molecule could bind to different receptors for different purposes	
	Okay, and if it's the same- if it's multiple copies of the same kind of receptor, does that make a difference?	
	Um, I guess in those regards I wouldn't say it would be uh specific, as long as they're- the receptor in its whole is identical to the others and that extracellular molecule has a specific objective to get- let's say that it's supposed to bring it into the cell, um, it- I would just think of those other receptors as just other copies	4
1	to increase the amount or the rate at which the molecules are brought in	
	is that how- like in the second option there, is that how you interpreted that one- that option? Or was that kind of ambiguous as to what that was... referring to?	
	I sort of thought of it as: you have a type of receptor and then you ha- which is made up of different molecules, and your particular extracellular molecule could bind to any of those different types, as opposed to how you described it, as one type of receptor that's identical and you can bind to any of them	1
1		
4	Yeah, that's-_ that's the same way I kind of interpreted that too	1
	And how about the last one there: All types of molecules have an objective?	
2	I think I put true for that one.	2

3	Yeah, I think I put true as well	2
3	obviously each molecule has like a different chemical property behind it? Um, so I- I think that that has a big factor in it having an- an objective, so different molecules with so many different chemical properties, there has to be...	1
2	Some purpose	2
	When you say an objective or a purpose, do you mean that it actually has um, a mission of some kind to complete?	
2	That's what I picture	2
	Or, that it is well suited because of its configuration	
3	Well suited, sorry, yeah...To a variety of jobs, and with so much different uh types of molecules and- <it> should be able to see like a very large variety of different jobs	1
	when I think of the word purpose, I think- I interpret it as you're saying that the molecule knows that it has to bind with this, and that it knows what its job is and it needs to complete it	
2	That's what I picture <that helps> yeah, like- like a very focused and driven- like that's- that's what I think of? Um, like it has an actual purpose and it has like an actual like role in a chemical process or in the processes that are going on, so I kind of like interpret it as like an intentional type thing, even though it's probably not because it has like guiding forces and guiding molecules, but I see the molecule as like something that's deliberately trying to accomplish something	2
	So if- um- if like you said, a molecule might have a variety of- of purposes, uh let's say you have a- a ligand <like this> extracellular molecule and it can bind to two different types of- of receptors and that the downstream effects in the cell might be different. So molecule- or receptor A, receptor B and if the molecule is here, does it have a particular objective to one or the other? Or is it equally likely that it would bind to one or the other?	
1	For that, if let's say the molecule was- was working on its own, I would say then uh it could go to either, but if we are let's say dealing with complex or other interactions could- that could affect that molecule's let's say affinity to each of the receptor, uh, then I would go with uh it would have a specific purpose let's say, but if the chemistry was like identical and we're only dealing with those receptors, they're the same- um they're the s- the extracellular components are the same, the intracellular component alters it and produces different results, I would say then it- it could bind to either or	2
	An extracellular molecule knows the location of its receptor. True or false? If it's- there's some distance between them uh- let's say- say you have mol- uh receptor and a ligand, there over here. Does it- does this molecule know where this is?	
3	I would say it's true	2
3	Um, I'm- the idea I'm thinking of right now is with DNA? So transcription and translation, and the fact that we need to have all the complexes bind to the um the DNA strand so that it can uh start the DNA replication process, uh, like you have all these complexes coming from different parts of the cell, um, and they obviously must know where the DNA strand is in order to come together in such a way that it can function, um, in DNA replication, so I would say yes	2
	How do the com- the transcription complexes know where the DNA is?	

3	Uh, again, I- I was just kinda just basing it off what I've know before...So that's kind of where_ I got my idea and then kind of just linked it back to something I'd learned in the past	2
1	I would go with a little bit of let's say hard-wired and interactions when it's close to the receptor, cause everything to me when I'm thinking of uh those interactions is localized and compartmentalized into some- into some region, and so um, to know the location of one's receptor, it would have to be in a specific region?	2
1	what gets me though I guess with the question is- and even for- it might just be me is that um...	1
2	The word know?	1
1	The word know	1
4	The word- yeah	1
2	Yeah, that threw me off too	1
1	it's still hard to sort of grasp that- that seemed like a very uh human sort of understanding [others agreement] when the word know is like- for us when- do you know this answer, yes or no? Like, for me I don't think of molecules as having the ability to think	0
4	To like _interpret, yeah, like- yeah yeah	0
3	Yeah, definitely_	0
1	And it's still- it's still weird for me to think about that as in how the molecules are <hard to *>	0
2	Cause it seems like it can make a choice, if it _knows_ then it can like- yeah it can make decisions, whereas the options are like it has hard-wile- hard-wired knowledge, so it's already going to do it, so I don't know	2
	So it could be hard-wired, but not necessarily _know something_	0
3	_You know, yeah	0
1	_Yes, exactly_	0
4	When I think of know, I feel like um, like they made a conscious decision, _like_ this is what I'm going to _do_	0
1	_Yeah_ _Exactly_	0
4	But um, yeah I feel it's more the hard-wired knowledge, like-	2
	if you're able to expand on the hard-wired knowledge...how does that information exist in the ligand?	
1	Uh, the- the structure of uh both components, I guess would be the best way of describing how a molecule would know to bind to something else	4
	So how do the- how do the structures direct one to bind to the other if they haven't already come in contact?	
1	in textbooks or classes we've learned that molecules are brought by something else to something else, but how exactly is it directed there... uh cause we know that interactions are based on let's say affinity, but going back to the concept of knowing...	3

4	molecules that are going through- flowing through your blood and then like they bound to receptors that are in cells, right?...they would be brought through the blood and then if they came into proximity of the receptor then they would like have the attraction and they would bond there	2
4	But if like- if they didn't come into proximity with that certain receptor, then they wouldn't bind to that- like they wouldn't have the affinity to go there	2
	So if the- if they're not in the blood, if it's just in a like- let's say between uh- in a synapse or something like that, there's no other molecule bringing it or fluid flow bringing it, do they- how do molecules get around?	
2	Well I was thinking like enzymes, and you know how they like- is it enzymes, they attach to certain- I was thinking lock and key type thing...	4
2	so they're gonna- like they're always just going to attach to that certain receptor regardless of distance? So like I always thought they had a predisposed- predispos- predisposition, so like attaching, regardless of proximity, but yeah, what she said sounds pretty accurate too, like how if they're in proximity, then they're going to be more likely to interact	2
4	we just kind of thought of it as something else brings it by	3
	…so what's bringing it by? Another molecule or-?	
1	Yeah, I would say another molecule	3
4	Yeah	3
3	I would- I would say then I guess like everything kind of- obviously everything has to do like- has a purpose to do something, so I guess it kind of depends on each other in a sense, so one thing needs to be made before the other can be made and then those two can maybe like help each other kind of get to where they need to go, so I guess it's really dependent on one another, so that's not so much independent work but _more dependent?_	2
2	It's all directed, like everything seems to _have a purpose_... yeah	2
3	Fall into place_	2
	Kind of like um, like a clock mechanism, all the gears are... _in place?_	
	Yeah, yeah_ <that's really good>	2
	An extracellular molecule can change trajectory on its own. Change the direction that it's moving. How do you feel about that?	
2	I don't think it can change it on- like on it's own, just like floating through space and then it decides not to attach to that receptor and... _yeah	4
1	I would agree, they- there would have to be some uh other factor _that causes it to change..._ yeah, to change its trajectory, if it, let's say it's build in a certain way to go to a certain location, and uh it has affinity for something and it's moving towards it, it can't just say "Okay well, I'm not going to do this today"...it has to be something else <*> that's going to, let's say have a greater affinity for that, causing it to change its trajectory	2
2	Or like a catalyst or something	2

What- what if its trajectory- like it- say the receptor is here and it's moving this way and it's going to miss it… Could it at that point change its trajectory?

1	Yes, uh but again, I would say that would be- like the- that other factor for it to- the factor is that you have this receptor there that has an affinity for this molecule…It's not just deciding to move in that direction	2
4	Yeah, I feel the same way	2
2	Cause I think when you say on its own, you're- it's kind of like saying that the molecule has- can make its own decisions and it's like capable of like- for- thinking for itself, whereas I feel like like- the example that she gave, even if it did go off the trajectory, it's still fulfilling its purpose and it's still doing what it's predisposed to do, so it's not really doing it on its own, _like_ it's still compelled to do it by what- why- like why it exists	2

Um... molecules don't have that kind of human decision making _capacity_, but they're embedded with a set of instructions that they need to fulfil

1	Yeah, yes,_ Yes	2

So in what part of the structure of the molecule would the instructions be located?

1	Uh, in its, like the core structure, so let's- if I'm going to say this in terms of proteins, their primary structure determines their overall goal, their overall purpose because primary structure leads to secondary which leads to tertiary which leads to quaternary structure, so without that original like fundamental base, um, it wouldn't be able to do anything it could do. So like it- the basic- like the building blocks, yeah the building blocks of that molecule determine uh its purpose, its- its objective	3

But how is the actual purpose defined? Like you can say that this pen is well suited to writing [others agree]... but does that make its purpose writing

3	I guess that kinda comes from- that it links back to DNA as well? The idea of how it-	4
1	I would go back to structure uh equals function. So, purpose is the function of whatever it is. It's based on the structure, and like she said, it's all linked back to DNA, because the DNA codes for a particular structure and then that structure yields a cer- a certain function	4
4	I think the purpose is also determined by its inability to do any- like anything else apart from like its- _like the tas-_ what it's supposed to be doing	2
1	But then again it's also weird to think about like when we're- we're talking about DNA and proteins, but then when you talk about just <sort of> inorganic molecules such as carbon dioxide or other things... that's a little bit trickier to understand	2

so these- these have to do with how directly or purposefully a molecule might move if it's less critical to cell function...but would you agree that a molecule that's more important to cell- proper cell function moves more directly?

1	Yeah, I would- I would agree with that question	2
4	Yeah, true	2
3	True_	2
1	Cause if it has a- if it needs to- if it needs to do something, then the cell would have a- uh would have a reason to make sure it completes that function as opposed to something that is less critical	2

2	I pictured like blood clotting, cause like when you- like if you ne- if you've been cut and you need your blood to clot, like the molecules are going to move quickly to the spot, cause it's their- like they have purpose and they have direction, whereas something- another process that might be happening in the body that doesn't need um those molecules as much	2
	And how about the second question? Uh, it moves more directly when it has been activated, like you- uh- you- are you familiar with the idea that pho- like phosphorylation _in certain cases_ sort of act- activates it, whether it's opening up a binding site or something like that	
1	I would- I would completely agree with it, uh that there are certain uh modifications made on certain molecules to uh really specify its function, so it could be present but it could inactive like the question says, but then once a certain modification is done to it, then it completely alters uh its purpose, which brings it back to its structure. Its structure has been changed and now it has a new function	1
	In the case of simple diffusion at the molecular level, solvent and solute molecules have equivalent roles. Now that- how do- how do you interpret that question and how did you answer that?	
3	linking back to like the d- the basic diff- definition of diffusion, so from particles moving from higher to lower concentration, I would say that um, the solute has a bit more of an important role in the sense where it's the one moving and not the solvent itself?	2
	How would you um define- could you define the concentration of the solvent? Does it have a higher and lower concentration	
1	I wouldn't know if I'd be able to say true or false like completely for this question again, cause I think of it in so many different ways. You mentioned the solutes have a- have the role of let's say moving across an area, but also let's say if the solvents restricting it, then the solvent could have a role also in diffusion, but if that's not the case then they wouldn't and it would be completely dependent on the solutes	0
2	I look at it like as a- like a give and take type process, so like as the solute is- as the solvent is being dissolved, the um the reaction- the interactions between molecules um, I feel like they're pretty much equiv- equivalent cause both of them are contributing the same, like at a molecular level, they're both interacting with one another, um...	4
3	Yeah	4
4	Um, yeah I feel the same way, it's just um, I picture more like um if like if the concentration is more on this side and there is like more solute but less solvent, then the solvent would move here, right, so like- I feel like it's dependent on both, so yeah I feel like they do have an equal role	4
	And the second question there, uh, simple diffusion across a permeable membrane, so this- so the molecules can move in both directions and the solvent can move across the membrane as well, once solute molecules reach an equilibrium, once the concentration is the same on either side of the membrane, they cease to cross the membrane	
4	_I think they're_ constantly moving	4
2	They're constantly-	4
3	Yeah <I'd say> false	4

1	Yeah, there's- there's uh- like I would say the same thing false right away	4

Participant	Focus Group 2: Statement / Question	Code
	An extracellular molecule attempts to move towards its receptor. Ie it has a binding objective." How do you interpret that question; what're your impressions of that idea?	
8	In class or anywhere, we usually learn about how different um molecules have a specific job in the cell or something like that, so automatically I think, Oh yeah, it does have a specific thing- a- an objective	2
7	Yeah, I would say the same thing and how, if- it has- it mo- moves towards one receptor or if it moves towards more than one so there are variety in the- … I think like everything has a job, but everything is like- they can have more <like> functions as well,	2
	"An extracellular molecule attempts to move towards its receptor." We want to get your thoughts and impressions of that concept and whether you think that would be true or false and why?	
5	Um, I know it like- ha- tries to move towards a receptor because it wants to attach to the receptor to like um... stimulate another- another reaction to occur as it attaches to the receptor, um, there's specific cases where it wouldn't when and- when it doesn't match with the- the shape of the receptor when it can't bind to that properly	2
6	When I think of this, I think of a cell- like when we learned back in grade school, we learned about cells and how one enzyme is specifically made for the other, so they're kinda like those blocks where only one fits the other, so it moves toward it but if they're not- like the puzzle piece together, then they're not _going to bind together_	4
	Lock and key	
6	Yeah, _lock and key	4
5	Lock and key, yeah	4
	And would you say that all types of molecules have an objective? Or a goal?	
6	They have some sort of a goal, in some way they're binding to one another, but I don't think every molecule has a _binding receptor_	1
5	_Yeah, like if its_ function is to bind to a receptor, then it will but then if there's some molecules that cannot bind to the receptor, it will just kind of float around, but they won't really bind to the receptor and perform its function	2
	Can you give me an example of a molecule that wouldn't have an objective?	
8	I kinda disagree with _that, so...	2
7	_Me too_	2
8	Umm, I disagree just because from what I've learned so far, everything that we've talked about has some kind of objective, maybe it isn't carrying out that objective right away, or in that moment, but they have something that they are- they have- they tend to do within maybe a cell	2

7	yeah you can um bind to receptors but there are like active and passive type of transports, I feel like their molecules are moving and they're doing some sort of- they have a role in the body, so that's how I think of it	0
	Where does this objective or role come from?	
5	I think there's like specific messengers or um like we know the core of the cell is the nucleus, which is able to um carry out the messages and you know like- to convey whether like this needs to join with this to perform this function, so I think everything starts from the nucleus, so that could have- that could you know have specific vesicles to um yo- actually carry out the messages	3
8	Um, I don't know- uh like through evolutionary I suppose that they've learned to- which kind of molecules need to do what to be able to carry out things efficiently in like the simplest manner, so I think it's something that's occurred over a long time period to get to a certain point to be able to be this complex maybe or to be able to actually have that specific objective	3
	So one more question before we move on, would this learned behaviour be located within the actual molecules themselves or within the nucleus of the cell?	
5	Umm, I want to say nucleus? _But um, I'm really not sure_	3
6	Yeah, _because the way we were taught_ it was like the nucleus was kind of like the brain of the cell, where it tells the molecules kind of what to do, so it's kind of like the director or the boss, where it like directs the molecules to do everything, so the molecules themselves wouldn't do anything, unless the nucleus specifically kind of sends out a message, like she said to mRNA or- like not mRNA but like the messengers that they have	3
5	Um, I also think that it depends um because sometimes some molecules already have the function ingrained in themselves; they're able to carry out on their own, they just require that message from the nucleus to kind of do the function, but some- there's some molecules that are kind of weak and they require that function and um the message from the nucleus so I think it depends on both ends	3
	An extracellular molecule knows the location of its receptor.	
7	the molecule knows where to go, the receptor I believe will know what molecule it needs to bind to, so I feel like there's a c- a location- a signal type of communication, both uh receptor and molecule?	2
5	It could also be bonds that kind of um help connect or like them recep- the- the uh molecule's able to kind of attract specific bonds that are between it- the mol- molecule and the receptor and so it can bind to the receptor	2
	So just going back to the idea of the signal being passed from the receptor to the molecule, would- is that signal a- a- another molecule, would you think or? _Or- yeah what's- what would be the nature of that signal?_	
7	What- well I don't know, the signal may be coming from like the control centre, the _nucleus,_ I'm not sure like what that signal...	3
6	Or that signal could be included as part of the molecule, where- like once the nucleus tells that- that molecule has to go bind- like to its location, so its signal- the signals would go out, I don't know how it would work but like the signals would go out of the molecule and they would kind of direct the molecule to go find its receptor	3
8	Maybe I thought the molecules were more freely moving and so the way they were built, so their polarity and things like that would affect ho- where- to where in the cell they would move towards,	2

8	I'm trying to think of the example um- was um for contractions in a muscle, um, when the action potential in like the synaptic cleft, you see the calciums move to- um... to the other side- to the less neg- to make it more- less- make it less negative?	4
8	So I think that interaction, that polarity, things like that would in a sense cause- get the molecule to n- go towards its receptor...but I don't think they always know the exact location of it. They're- I would think they're more free moving in that way, through like the cytoplasm and things like that, there's just things that affect it	4
7	I think all of these kind of go together, like yeah there's signals that are being sent to them but also like based on where they are in the cell, if they're close by maybe they'll bind like the receptor and the um molecule	2
	An extracellular molecule can change trajectory on its own. Change the direction that it's moving?	
6	Yes if its environments change around it? Like if the molecule, like she said with the polarity and the electronegativity. So if you change its surrounding and it finds its surrounding where it could attract or another molecule is so high the electronegativity that it could pull that molecule from that place, then in that case the molecule kind of loses its control and moves toward it because the surroundings of the molecules have changed	2
	It- okay, so, if the environment was stable, then...	
5	Yeah, <I think so>	2
8	I think through collisions it can change its trajectory, but I don't think it can on its _own_	4
6	_Yep_	4
7	I- I mean like our body works in efficiency so I- I'm thinking like more of along the lines of you do have a molecule that's su- supposed to go to one receptor, I feel like whatever- whatever the most efficient route it will- it'll take- I'm not sure how it- like if it will change the direction, but maybe the nucleus or whatever some signal does pick the- the most efficient route. It's a guess	2
	A molecule that is critical to normal cell function would move more directly than a less critical molecule. And also, I- maybe before asking this question, what do you think this question means when it asks about moving more directly versus- what- what would the opposite of moving directly be?	
6	Like taking its time to get to its _receptor_, whereas just getting straight to it, so instead of like she said, like taking a long long path or like instead of stumbling around and finding its way, it would have a higher signal which would direct it straight to go to the receptor?	4
7	Like I was thinking more along like second messengers	1
5	And just adding on to that, um I feel like the- I feel like the molecules cannot just take one path or one long path. <The> multiple paths that kind of lead to that one destination, but they might be longer or shorter depending on how directly or indirectly its related to the receptor	0
	A molecule moves dir- more directly when it's been activated, for example by phosphorylation, and you're aware the- the kind of process of- of something phos- phosphorylated and then might change conformation and have- [agreement] good. Um, so how do you feel about that?	

5	I kind of, yeah I kind of agree with it because um it's been activated through uh a natural reaction that occurs in the cell, and as a result um it could provide signals and uh kind of uh provide that force to move in a direct manner	2
7	But there's no function to it I feel like, it's just sitting there	2
6	So, once it becomes active it kind of has a purpose and not just floating around but actually like doing its function, whereas the inactive would just sit around waiting for <it> to bind and become active and then to start its function	2
	in a hypothetical scenario you have a receptor and a molecule and in order for that molecule to bind properly to the receptor it has to be activated by phosphorylation or something like [agreement]. Do you think that the... a collision between the molecule and the receptor ha- would happen more frequently if its activated versus inactivated? ...would the inactive form of the molecule come into contact with the receptor just as likely?	
7	Don't think so	2
8	I wanna say, it would come- like they would be equally in contact, it was just that the one that is actually active would actually connect, because for- in my mind I think it- I kinda d- I guess it depends on the amount of those- the amount- the number of molecules that are there	4
8	If there was an equal amount,_ I would say due to collisions or whatever, they would equally just about hit the receptor, it was just that the active ones would only actually bind and create another sequence of reactions	4
6	Uh, yeah	4
	does that change your idea of the molecule moving more directly when it is activated?	
8	Umm, yes... because okay, when I looked at that question, I kind of thought about ho- what you would consider less critical as compared to critical...Because in my m- my head, I would as- I would- I think they're all kind of critical, _somehow_	1
	okay ignoring the- the critical function idea...so you're saying that an inactive molecule and an active molecule might collide with the receptor equally if they're the same concentration or there are the same number of them in the cell	
8	Yeah	4
	so how do you then interpret the question uh whether the molecule moves more directly when it's been activated than when it's inactive	
8	I would disagree...I would think... there is really no di- more direct movement? I think they're all just kind of random collisions in a way	4
7	Um I thought it was true because when a molecule is activated, like it does go to where it needs to go, when it's inactivated, it will just sit there and not really have a purpose until it waits for the- it to get activated	2
5	Yeah, I agree with it being true because um it's been driven by a reaction so it has more potential to move- to connect to the receptor in a more direct manner than the one that's not driven by a reaction	2

	if a group of molecules is released into an extracellular space, ie through exocytosis, so you uh I can't remember somebody uh mentioned the example of calcium in a synapse or lets say there's neurotransmitters being released into a synaptic cleft, are they certain to spread out over time?	
7	Whenever I think of that I think of diffusion, so going from a high concentration to low, so over time I would think that they would spread out? But I'm not sure	4
6	I agree with it, but also disagree with it in the sense if- like they would release out like she said into diffusion but if that molecule had a specific purpose or _function_ where it needs to stay in that certain area, then I'm guessing it would not diffuse all the way out of the <cell>	2
	Yeah	2
	So you're saying that the f- the purpose supersedes the diffusion?	
6	Yeah	2
5	Kinda all depends on the molecule_ what its main purpose is to-	2
6	What its like function _<is or>_ what it does around the cell	2
5	Yeah_ <can> really affect its movement	2
8	I'm not sure, I feel like it would spread out. I don't think it would stay necessarily in a certain area... kind of. I'm still thinking about that actually	4
	So in this case a solvent would be the water let's say, and the solute molecules let's say it's dye molecules. At the molecular level, they have equivalent roles. True or false?	
7	_I'm kind of confused about the_ equivalent roles, like I know each of them have a role, but like how- like what do you mean by that?	1
8	Right now, I want to say- I would have answered true, right _away_, I'm thinking just looking at it, but mm- I don't- when you think about it, I'm not sure if they would have equivalent roles	1
5	I mean does water being the solvent ha- have any effect on the statement...Does it matter which type of solvent was used	0
7	I feel like because solvent and solute they have to work together, I feel like they would have equivalent roles in order for diffusion to take place.	4
	Okay, and in a different scenario, if you have simple diffusion across a permeable membrane...once solute molecules, so like a salt or- or a sugar reach an equilibrium, in other words there's the same concentration on both sides, right? They cease to cross the membrane, true or false?	
7	I think they've reached their ** because they-> Yeah, so <*>	4
5	<Yeah I was thinking the same>	4
6	I think they would cross back and forth, because they're under the same concentration	4
8	Equal- it'll be equal	4
	How much empty space is in an intracellular environment? Just a gut reaction. Just a- what do you think?	
5	<Low> empty space?...Yeah, that's what I think I put for this	2

8	Low proportion, yeah	2
6	Low	2
	And uh- what do you think about when you think of empty space, like is it a vacuum?	
8	I don't think of vacuum, I think more where maybe there isn't any molecules, just like colliding with each other or interacting with anything, it's just- just little empty spaces that are in between- uh in between molecules, kind of, <enough> in say the cytoplasm of the c- cell, I would just say, it's just a bit of empty space that's there, but... I don't know if- if by empty space do you mean space that there's absolutely nothing, or it- can there be some kind of like _say like cytoplasm_	1
6	_<other different molecules>_	1
8	And then there's just molecules in that	1
	So what is cytoplasm, if there's molecules in the cytoplasm what is the cytoplasm?	
8	That's true... I don't-, then in that case I'm changing it to no empty space [group laughs] and uh I don't think there would be empty space in <this>	4
	But when- when you interpreted the question, you weren't really thinking of at the molecular level	
5,6,8	No	1
	what is- what is the cytoplasm? What's in it?	
5	Fluid?	4
7	Yeah, fluid	4
8	...fluid that's there, that holds to- holds on to the molecules that are-	4
6	But, _<it's not> ribosomes_	0
5	_If there are ribosomes,_ I can see <they> might be like specific enzymes that are in the cytoplasm, but...	0
6	I think of it, it's just like an empty container, like, it has cytoplasm because every cell has a cytoplasm, but the molecules <above> the cytoplasm don't really counteract with... it being a molecule, so... that doesn't factor in because it's there and everything, so I just think of it as like being air	2
	So would you describe like- so you're thinking gas _rather_ than liquid or solid	
6	_Yeah	3
8	Yeah like equivalent, like _I know it's a fluid_, but _to m- like us moving_ through here, there- I would consider this empty _space_ but really it's not, right?	1
6	_It- yeah- it yeah- it is a liquid, but like-_ yeah, _being the cytoplasm	1
7	_Yeah liquid_ _space yeah_	1
5	_It's like, I guess not visibly seen?_	1
6	_There's molecules, there's-_ yeah	4

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