Supporting Information for

Investigating Evidence in Support of Validity and Reliability for Data Collected with the Meaningful Learning in the Laboratory Instrument (MLLI)

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Demographics

Table S1. Self-reported demographics data of students who completed the pre-course MLLI and consented to participate in this study.

	Percentage of Students (n=869)
Gender Identity	
Man	36.02
Woman	59.72
Other Identity	2.99
Prefer Not to Share	1.27
Race/Ethnicity	
Non-URM	63.06
URM	34.64
Prefer Not to Share	2.30
Age Bracket	
18-22 (Traditional)	86.42
23+ (Nontraditional)	13.58
Major	
Biology	36.25
Chemistry	3.57
Biochemistry	5.29
Engineering	15.19
Other Science	31.88
Non-Science	6.33
Undecided	1.50
University Status	
Postbaccalaureate	3.11
Undergraduate	96.32
Other	0.58
Transfer Status	
Transfer from 2-Year College	20.37
First Generation Status	
First Generation Student	32.80

Item Descriptive Statistics

Table S2. MLLI item descriptive statistics for the training data set (n=434). Assigned categories for items include Cognitive (C), Affective (A), and Cognitive/Affective (C/A). Item wording includes positively worded items (+) and negatively worded items (-).

Item		Assigned Category	Item Wording	Mean	Standard Deviation	Skew	Kurtosis
1	to learn chemistry that will be useful in my life.	C/A	+	69.13	28.19	-0.66	1.35
2	to worry about finishing on time.	A	-	38.04	31.11	0.39	1.49
3	to make decisions about what data to collect.	C	+	74.06	23.22	-0.75	1.11
4	to feel unsure about the purpose of the procedures.	C/A	-	60.40	29.56	-0.44	1.42
5	to experience moments of insight.	C	+	76.66	22.52	-0.96	1.08
6	to be confused about how the instruments work.	C	-	60.42	29.47	-0.47	1.41
7	to learn critical thinking skills.	C	+	81.24	21.45	-1.35	1.03
8	to be excited to do chemistry.	A	+	73.64	26.32	-0.92	1.26
9	to be nervous about making mistakes.	A	-	41.55	31.11	0.24	1.49
10	to consider if my data makes sense.	C	+	80.22	21.74	-1.29	1.04
11	to think about what the molecules are doing.	C	+	72.53	24.29	-0.74	1.17
12	to feel disorganized.	C/A	-	68.94	28.05	-0.80	1.35
13	to develop confidence in the laboratory.	A	+	80.97	21.56	-1.36	1.03
14	to worry about getting good data.	C/A	-	36.57	28.33	0.48	1.36
15	the procedures to be simple to do.	C	-	58.68	25.56	-0.39	1.23
16	to be confused about the underlying concepts.	C	-	56.26	29.53	-0.34	1.42
17	to "get stuck" but keep trying.	C	+	72.51	25.77	-0.80	1.24
17	to be nervous when handling chemicals.	A	-	57.19	31.11	-0.33	1.49
19	to think about chemistry I already know.	C	+	70.77	27.18	-0.74	1.30
20	to worry about the quality of my data.	C/A	-	37.55	29.39	0.46	1.41
21	to be frustrated.	A	-	49.35	32.58	-0.13	1.56
22	to interpret my data beyond only doing calculations.	C	+	73.90	24.31	-1.03	1.17
23	Check Item.	---	---	---	---	---	---
24	to focus on procedures, not concepts.	C	-	53.87	25.85	-0.07	1.24
25	to use my observations to understand the behavior of atoms and molecules.	C	+	78.08	21.71	-1.03	1.04
26	to make mistakes and try again.	C	+	82.01	22.08	-1.36	1.06
27	to be intrigued by the instruments.	C/A	+	68.93	26.05	-0.63	1.25
28	to feel intimidated.	A	-	55.18	31.76	-0.23	1.52
29	to be confused about what my data mean.	C	-	56.19	28.53	-0.31	1.37
30	to be confident when using equipment.	A	+	71.69	22.57	-0.63	1.08
31	to learn problem solving skills.	C	+	82.17	20.77	-1.47	1.00

Factor Loadings

Table S3. Standardized factor loadings for Model A (30 items) and Model A2 (20 items) using the training data set (n = 434). Three dashes (---) indicate that an item was not included in the model.

Standardized Factor Loadings		
	Model A	**Model A2**
Cognitive Items		
3	0.499	0.461
5	0.634	0.612
6	0.217	0.355
7	0.777	0.766
10	0.469	---
11	0.655	0.622
15	-0.061	---
16	0.279	0.422
17	0.260	---
19	0.465	---
22	0.579	0.518
24	0.204	---
25	0.726	0.672
26	0.317	---
29	0.242	0.376
31	0.746	0.755
Affective Items		
2	0.644	---
8	0.427	0.732
9	0.714	0.345
13	0.379	0.699
18	0.505	---
21	0.740	0.514
28	0.725	0.441
30	0.423	0.566
Cognitive and Affective Items		
1	0.288	0.531
4	0.694	0.428
12	0.680	0.484
14	0.627	---
20	0.642	---
27	0.108	0.424

Table S4. Standardized factor loadings for Model B (28 items), Model B2 (20 items), and Model B3 (16 items) using the training data set (n = 434). Three dashes (---) indicate that an item was not included in the model.

Standardized Factor Loadings			
	Model B	**Model B2**	**Model B3**
Positive Items			
1	0.580	0.590	0.606
3	0.495	0.479	0.475
5	0.647	0.646	0.653
7	0.792	0.795	---
8	0.722	0.731	0.745
10	0.448	---	---
11	0.649	0.644	---
13	0.720	0.726	0.720
17	--	---	---
19	0.454	---	---
22	0.556	0.538	0.526
25	0.686	0.672	0.661
26	0.303	---	---
27	0.524	0.519	0.526
30	0.533	0.541	---
31	0.768	0.772	0.750
Negative Items			
2	0.603	---	---
4	0.719	0.717	0.721
6	0.752	0.763	0.762
9	0.690	0.644	---
12	0.692	0.709	0.717
14	0.580	---	---
15	--	---	---
16	0.769	0.792	0.799
18	0.542	---	---
20	0.611	---	---
21	0.742	0.747	0.739
24	0.426	---	---
28	0.718	0.717	0.695
29	0.757	0.777	0.784

Table S5. Standardized factor loadings for Model C (20 items) using the training data set (n = 434). Three dashes (---) indicate that an item was not included in the model.

Standardized Factor Loadings		
	Model C	**Negative Method Factor**
Cognitive Items		
3	0.485	---
5	0.648	---
6	0.001	0.771
7	0.795	---
11	0.666	---
16	0.072	0.780
22	0.564	---
25	0.702	---
29	0.021	0.779
31	0.755	---
Affective Items		
8	0.627	---
9	-0.030	0.661
13	0.812	---
21	0.116	0.718
28	0.099	0.701
30	0.615	---
Cognitive and Affective Items		
1	0.323	---
4	0.126	0.708
12	0.170	0.692
27	0.794	---

Table S6. Standardized factor loadings for the MLLIv2 (Model B3, 16 items) using the training data set (n = 434), testing data set (n = 435), and post-course data set (n = 622).

Standardized Factor Loadings				
		Training	**Testing**	**Post-Course**
Positive Items				
1	to learn chemistry that will be useful in my life.	0.606	0.609	0.665
2	to make decisions about what data to collect.	0.475	0.541	0.427
3	to experience moments of insight.	0.653	0.677	0.677
4	to be excited to do chemistry.	0.745	0.700	0.763
5	to develop confidence in the laboratory.	0.720	0.694	0.730
6	to interpret my data beyond only doing calculations.	0.526	0.548	0.572
7	to use my observations to understand the behavior of atoms and molecules.	0.661	0.729	0.616
8	to be intrigued by the instruments.	0.526	0.600	0.521
9	to learn chemistry that will be useful in my life.	0.750	0.750	0.674
Negative Items				
10	to feel unsure about the purpose of the procedures.	0.721	0.735	0.670
11	to be confused about how the instruments work.	0.762	0.764	0.699
12	to feel disorganized.	0.717	0.675	0.697
13	to be confused about the underlying concepts.	0.799	0.806	0.746
14	to be frustrated.	0.739	0.700	0.717
15	to feel intimidated.	0.695	0.670	0.693
16	to be confused about what my data mean.	0.784	0.780	0.668

Table S7. Standardized factor loadings for each individual factor of the MLLIv2 using the training data (n=434).

Standardized Factor Loadings			
Positive		**Negative**	
1	0.605	10	0.718
2	0.479	11	0.766
3	0.660	12	0.712
4	0.739	13	0.799
5	0.714	14	0.736
6	0.531	15	0.696
7	0.661	16	0.788
8	0.535		
9	0.749		

MLLIv2 Post-Course Items

Table S8. MLLIv2 Post-Assessment factors and items.

Meaningful Learning in the Laboratory Instrument – Version 2 (MLLIv2)	
Post-Course Item Stem	*When I performed experiments in my chemistry laboratory course, I…*
Positive Items	
learned chemistry that will be useful in my life.	
made decisions about what data to collect.	
experienced moments of insight.	
was excited to do chemistry.	
developed confidence in the laboratory.	
interpreted my data beyond only doing calculations.	
used my observations to understand the behavior of atoms and molecules.	
was intrigued by the instruments.	
learned problem solving skills.	
Negative Items	
felt unsure about the purpose of the procedures.	
was confused about how the instruments work.	
felt disorganized.	
was confused about the underlying concepts.	
was frustrated.	
felt intimidated.	
was confused about what my data mean.	