

Supplemental Material

CBE—Life Sciences Education

Tracy *et al.*

SUPPLEMENTAL MATERIALS

Why students struggle in undergraduate biology: sources and solutions

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Table S1. *Survey Items.*

Survey Question
Did you encounter struggle in introductory biology this semester? o Yes o No
You report that you did encounter struggle. Were you able to overcome struggle that you encountered? o Yes o No
Display This Question: If “Did you encounter struggle in introductory biology this semester?” = No Your response suggests that you did not encounter struggle in introductory biology this semester. Please explain why this is or is not an accurate description of your experience
Display This Question: If Did you encounter struggle in introductory biology this semester? = Yes And You report that you did encounter struggle. Were you able to overcome struggle that you encountered? = Yes Your response suggests that you encountered struggle and successfully overcame this struggle in introductory biology this semester. Please explain why this is or is not an accurate description of your experience.
Display This Question: If “Did you encounter struggle in introductory biology this semester?” = Yes And You report that you did encounter struggle. Were you able to overcome struggle that you encountered? = No Your response suggests that you encountered struggle and could not overcome this struggle in introductory biology this semester. Please explain why this is or is not an accurate description of your experience.
What year are you? o First year (Freshman) o Second year (Sophomore) o Third year (Junior) o Fourth year (Senior)
What term best describes your gender identity? <input type="checkbox"/> Man <input type="checkbox"/> Woman <input type="checkbox"/> Intersex <input type="checkbox"/> Transgender <input type="checkbox"/> Gender Queer <input type="checkbox"/> Nonbinary <input type="checkbox"/> my gender is:
What is your race/ethnicity? (Select multiple as they apply) <input type="checkbox"/> American Indian/Alaska Native <input type="checkbox"/> Asian/Asian American <input type="checkbox"/> Black/African American <input type="checkbox"/> Latino/Hispanic/Hispanic American <input type="checkbox"/> Native Hawaiian or Other Pacific Islander

White/European American

My race/ethnicity is...

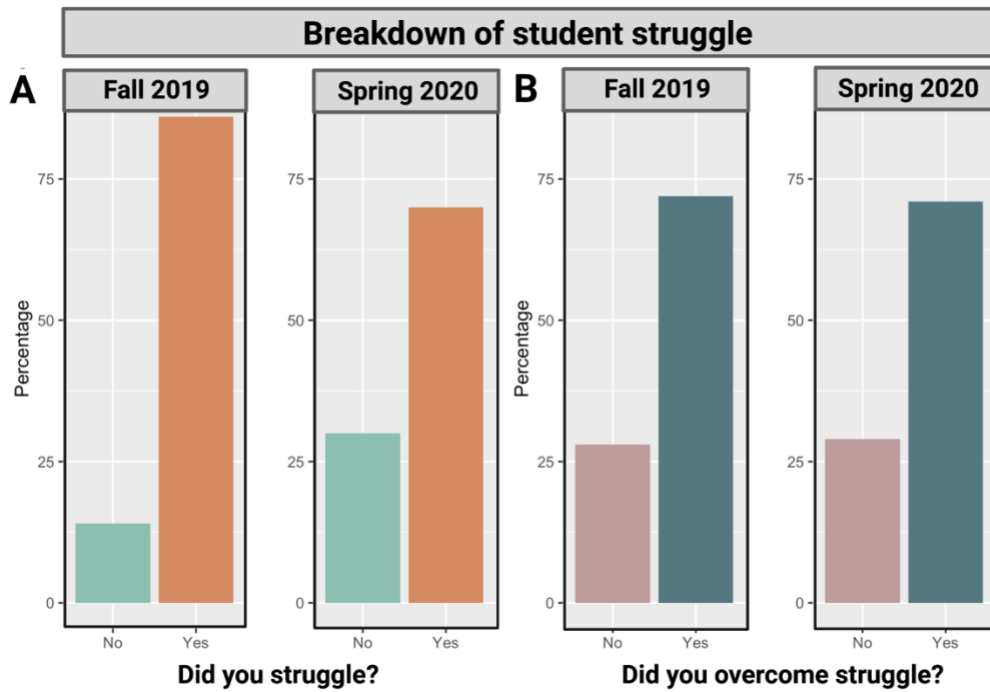


Figure S1. *Breakdown of student struggle across two semesters.* The percentage of students across two semesters who A) reported they did not struggle in biology (No) or reported they did struggle (Yes); B) Among students who reported experiencing struggle, we asked students whether they overcame that struggle. Students either reported they did not overcome their struggle (No) or reported they did overcome their struggle (Yes).

Table S2. *Demographics of all enrolled students in the six classes as well as for only those that participated in our study.*

Gender/Sex	Number of enrolled students	Percent of enrolled students	Number of participating students	Percent of Participating students
Men	508	34.96%	258	26.6%
Women	945	65.04%	679	70.4%
Gender Queer			1	0.1%
Intersex			1	0.1%
Man, Woman			1	0.1%
Nonbinary			2	0.2%
Race/Ethnicity				
American Indian or Native Alaskan	3	0.21%	3	0.3%
Asian	44	3.02%	38	3.9%
Black or African American	80	5.51%	50	5.2%
Caucasian/White	1,174	80.80%	770	79.8%
Hispanic	68	4.68%	16	1.7%
Non-residents	28	1.93%	0	0%
Two or more races or ethnicities	48	3.30%	56	5.8%
Unknown	8	0.55%	8	0.8%
Total	1453	100%	965	100%

**The information representing the number and percent of enrolled students was obtained from institutional data, explaining why Gender/Sex is binary because it is actually representing binary sex. On the other hand, the information representing the number and percent of participating students was collected via survey from the participating students and represents self-reported gender, rather than sex, and race/ethnicity. Of note, the options available on the survey are described in Table S1.*

Table S3. Breakdown of sample sizes for students reporting encountering and overcoming struggle in both the quantitative and qualitative datasets.

Quantitative Dataset (N=960)			
	Fall 2019 Sample Size	Spring 2020 Sample Size	Total
Encounter Struggle (No)	63	190	253
Encounter Struggle (Yes)	382	325	707
Overcome Struggle (No)	101	89	190
Overcome Struggle (Yes)	280	235	515
Qualitative Dataset (N=707)			
Encounter Struggle (No)	47	100	147
Encounter Struggle (Yes)	307	253	560
Overcome Struggle (No)	79	69	148
Overcome Struggle (Yes)	228	184	412

Table S4. Model selection determining factors influencing how students encounter struggle.

Df	AIC	Model
5	938.8	Encounter_Struggle ~ PC1 + Instructor
4	936.8	Encounter_Struggle ~ PC1 + Course
8	937.3	Encounter_Struggle ~ PC1 * Instructor
6	933.7	Encounter_Struggle ~ PC1 * Course
10	951.0	Encounter_Struggle ~ PC1 * Year_Rank
6	951.3	Encounter_Struggle ~ PC1 + Year_Rank
7	933.6	Encounter_Struggle ~ PC1 * Course + (1 AUID)
7	924.7	Encounter_Struggle ~ PC1 * Course + (1 Year_Rank)
7	935.7	Encounter_Struggle ~ PC1 * Course + (1 Section)
7	935.7	Encounter_Struggle ~ PC1 * Course + (1 Semester)
7	935.7	Encounter_Struggle ~ PC1 * Course + (1 Instructor)
8	925.4	Encounter_Struggle ~ PC1 * Course + (1 AUID) + (1 Year_Rank)
8	926.7	Encounter_Struggle ~ PC1 * Course + (1 Instructor) + (1 Year_Rank)
8	935.6	Encounter_Struggle ~ PC1 * Course + (1 AUID) + (1 Semester)
8	926.7	Encounter_Struggle ~ PC1 * Course + (1 Semester) + (1 Year_Rank)
8	937.7	Encounter_Struggle ~ PC1 * Course + (1 Section) + (1 Semester)
8	926.7	Encounter_Struggle ~ PC1 * Course + (1 Section) + (1 Year_Rank)
8	935.6	Encounter_Struggle ~ PC1 * Course + (1 Section) + (1 AUID)
9	937.6	Encounter_Struggle ~ PC1 * Course + (1 Section) + (1 AUID) + (1 Semester)
9	927.4	Encounter_Struggle ~ PC1 * Course + (1 Section) + (1 AUID) + (1 Year_Rank)
9	928.7	Encounter_Struggle ~ PC1 * Course + (1 Section) + (1 Year_Rank) + (1 Semester)
9	927.4	Encounter_Struggle ~ PC1 * Course + (1 Year_Rank) + (1 AUID) + (1 Semester)
10	929.4	Encounter_Struggle ~ PC1 * Course + (1 Section) + (1 AUID) + (1 Semester) + (1 Year_Rank)

Table S5. Model selection determining factors influencing how students overcome struggle.

Df	AIC	Model
5	764.3	<i>Overcome_Struggle ~ PC1 + Instructor</i>
4	778.4	Overcome_Struggle ~ PC1 + Course
8	766.0	Overcome_Struggle ~ PC1 * Instructor
6	779.6	Overcome_Struggle ~ PC1 * Course
10	784.2	Overcome_Struggle ~ PC1 * Year_Rank
6	779.8	Overcome_Struggle ~ PC1 + Year_Rank
6	764.6	Overcome_Struggle ~ PC1 + Instructor + (1 AUID)
6	766.3	Overcome_Struggle ~ PC1 + Instructor + (1 Year_Rank)
6	766.3	Overcome_Struggle ~ PC1 + Instructor + (1 Section)
6	766.3	Overcome_Struggle ~ PC1 + Instructor + (1 Semester)
7	766.6	Overcome_Struggle ~ PC1 + Instructor + (1 AUID) + (1 Year_Rank)
7	766.6	Overcome_Struggle ~ PC1 + Instructor + (1 AUID) + (1 Semester)
7	768.3	Overcome_Struggle ~ PC1 + Instructor + (1 Semester) + (1 Year_Rank)
7	768.3	Overcome_Struggle ~ PC1 + Instructor + (1 Section) + (1 Semester)
7	768.3	Overcome_Struggle ~ PC1 + Instructor + (1 Section) + (1 Year_Rank)
7	766.6	Overcome_Struggle ~ PC1 + Instructor + (1 Section) + (1 AUID)
8	768.6	Overcome_Struggle ~ PC1 + Instructor + (1 Section) + (1 AUID) + (1 Semester)
8	768.6	Overcome_Struggle ~ PC1 + Instructor + (1 Section) + (1 AUID) + (1 Year_Rank)
8	770.3	Overcome_Struggle ~ PC1 + Instructor + (1 Section) + (1 Year_Rank) + (1 Semester)
8	768.6	Overcome_Struggle ~ PC1 + Instructor + (1 Year_Rank) + (1 AUID) + (1 Semester)
9	770.6	Overcome_Struggle ~ PC1 + Instructor + (1 Section) + (1 AUID) + (1 Semester) + (1 Year_Rank)

Table S6. Linear model results of Encounter Struggle ~ PC1 * Course + (1 | Year_Rank).

Effects of Prep. Scores on Encountering Struggle					
<i>Fixed Effects</i>	<i>Estimates</i>	<i>St. Er.</i>	<i>Z value</i>	<i>Pr(> z)</i>	
(Intercept)	1.6386	0.2668	6.143	8.11e-10	***
PC1	-0.6618	0.1335	-4.957	7.15e-07	***
Course 2	-1.0670	0.2178	-4.899	9.65e-07	***
Course 3	-1.4248	0.2410	-5.911	3.40e-09	***
PC1:Course 2	0.3225	0.1732	1.863	0.0625	.
PC1:Course 3	0.4512	0.1791	2.519	0.0118	*
<i>Random Effects:</i>					
	<i>Variance</i>	<i>St. Dev.</i>			
Year_Rank (Intercept)	0.1347	0.367			
N Student	5				
N Observations	906				
<i>Correlation of Fixed Effects:</i>					
	(Intr)	PC1	Course 2	Course 3	PC1:Course
PC1	-0.251				
Course 2	-0.587	0.319			
Course 3	-0.580	0.278	0.605		
PC1:Course 2	0.242	-0.766	-0.310	-0.251	
PC1:Course 3	0.204	-0.744	-0.247	-0.298	0.572

Table S7. Linear model results of *Overcome Struggle* ~ *PC1* + *Instructor* + (*1* / *Student*).

Effects of Prep. Scores on Overcoming Struggle					
<i>Fixed Effects</i>	<i>Estimates</i>	<i>St. Er.</i>	<i>Z value</i>	<i>Pr(> z)</i>	
(Intercept)	1.14223	0.21520	5.308	1.11e-07	***
PC1	0.25209	0.08559	2.945	0.00322	**
Instructor 1	-0.48089	0.25758	-1.867	0.06191	.
Instructor 4	0.19719	0.30917	0.638	0.52359	
Instructor 2	0.57199	0.26643	2.147	0.52359	*
<i>Random Effects:</i>					
	<i>Variance</i>	<i>St. Dev.</i>			
Student (Intercept)	0.5694	0.7546			
N Student	593				
N Observations	672				
<i>Correlation of Fixed Effects:</i>					
	(Intr)	PC1	InstrB	InstrD	
PC1	0.238				
Instr 1	-0.659	-0.084			
Instr 4	-0.415	-0.018	0.380		
Instr 2	-0.457	0.084	0.426	0.404	

Figure S2

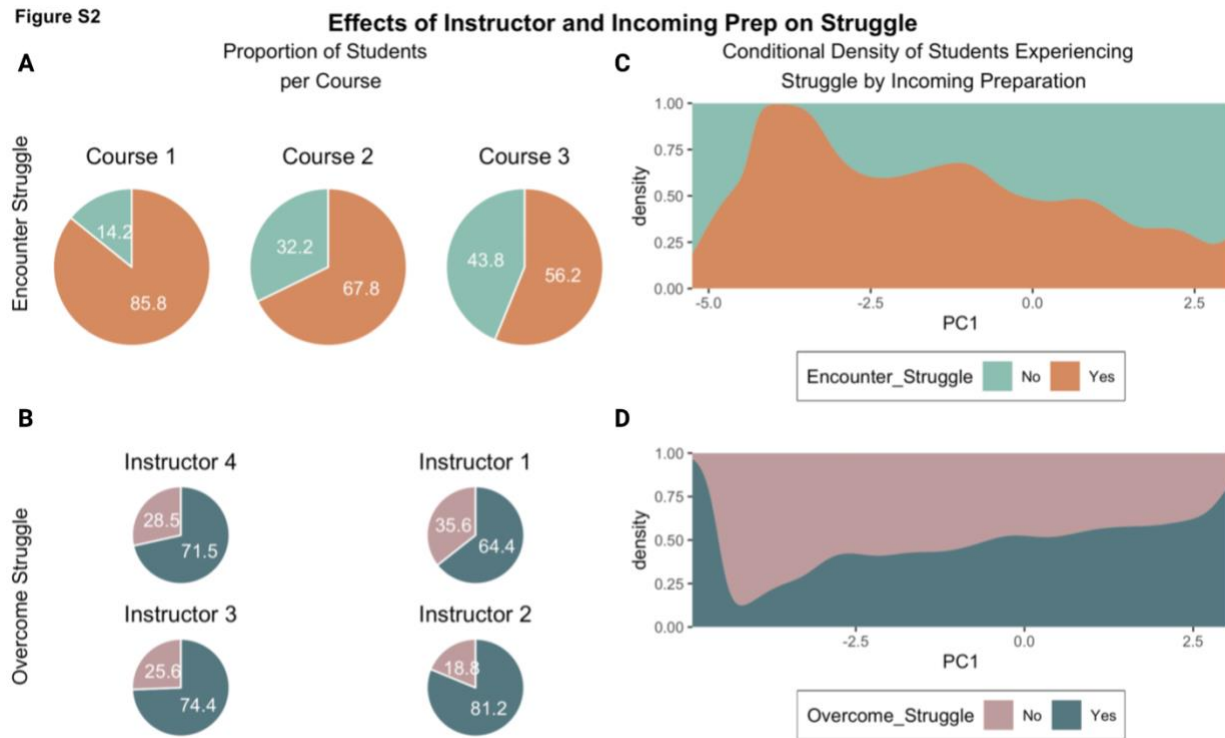


Figure S2. *Effects of Instructor and Incoming Preparation on Struggle.* Proportion of students who A) encountered struggle grouped by course (the factor that was a significant in the model selection for encountering struggle), and B) overcame struggle grouped by instructor (the factor that was a significant in the model selection for overcoming struggle). Conditional density plots of students who C) encountered struggle and D) overcame struggle correlated to their incoming preparation (PC1).

Table S8. Model selection determining best fit model examining if encountering struggle influences course performance.

Df	AIC	Model
3	6842.0	Final.Score ~ Encounter_Struggle
4	6295.6	Final.Score ~ Encounter_Struggle + PC1
5	6295.8	Final.Score ~ Encounter_Struggle*PC1
5	6255.2	Final.Score ~ Encounter_Struggle + PC1 + (1 Instructor)
5	6257.6	Final.Score ~ Encounter_Struggle + PC1 + (1 Section)
5	6271.7	Final.Score ~ Encounter_Struggle + PC1 + (1 Semester)
5	6280.3	Final.Score ~ Encounter_Struggle + PC1 + (1 AUID)
6	6223.9	Final.Score ~ Encounter_Struggle + PC1 + (1 Instructor) + (1 AUID)
6	6234.8	Final.Score ~ Encounter_Struggle + PC1 + (1 Course) + (1 AUID)
6	6225.8	Final.Score ~ Encounter_Struggle + PC1 + (1 Section) + (1 AUID)
6	6246.2	Final.Score ~ Encounter_Struggle + PC1 + (1 Semester) + (1 AUID)
6	6257.1	Final.Score ~ Encounter_Struggle + PC1 + (1 Instructor) + (1 Section)
6	6256.9	Final.Score ~ Encounter_Struggle + PC1 + (1 Instructor) + (1 Semester)
6	6258.5	Final.Score ~ Encounter_Struggle + PC1 + (1 Section) + (1 Semester)
7	6226.7	Final.Score ~ Encounter_Struggle + PC1 + (1 Section) + (1 Semester) + (1 AUID)
7	6258.8	Final.Score ~ Encounter_Struggle + PC1 + (1 Section) + (1 Semester) + (1 Instructor)
7	6225.5	Final.Score ~ Encounter_Struggle + PC1 + (1 Section) + (1 Instructor) + (1 AUID)
7	6225.7	Final.Score ~ Encounter_Struggle + PC1 + (1 Instructor) + (1 Semester) + (1 AUID)
8	6227.2	Final.Score ~ Encounter_Struggle + PC1 + (1 Instructor) + (1 Semester) + (1 AUID) + (1 Section)

Table S9. *Linear model of Final Score by Encounter Struggle (Y/N) and Incoming Preparation.*

Effects of Encountering Struggle and Incoming Preparation on Performance					
<i>Fixed Effects</i>	<i>Estimate</i>	<i>Std. Error</i>	<i>t value</i>	<i>Pr (> t)</i>	
(Intercept)	86.2	1.4	62.4	<0.001	**
Encounter Struggle (Yes)	-3.7	0.66	-5.5	<0.001	**
PC1	3.9	0.24	16.2	<0.001	**
					*
<i>Random Effects:</i>					
	<i>Variance</i>	<i>St. Dev.</i>			
Student ID (Intercept)	41.0	6.4			
Instructor (Intercept)	6.3	2.5			
Residual	29.2	5.4			
N Student ID	769				
N Instructor	4				
N Observations	882				
<i>Correlation of Fixed Effects:</i>					
	(Intr)	Enc. Str.			
Encounter Struggle (Y)	-0.4				
PC1 (Incoming Prep)	-0.1	0.2			
	<i>Min.</i>	<i>1Q</i>	<i>Media</i>	<i>3Q</i>	<i>Max</i>
Scaled Residuals	-4.5	-0.4	<i>n</i> 0.1	0.4	2.2

Table S10. Model selection determining best fit model examining if overcoming struggle influences course performance.

Df	AIC	Model
3	5082.4	Final.Score ~ Overcome_Struggle
4	4718.2	Final.Score ~ Overcome_Struggle + PC1
5	4718.1	Final.Score ~ Overcome_Struggle*PC1
5	4698.3	Final.Score ~ Overcome_Struggle + PC1 + (1 Instructor)
5	4699.8	Final.Score ~ Overcome_Struggle + PC1 + (1 Section)
5	4705.4	Final.Score ~ Overcome_Struggle + PC1 + (1 Semester)
5	4716.1	Final.Score ~ Overcome_Struggle + PC1 + (1 AUID)
6	4690.3	Final.Score ~ Overcome_Struggle + PC1 + (1 Instructor) + (1 AUID)
6	4691.9	Final.Score ~ Overcome_Struggle + PC1 + (1 Section) + (1 AUID)
6	4700.4	Final.Score ~ Overcome_Struggle + PC1 + (1 Semester) + (1 AUID)
6	4700.2	Final.Score ~ Overcome_Struggle + PC1 + (1 Instructor) + (1 Section)
6	4699.9	Final.Score ~ Overcome_Struggle + PC1 + (1 Instructor) + (1 Semester)
6	4700.9	Final.Score ~ Overcome_Struggle + PC1 + (1 Section) + (1 Semester)
7	4693.0	Final.Score ~ Overcome_Struggle + PC1 + (1 Section) + (1 Semester) + (1 AUID)
7	4701.9	Final.Score ~ Overcome_Struggle + PC1 + (1 Section) + (1 Semester) + (1 Instructor)
7	4692.2	Final.Score ~ Overcome_Struggle + PC1 + (1 Section) + (1 Instructor) + (1 AUID)
7	4692.0	Final.Score ~ Overcome_Struggle + PC1 + (1 Instructor) + (1 Semester) + (1 AUID)
8	4693.9	Final.Score ~ Overcome_Struggle + PC1 + (1 Instructor) + (1 Semester) + (1 AUID) + (1 Section)

Table S11. *Linear model of Final Score by Overcoming Struggle (Y/N) and Incoming Preparation.*

Effects of Overcoming Struggle and Incoming Preparation on Performance					
<i>Fixed Effects</i>	<i>Estimate</i>	<i>Std. Error</i>	<i>t value</i>	<i>Pr (> t)</i>	
(Intercept)	79.9507	1.2837	62.279	< 0.001	***
Overcome Struggle (Yes)	3.5555	0.7579	4.691	< 0.001	***
PC1	3.9808	0.2871	13.866	< 0.001	***
<i>Random Effects:</i>					
	<i>Variance</i>	<i>St. Dev.</i>			
Student ID	34.293	5.856			
Instructor	4.828	2.197			
Residual	38.172	6.178			
N Student ID	585				
N Instructor	4				
N Observations	659				
<i>Correlation of Fixed Effects:</i>					
	(Intr)	Ov Str			
Overcome Struggle (Y)	-0.438				
PC1 (Incoming Prep)	0.073	-0.117			
	<i>Min.</i>	<i>1Q</i>	<i>Median</i>	<i>3Q</i>	<i>Max</i>
Scaled Residuals	-4.9859	-0.3949	0.1047	0.46	2.3835