

## **Improving student understanding of lipids concepts in a biochemistry course using test-enhanced learning**

*Savannah Horn\* and Marcy Hernick\*†*

\*Department of Pharmaceutical Sciences, Appalachian College of Pharmacy, Oakwood, VA 24631

†To whom correspondence should be addressed: Marcy Hernick, Department of Pharmaceutical Sciences, Appalachian College of Pharmacy, Oakwood, VA. Phone: (276) 498-5244; email: [mhernick@acp.edu](mailto:mhernick@acp.edu)

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Statistic	Cohort <sup>a</sup>	GPA <sup>b</sup>		Credit Hours	
		Year 1	Year 2	Year 1	Year 2
N	Total	34 (46%)	36 (48%)	34 (46%)	36 (48%)
	Non-repeat	27 (36.5%)	31 (41.3%)	27 (36.5%)	31 (41.3%)
	Repeat	7 (9.5%)	5 (6.7%)	7 (9.5%)	5 (6.7%)
Mean	Total	2.12	2.32	6.76	6.53
	Non-Repeat	2.18	2.43	5.07	5.26
	Repeat	1.87	1.69	13.3	14.4
Median	Total	2.05	2.0	4.0	5.0
	Non-Repeat	2.0	2.0	4.0	4.0
	Repeat	2.1	1.5	12.0	13.0
Standard Deviation	Total	0.93	0.86	4.7	4.3
	Non-Repeat	0.99	0.86	3.2	2.8
	Repeat	0.60	0.57	3.7	3.9
<i>p</i> -value <sup>c</sup>	Total	0.335		0.827	

<sup>a</sup> Total refers to the statistics for all students that took biochemistry course(s) prior to enrolment. Non-repeat refers to the statistics for students that did not repeat previous biochemistry course(s) prior to enrolment. Repeat refers to the statistics for students that repeated one or more biochemistry course(s) prior to enrolment. <sup>b</sup> Grade point average (GPA) is out of a 4.0 scale. <sup>c</sup> P-values between years 1 and 2 for GPA and credit hours were calculated using the ANOVA function in KaleidaGraph (alpha = 0.05) for the Total students in each year.

Table S2. Student Performance on Modules by Topic

Topic ( <i>N</i> ) <sup>a</sup>	Parameter <sup>b</sup>	Mean (SD)				Change ( <i>p</i> ) <sup>c</sup>
		First	Last	High	All	
Cholesterol Metabolism & Transport (14)	Difficulty	55.4 (17.0)	83.3 (10.5)	87.1 (8.8)	72.3	31.7 (<0.0001)
	DI	42.7 (16.8)	50.7 (11.9)	42.8 (16.9)	60.9 (9.0)	
Eicosanoids (10)	Difficulty	52.5 (9.7)	84.5 (5.3)	86.8 (5.0)	71.3 (4.8)	34.3 (<0.0001)
	DI	47.3 (9.7)	52.6 (12.3)	43.1 (17.9)	63.4 (5.5)	
Ethanol Metabolism (4)	Difficulty	47.9 (14.7)	81.2 (4.9)	85.4 (4.8)	68.4 (7.1)	37.5 (0.0029)
	DI	51.9 (14.7)	56.7 (6.8)	39.0 (10.0)	65.0 (9.1)	
Fatty Acid Metabolism & Transport (32)	Difficulty	58.5 (13.2)	85.0 (8.1)	90.0 (7.1)	74.6 (7.8)	31.5 (<0.0001)
	DI	50.4 (11.6)	58.9 (12.4)	34.5 (20.0)	65.1 (9.2)	
General Properties (8)	Difficulty	74.4 (8.2)	90.6 (3.7)	94.2 (4.2)	82.9 (4.3)	19.8 (<0.0001)
	DI	54.5 (9.4)	64.9 (9.0)	20.0 (19.4)	68.0 (5.8)	
Hormonal Regulation (15)	Difficulty	56.9 (12.0)	81.7 (7.2)	88.2 (5.3)	72.5 (7.5)	31.3 (<0.0001)
	DI	47.3 (10.3)	53.4 (11.9)	40.3 (20.1)	60.3 (8.9)	
Steroids (6)	Difficulty	61.5 (17.9)	89.7 (7.2)	90.5 (7.8)	77.1 (8.9)	31.3 (0.0046)
	DI	49.6 (8.0)	52.1 (12.4)	39.0 (17.1)	64.5 (4.2)	
<b>General</b>						
Metabolism (39)	Difficulty	58.2 (11.4)	85.4 (6.5)	89.7 (5.7)	74.6 (6.4)	31.5 (<0.0001)
	DI	50.1 (9.4)	57.7 (12.3)	37.5 (18.6)	65.2 (8.2)	
Transport (13)	Difficulty	56.6 (18.6)	85.7 (10.5)	89.0 (9.6)	74.3	32.4 (<0.0001)
	DI	45.5 (18.4)	55.7 (13.0)	35.1 (19.8)	62.4 (9.8)	
Structure (9)	Difficulty	61.0 (16.7)	86.4 (7.2)	88.7 (8.0)	75.2 (9.1)	27.7 (0.00038)
	DI	51.9 (8.3)	56.1 (13.2)	34 (21.3)	65.6 (3.2)	

<sup>a</sup> The number of questions (*N*) for each topic is shown in parentheses. Questions may fall into more than one topic, so the sum of individual topics is greater than the total number of questions. <sup>b</sup> Difficulty = facility index (or mean); DI = discrimination index. <sup>c</sup> *P*-values for response rates to first and high attempts were calculated using the ANOVA function in KaleidaGraph with an alpha = 0.05.

Table S3. Student Performance on Modules by Question Type

Type (N) <sup>a</sup>	Parameter <sup>b</sup>	Mean (SD)				Change (p) <sup>c</sup>
		First	Last	High	All	
All (74)	Difficulty	58.3 (14.1)	85.6 (7.1)	89.6 (6.4)	74.7 (7.8)	31.3 (<0.0001)
	DI	49.2 (11.6)	56.9 (12.2)	37.1 (19.3)	64.6 (7.7)	
A-Type (23)	Difficulty	60.0 (14.5)	88.0 (5.7)	91.5 (5.6)	76.4 (7.0)	31.5 (<0.0001)
	DI	48.1 (11.5)	58.0 (12.4)	32.6 (19.0)	65.1 (5.2)	
K-Type (15)	Difficulty	46.5 (14.9)	80.5 (9.6)	85.5 (8.3)	69.3 (9.6)	39.0 (<0.0001)
	DI	43.0 (12.7)	53.6 (10.2)	46.6 (19.3)	60.3 (7.6)	
SATA (18)	Difficulty	62.9 (7.6)	85.2 (5.7)	89.8 (5.1)	75.2 (5.8)	27.0 (<0.0001)
	DI	55.3 (12.1)	59.5 (12.7)	32.1 (18.8)	68.3 (9.8)	
Matching (17)	Difficulty	61.9 (13.7)	87.7 (5.8)	90.3 (5.9)	76.9 (7.6)	28.4 (<0.0001)
	DI	49.8 (7.1)	55.6 (13.6)	39.8 (18.6)	63.8 (6.8)	
FITB/Numerical (1)	Difficulty	50.0 (-)	82.4 (-)	90.5 (-)	73.2 (-)	40.5 (-)
	DI	44.8 (-)	56.6 (-)	44.8 (-)	65.9 (-)	

<sup>a</sup> The number of questions (N) for each question type is shown in parentheses. <sup>b</sup> Difficulty = facility index (or mean); DI = discrimination index. <sup>c</sup> P-values for response rates to first and high attempts were calculated using the ANOVA function in KaleidaGraph with an alpha = 0.05.

Table S4. Student Performance on Formal Assessments by Topic

Topic	Parameter <sup>a</sup>	Mean (SD)			
		Yr 1: Quiz	Yr 1: Exam	Yr 2: Quiz	Yr 2: Exam
All	Number	16	29	18	25
	Difficulty	79.0 (11.9)	63.4 (26.9)	69.9 (18.7)	80.3 (19.7)
	DI	26.3 (14.3)	27.8 (20.0)	40.4 (22.5)	29.2 (18.9)
Structure-based	Number	1	2	4	2
	Difficulty	72.6 (-)	77.8 (2.9)	82.3 (14.2)	78.0 (4.2)
	DI	28.0 (-)	22.5 (17.7)	35.0 (27.0)	32.5 (3.5)
<i>Lipids I</i>	Number	13	13	11	13
	Difficulty	76.1 (11.3)	70.3 (24.6)	76.0 (17.5)	85.1 (13.3)
	DI	29.8 (13.3)	23.8 (18.1)	35.4 (20.8)	22.8 (19.4)
Ethanol Metabolism	Number	1	2	1	2
	Difficulty	86.3 (-)	47.3 (15.3)	68.0 (-)	87.0 (8.5)
	DI	21.0 (-)	42.5 (10.6)	65.0 (-)	25.0 (21.2)
Fatty Acid Metabolism & Transport	Number	9	9	7	8
	Difficulty	75.3 (13.1)	72.4 (26.3)	71.0 (18.9)	83.4 (15.7)
	DI	31.7 (15.6)	22.2 (18.9)	35.6 (22.1)	24.5 (22.7)
General Properties	Number	1	1	2	1
	Difficulty	72.6 (-)	79.7 (-)	92.0 (5.7)	75.0 (-)
	DI	28.0 (-)	10.0 (-)	20.0 (7.1)	30.0 (-)
Hormonal Regulation	Number	8	6	7	4
	Difficulty	70.7 (9.7)	80.9 (11.2)	72.7 (14.0)	87.5 (11.0)
	DI	37.0 (10.3)	24.1 (20.4)	43.1 (19.8)	21.5 (14.1)
<i>Lipids II</i>	Number	3	16	7	12
	Difficulty	91.8 (2.7)	57.7 (28.2)	60.4 (17.7)	75.1 (24.4)
	DI	11.0 (5.3)	30.9 (21.4)	48.4 (24.2)	36.3 (16.4)
Cholesterol Metabolism & Transport	Number	4	7	3	7
	Difficulty	87.0 (9.8)	50.8 (22.1)	50.2 (18.1)	68.4 (30.0)
	DI	13.5 (6.6)	35.7 (27.0)	52.7 (30.4)	36.4 (16.3)
Eicosanoids	Number	-	7	2	5
	Difficulty	-	55.4 (32.9)	56.0 (9.4)	84.6 (10.1)
	DI	-	31.4 (16.8)	63.0 (17.0)	34.0 (21.6)
Steroids	Number	-	2	2	1
	Difficulty	-	90.1 (3.2)	80.0 (3.8)	95.9 (-)
	DI	-	12.5 (3.5)	27.5 (3.5)	15.0 (-)

<sup>a</sup> N = number of questions for each topic. <sup>b</sup> Difficulty = facility index (or mean); DI = discrimination index.

Table S5. Student Performance on Formal Assessments by Question Type

Type	Parameter <sup>a</sup>	Mean (SD)			
		Yr 1: Quiz	Yr 1: Exam	Yr 2: Quiz	Yr 2: Exam
All	Number	16	29	18	25
	Difficulty	79.0 (11.9)	63.4 (26.9) 70.6 (19.7)*	69.9 (18.7) 71.9 (19.5)*	80.3 (19.7) 84.4 (15.8)*
	DI	26.3 (14.3)	27.8 (20.0)	40.4 (22.5)	29.2 (18.9)
	Point Biserial	33.4 (10.9)	26.2 (14.6)	38.3 (14.6)	30.0 (12.1)
A-Type	Number	5	4	7	8
	Difficulty	84.1 (10.7)	70.3 (22.2)	74.1 (16.2)	84.8 (21.8)
	DI	14.0 (10.0)	27.5 (18.5)	36.7 (20.2)	22.5 (17.9)
	Point Biserial	20.6 (8.4)	24.0 (14.8)	34.7 (13.4)	24.9 (13.1)
K-Type	Number	10	18	6	8
	Difficulty	76.3 (12.8)	70.1 (21.8)	54.9 (16.8)	83.3 (10.8)
	DI	32.7 (12.9)	26.7 (19.8)	51.8 (19.6)	29.5 (25.0)
	Point Biserial	39.9 (5.3)	25.6 (15.0)	42.3 (13.6)	30.8 (15.3)
SATA	Number	-	-	2	2
	Difficulty	-	-	84.5 (10.6) 92.0 (2.8)	90.5 (3.5) 96.0 (1.4)*
	DI	-	-	35.0 (28.3)	22.5 (10.6)
	Point Biserial	-	-	44.5 (16.3)	31.5 (2.1)
Matching	Number	-	1	2	5
	Difficulty	-	76.0 (-) 88.0 (-)*	74.0 (19.8) 84.0 (12.7)*	80.6 (11.1) 88.0 (6.8)*
	DI	-	75.0 (-)	45.0 (28.2)	36.0 (10.8)
	Point Biserial	-	55.0 (-)	46.0 (15.6)	34.8 (7.4)
FITB/Numerical	Number	1	6	1	2
	Difficulty	80.8 (-)	36.5 (32.3) 69.2 (13.5)*	93.3 (-) 93.3 (-)	39.0 (28.2) 66.5 (26.2)
	DI	24.0 (-)	23.3 (15.4)	0 (-)	45.0 (14.1)
	Point Biserial	32.0 (-)	24.8 (11.3)	11.0 (-)	34.5 (9.2)

<sup>a</sup> The number of questions (*N*) for each question type is shown in parentheses. Difficulty = facility index (or mean); DI = discrimination index. \*Reflects scoring with partial credit.

Table S6. Predicted Performance Based on Modules

Assessment	Number of Questions	Parameter <sup>a</sup>	Module Performance Mean (SD)				Assessment Mean (SD)
			First	Last	High	All	
Quiz Year 1	16	Difficulty	56.7	84.3 (6.7)	89.8 (5.7)	73.2 (7.4)	79.0 (11.9)
		DI	49.6	55.1 (11.7)	36.4 (19.8)	63.2 (9.1)	26.3 (14.3)
Exam Year 1	30	Difficulty	55.8	84.3 (8.7)	88.1 (7.2)	72.9 (8.6)	70.6 (19.7)
		DI	45.5	54.0 (11.3)	41.6 (13.1)	62.3 (7.9)	27.8 (20.0)
Quiz Year 2	16	Difficulty	55.8	84.0 (7.1)	88.5 (5.2)	73.3 (7.7)	71.9 (19.5)
		DI	49.0	54.9 (12.3)	38.3 (21.5)	60.9 (8.3)	40.4 (22.5)
Exam Year 2	25	Difficulty	55.7	85.1 (5.5)	88.7 (5.5)	73.3 (7.1)	84.4 (15.8)
		DI	46.5	57.2 (10.9)	42.1 (17.1)	65.2 (8.0)	29.2 (18.9)

<sup>a</sup> Difficulty = facility index (or mean). Since Moodle scores all questions with partial credit, the formal assessment scores shown are adjusted for partial credit. DI = discrimination index.