Improved Student Performance in a First-Year Engineering Course with Integration of Entrepreneurial Minded Learning

Methods

We used a mixed methods quasi-experimental investigation to assess student learning and EML competencies. Students self-selected enrollment (72 capacity) in either one of 8 sections of the Integrated Transportation System (ITS) course or one of 8 sections of the Advanced Energy Vehicle (AEV) course (control group). The ITS sections were the EML integrated curricula while the AEV sections were the traditional sections. Quantitative data included pre- and post-collection of Kashdans' Five-Dimensional Curiosity Scale (5DC), which measures students' curiosity in the following areas: joyous exploration, deprivation sensitivity, stress tolerance, social curiosity, and thrill seeking [4]. Assessment of EML skillset related to creating value and creating connections, defined as the ability to integrate information from many sources to gain insight, were measured using students' grades for project assignments. Technical learning was assessed using four common engineering graphics exams and one lab proficiency quiz.

Results

With IRB approval, we conducted the consent process with 1,072 students in 16 sections (8 AEV and 8 ITS). We received and documented consent for participation in the assessment study from 857 students.

Of these 857 students, a total of 767 students participated in the pre-data collection and 634 participated in the post-data collection. For the AEV group, the average score for stress tolerance decreased from 4.51 in the pre-survey to 4.35 in the post-survey ($p<.05$), which indicates that students were less tolerant to stress after taking the traditional version of the course. However, no significant difference was found in stress tolerance for the ITS students before and after taking the EML version of the course. In the ITS group, the average score for social curiosity increased from 4.72 to 5.00 ($p<.001$) after taking the course, indicating that students were more curious about the social world around them after taking the EML version of the course. In comparison, no significant difference was found for students in the AEV group between the pre- and post-5DC surveys. With respect to creating connections, the ITS students demonstrated proficiency (score of 80% or higher) in all but 6 of 41 course learning objectives. All learning objectives for creating value were met with a score of 80% or higher. ITS students performed significantly better than AEV students on 3 of 4 graphics exams, and significantly better on the lab proficiency quiz.

Conclusions

The integration of EML concepts into a first-year engineering course significantly improved student performance with respect to technical learning objectives, increased likelihood of taking

risks, and increased social curiosity – all while creating aptitude in EML related competencies of creating connections and creating value.

Research design
In a twenty-month pilot project, the curriculum was revised in the second course of a two-semester Fundamentals of Engineering sequence, and an assessment structure was created and implemented to evaluate students' demonstration of the 3C's and eKSOs as shown in Table 1. The EML curriculum allowed students to complete an open-ended Integrated Transportation System (ITS) project that provided students in large classes opportunities to engage in customer discovery, open-ended ideation, and entrepreneurial engineering discussions. With Institutional Review Board (IRB) approval, the impact on student learning and engagement of the 3C's and 32 of the over 50 eKSOs into the course curriculum was assessed according to the assessment plan shown in Table 1. Data were collected over the spring semester of 2019.

We used a mixed methods quasi-experimental investigation to assess student learning and EML competencies (eKSOs) as shown in Table 1. Students self-selected enrollment (72 capacity) in either one of 8 sections of the Integrated Transportation System (ITS) course (experimental group) or one of 8 sections of the Advanced Energy Vehicle (AEV) course (control group). The ITS sections were the EML integrated curricula while the AEV sections were the traditional sections. In both the ITS and AEV sections students worked in groups of 3 or 4 to conceive, design, prototype, and document a transportation vehicle, while only the AEV sections built and tested their vehicle. Only the ITS sections used the EM-integrated approach beginning with looking at the problem from the perspective of the user and their needs.

Table 1. Overall Project Assessment Plan

Quantitative Evaluation									
EML Construct	**Assessment Instrument**	**Pre/Post Test?**	**ITS Collection Date(s)**	**AEV Collection Date(s)**	**Method of Data Collection**	**Requires Intervention Beyond Normal Curriculum?**	**Expected Additional Student Time to Complete**	**In-Class?**	**Covered in this paper?**
Curiosity	5 Dimensions of Curiosity	Pre & Post	Week 2, Week 15	Week 2, Week 15	Qualtrics Survey (combined with Intrinsic Motivation)	No	15 min each occurrence	No	Yes
Technical Learning	Exams	Multiple	4 graphics & 1 lab proficiency	4 graphics & 1 lab proficiency	Pencil and paper/document upload/other	No	None	Yes	Yes
EML Student Outcome: Value Creation	Project report: rubrics	Multiple	R1, R2, R3, Final Report	N/A	Regular assignment	No	None	No	Yes
Outcome: Connection	Project report: rubrics	Multiple	R1, R2, R3, Final Report	N/A	Regular assignment submission	No	None	No	Yes
Problem Solving/Adaptive Expertise	Problem Solving Prompt	Pre & Post	Week 1, Week 15	Week 1, Week 15	Qualtrics	No	15 min each occurrence	Yes	No
Intrinsic Motivation	Longitudinal Model of Motivation and Identity (LMMI) survey	Pre & Post	Week 2, Week 15	Week 2, Week 15	Qualtrics Survey (combined with Curiosity)	No	15 min each occurrence	No	No
Qualitative Evaluation									
(1 section per instructor)	**Class observation**	No	Week 1-15	N/A	Notes	No	None	Yes	No
(1 per section)	**Focus group**	No	Week 15	N/A	Audio Recording & notes	Yes	60 min	No	No
	Instructor Interview	No	Week 15	N/A	Audio Recording & notes	Yes	None	No	No

Quantitative data included collection of Kashdans' Five-Dimensional Curiosity Scale, which measures students' curiosity in the following areas: joyous exploration, deprivation sensitivity, stress tolerance, social curiosity, and thrill seeking [4]. Students' tendencies in these five dimensions were assessed through pre- and post- course surveys in both the ITS and AEV sections. The meanings of the five dimensions are as following:

- **Joyous exploration**: "a preference for new information and experiences, and the valuing of self-expansion over security."
- **Deprivation Sensitivity**: "seeking information to escape the tension of not knowing something."
- **Stress tolerance**: "the perceived ability to cope with the anxiety inherent in confronting the new."
- **Social curiosity**: "an interest and even fixation on how other people think and behave."
- **Thrill seeking**: "the belief that a good life is about seeking out pleasure and adventure, especially when significant physical, social, legal, and/or financial risks are required" [4].

Assessment of the EM components of creating value and creating connections were measured using students' grades for project assignments in the ITS sections (EM-integrated curriculum) only, as similar learning objectives were not included in the AEV sections. In the ITS sections students worked in groups of 3 or 4 to conceive, design, and prototype an integrated

transportation system in response to user needs they had identified through interviewing potential users and secondary research.

A comprehensive sequence of assignments and reports (represented respectively with "A" for assignment, and "R" for report) were designed specifically to assess EML related learning outcomes (eKSOs), with detailed rubrics created for each assignment/report. The learning outcomes were further delineated into three levels of proficiency: basic, intermediate, and high. When developing the assessment plan, the team went through all the assignments independently and then reached consensus on combinations of learning outcomes (and corresponding proficiencies) that reflect the skillsets in Connections and Creating value. A segment of the first assignment rubric pertaining to Creating value is shown as Table 2.

Table 2. Assignment 1 Rubric Criteria Pertaining to Creating Value.

Learning Outcome	Criterion	Strong	Good	Weak	Zero	Point Value
A01						
1.02 Define a Problem	Define a task	Presented a clearly defined task.	Presented a student task but did not clearly describe the task OR the specific scenario	Presented a student task with vague details that did not clearly describe the task AND the specific scenario	Did not define a student task	1.5
1.02 Define a Problem	Create User Experience Chart	Documented a user experience chart with inclusion of each action performed to carry out the task. Documented a description of this chart and its intended use within the design process.	Documented a user experience chart with inclusion of each action performed to carry out the task. Did not document a description of this chart and its intended use within the design process.	Documented a user experience chart with inclusion of some (but not all) actions performed to carry out the task. Partially documented a description of this chart and its intended use within the design process.	Provided no user experience chart	1.5
1.02 Define a Problem	Document 3-5 current pains	Identified a minimum of 3 unique pains as indicated by unpleasant activities on your user experience chart. Described each of the pains.	Identified 3 pains and described them but did not correlate them to unpleasant actions on user experience chart.	Identified 3 pains but did not describe them and did not correlate them to user experience chart.	Did not provide any pains associated with performing the task	1.5
1.02 Define a Problem	Document 3-5 gains	Listed at least three unique gains representing value created with a potential solution. Gains are clearly defined and are not simple reciprocals of pains.	Listed at least three unique gains representing value created with a potential solution. Gains are not clearly defined.	Listed at least three unique gains representing value created with a potential solution. Gains are not clearly defined and tend to be reciprocals of pains rather than potential value.	Did not provide any gains associated with the potential solution	1.5
1.02 Define a Problem	Identify ethical issues	Identify ethical issues associated with your selected task for more than one stakeholder groups and explain why these are ethical issues	Identify ethical issues associated with your selected task for more than one stakeholder groups but does not explain why these are ethical issues	Identify ethical issues associated with your selected task for only one stakeholder group	Poorly defined a task not meeting the defined opportunity.	1.5

Technical learning was assessed using four common engineering graphics exams and one lab proficiency quiz. The first exam covered the fundamentals of engineering technical drawing by hand, requiring students to translate orthographic and isometric objects into the other form, along with identifying lines that were missing in the orthographic projects. This exam primarily tested students' visualization and ability to draw given the engineering standards. The remainder of the exams tested students' ability to work in SolidWorks. The first tested their ability to create a part when given an engineering drawing of it, the second tested their knowledge of dimensioning practice, and the final covered assemblies and creating full technical drawing packets. The Lab Proficiency Quiz (LPQ) tested students on the hardware and software aspects of their prototype design. For example, questions asking them to identify components of the Arduino microcontroller board used in the project were included, along with others asking them to select the correct segments of code to accomplish a given task.

To accommodate for the additional EML curriculum, it is important to note that students taking the ITS version of the course did have significantly less time with the prototyping component of the design-build project which was anticipated to be a disadvantage for the LPQ. Both groups had the same methods and amount of instruction regarding the graphics aspect of the course, so neither group had an anticipated edge for these exams.

Only the quantitative results indicated in the last column of Table 1 will be presented in this paper.

Results

Students were consented on the first day of classes by a member of the research team in each of the 16 sections. Results for the 5-Dimensions of Curiosity instrument [4], Connections and Creating value using rubrics are all presented below.

Curiosity

The results from the 25-item 5-Dimensions of Curiosity (5DC) instrument developed by Kashdan et al. are presented here [4]. From both ITS and AEV groups, a total of 767 students participated in the pre-survey and gave consent to use their data, while 634 students did so in the post-survey.

Students who completed both the pre- and post-surveys and gave consent to use their data were paired by their unique IDs (paired sample n = 585), which allowed us to compare their curiosity scales before and after completion of the course. In the paired sample, there is no statistically significant difference in four of the five dimensions between the ITS and AEV students in the pre-survey. Data are shown in Figures 1 – 5 below. Additionally, note that in the complete pre-survey sample (N=767), there is no statistically significant difference in any of the five dimensions between ITS and AEV students in the pre-survey, which indicates that the self-

selected enrollment did not result in any systematic differences between the ITS and AEV students.
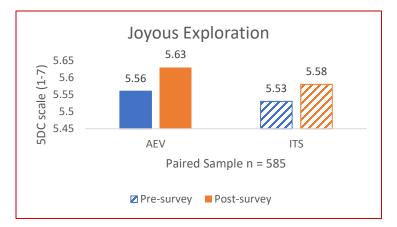

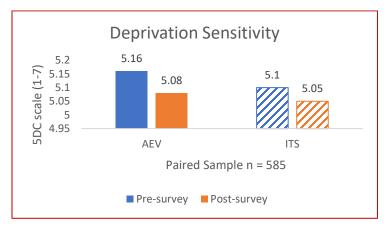*Figure 1: Comparison of pre-post 5 Dimensions of Curiosities' Joyous Exploration Factor*

Figure 2: Comparison of pre-post 5 Dimensions of Curiosities' Deprivation Sensitivity Factor
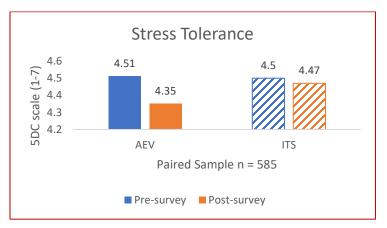

Figure 3: Comparison of pre-post 5 Dimensions of Curiosities' Stress Tolerance Factor
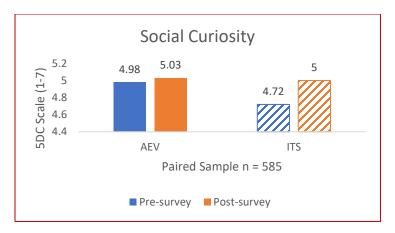
Figure 4: Comparison of pre-post 5 Dimensions of Curiosities' Social Curiosity Factor
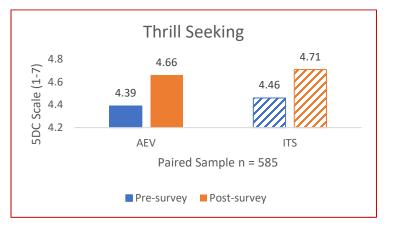

Figure 5: Comparison of pre-post 5 Dimensions of Curiosities' Thrill Seeking Factor

Some main results from Figures 1-5 are summarized below.

- Students in both groups (ITS and AEV) **did not demonstrate statistically significant difference in joyous exploration or deprivation sensitivity before and after taking the course**. Also, for both pre- and post- survey, there is **no statistically significant difference in joyous exploration or deprivation sensitivity between the ITS and AEV groups.**

- For the AEV group, the average score for stress tolerance decreased from 4.51 in the pre-survey to 4.35 in the post-survey (p<.05), which indicates that **students were less tolerant to stress after taking the traditional version** of the course. However, **no significant difference was found** in stress tolerance **for the ITS students** before and after taking the EML version of the course. Although the rate of change appears different, there is **no significant difference** in stress tolerance **between AEV and ITS students** in either the pre- or the post-survey.

- In the ITS group, the average score for social curiosity increased from 4.72 to 5.00 (p<.001) after taking the course, indicating that **students were more curious about the social world**

around them after taking the EML version of the course. In comparison, **no significant difference** was found for students **in the AEV group** between the pre- and post-surveys. Notably, **prior to the course**, students in the **AEV groups** on average had **significantly higher scores** for social curiosity than students in the **ITS group** (4.98 versus 4.72, p<.01). However, there is **no significant difference** in this dimension between ITS and AEV groups **after the course**.

- In both ITS and AEV groups, the average scores for thrill seeking significantly increased from the pre-survey to the post-survey, indicating that **students in both groups are more willing to take risks for satisfactory experiences after taking the course**. However, there is **no significant difference between the ITS and AEV groups** in either the pre- or post-survey.

Four comparisons were conducted for each of the five dimensions of curiosity: AEV-pre vs. AEV-post; ITS-pre vs. ITS-post; AEV-pre vs. ITS-pre; and AEV-post vs. ITS-post. The results are presented in Table 3.

Table 3. Comparisons between AEV and ITS in Kashdans' 5 Dimensions of Curiosity (Paired Sample, N=585)

	AEV	ITS	P
Joyous Exploration			
Pre-survey	5.56 (0.06)	5.53 (0.05)	0.64
Post-survey	5.63 (0.05)	5.58 (0.06)	0.51
P	0.14	0.26	
Deprivation Sensitivity			
Pre-survey	5.16 (0.06)	5.10 (0.06)	0.49
Post-survey	5.08 (0.07)	5.05 (0.06)	0.73
P	0.13	0.33	
Stress Tolerance			
Pre-survey	4.51 (0.08)	4.50 (0.08)	0.97
Post-survey	4.35 (0.08)	4.47 (0.08)	0.29
P	0.04*	0.66	
Social Curiosity			
Pre-survey	4.98 (0.07)	4.72 (0.07)	0.01
Post-survey	5.03 (0.07)	5.00 (0.07)	0.80
P	0.504	0.00***	
Thrill Seeking			
Pre-survey	4.39 (0.07)	4.46 (0.07)	0.53
Post-survey	4.66 (0.07)	4.71 (0.07)	0.63
P	0.00***	0.00***	
N	281	304	

Note: Standard errors in the parentheses. * p<.05; ***p<.001

Connections

The results of assessment of skillsets related to Connections using students' grades for project assignments are presented here. Table 4 reports students' performance on skillset related to connections on assignments, while Table 5 reports students' performance on skillset related to connections on reports. Again, "A" stands for assignment, "R" stands for report, and "A01" stands for assignment 01. The levels of proficiency for each learning outcome are represented by basic, intermediate, and high (represented respectively through "B, I, and H" in Tables 4 and 5). The original scores were converted to percentage of the full mark. The number of entries (column "N" in the Table 4) represents the number of groups whose grades were included in the analysis. The percentage of students that performed equal or better than a benchmark of 80% score was also reported. For example, for Assignment 02, 64% of students earned a grade of 80% or higher for "investigate the market: use information." Target ranges for each proficiency level were set. The target range for Basic and Intermediate level proficiencies are 75% and 60% respectively. In other words, a basic level of proficiency is adequately met if 75% of the students earned a grade of 80% or higher. As the last column in Table 4 and 5 show, **during the course of completing the weekly assignments, students adequately demonstrated proficiency on all but six areas related to connections (rows in red in Tables 4 and 5). Five of the six items that did not meet the target range (denoted in Table 4 with a ^) are related to "investigate the market," and one is related to "define user needs"**. It is important to note that **in more comprehensive reports (e.g. R1, R2, and R3), students adequately demonstrated proficiency on all proficiencies**.

Table 4. Students' Performance on Connection Related Rubrics (Assignments)

Variable	Level	N	Mean	SD	Min	Max	≥ .8 (%)
A02							
Investigate the market: use information	B	125	0.764	0.383	0	1	64.00^
Investigate the market: formulation of question	B	125	0.847	0.249	0	1	61.60^
Investigate the market: individual perspective	B	123	0.912	0.201	0	1	89.43
Define user needs	I	125	0.793	0.288	0	1	56.00^
A03							
Investigate the market	I	135	0.846	0.277	0	1	80.00
Investigate the market: competitive comparison	I	134	0.628	0.446	0	1	57.46^
Define user needs: user segment	I	136	0.693	0.386	0	1	66.18
Define user needs: persona content	I	133	0.93	0.194	0	1	87.97
Define user needs: chart	I	136	0.791	0.335	0	1	77.21
Define user needs: definition	I	136	0.784	0.377	0	1	77.94
Define user needs: pair-wise comparison	I	136	0.933	0.219	0	1	94.12
A04a							
Investigate the market: summarize research	I	134	0.771	0.325	0	1	55.97^
Investigate the market: identify interviewee	I	134	0.953	0.169	0	1	89.55
Investigate the market: summarize results of users	I	134	0.812	0.263	0	1	53.73^

Variable	Level	N	Mean	SD	Min	Max	≥ .8 (%)
Investigate the market: use IEEE standard	I	134	0.731	0.358	0	1	65.67
A04b							
Define user needs	I	118	0.882	0.243	0	1	87.29
Define user needs	I	101	0.824	0.336	0	1	81.19
Investigate the market	I	117	0.918	0.168	0	1	92.31
A05							
Define user needs	I	130	0.882	0.275	0	1	87.69
A19							
Validate user needs: needs	I	135	0.963	0.095	0.6	1	96.30
Validate user needs: method	I	135	0.828	0.232	0	1	79.26
Validate user needs: results	I	135	0.913	0.163	0	1	87.41
A20							
Evaluate economic benefits: expenses	B	134	0.933	0.161	0	1	94.03
Evaluate economic benefits: revenue	B	134	0.867	0.255	0	1	85.82
Evaluate social benefits	I	134	0.933	0.19	0	1	93.28

Table 5. Students' Performance on Connection Related Rubrics (Reports)

Variable	Level	N	Mean	SD	Min	Max	≥ .8 (%)
R1							
Investigate the market	I	136	0.843	0.207	0	1	83.09
Investigate the market	I	136	0.85	0.209	0	1	80.88
Define user needs	I	136	0.854	0.169	0.4	1	75.74
R2							
Investigate the market	I	135	0.926	0.14	0	1	93.33
Investigate the market	I	135	0.915	0.147	0.3	1	88.89
Define user needs	B	135	0.93	0.129	0.6	1	89.63
R3							
Investigate the market	I	88	0.94	0.126	0.5	1	79.55
Investigate the market	I	88	0.932	0.14	0.25	1	77.27
Define user needs	B	88	0.953	0.14	0.38	1	88.64
CDR							
Investigate the market	I	135	0.956	0.106	0.6	1	94.81
Investigate the market	I	135	0.941	0.106	0.4	1	97.78
Define user needs	I	135	0.958	0.103	0.6	1	94.81
Validates Market	B	135	0.956	0.126	0	1	95.56
Validates Market	B	135	0.933	0.169	0	1	95.56
Evaluate economic benefits	B	135	0.969	0.136	0	1	97.04
Evaluate societal benefits	I	135	0.95	0.146	0	1	96.30

Creating Value

A similar approach was taken to assess skillsets related to value creation (see Table 6). Once again, 80% was used as the benchmark for each proficiency. The last column in Table 6 reports the percentage of students who earned a score of 80% or higher. As shown in Table 6, students adequately demonstrated proficiency on all the proficiencies related to value creation.

Table 6. Students' Performance on Value Creation Related Rubrics

Variable	Level*	N**	Mean	SD	Min	Max	≥ .8 (%)
A01*							
Define a task	B	82	.893	.176	0	1	85.37
Create user experience chart	B	82	.854	.175	0	1	82.93
Document 3-5 pains	B	80	.950	.141	0	1	96.25
Document 3-5 gains	B	81	.864	.173	0	1	85.19
Identify ethical issues	B	81	.760	.369	0	1	75.31
A04b							
Identify opportunity	I	118	.958	.101	.6	1	95.76
A05							
Value proposition	B	130	.903	.185	0	1	90.73
A20							
Evaluate economic benefits: expenses	B	134	.933	.161	0	1	94.03
Evaluate economic benefits: revenue	B	134	.867	.255	0	1	85.82
Evaluate societal benefits	I	134	.933	.19	0	1	93.28
R1							
Identify opportunity	I	136	.858	.258	0	1	89.71
Define a problem	I	136	.827	.196	0	1	73.53
Create preliminary business model	B	135	.890	.178	0	1	86.64
R2							
Identify opportunity	I	134	.964	.114	0	1	97.76
Define a problem	I	135	.919	.162	0	1	92.59
Create preliminary business model	B	134	.925	.188	0	1	89.55
R3							
Identify opportunity	I	88	.986	.058	.75	1	94.32
Define a problem	I	88	.932	.13	.5	1	76.14
Create preliminary business model	B	88	.969	.113	.5	1	92.05
CDR							
Identify opportunity	I	135	.990	.042	.8	1	100
Define a problem	I	135	.949	.114	.6	1	93.33
Create preliminary business model	B	135	.964	.095	.6	1	95.56
Evaluate economic benefits	B	135	.969	.136	0	1	97.04
Evaluate societal benefits	I	135	.950	.146	0	1	96.30

Technical Learning

We used a t-test to compare the AEV and ITS students in terms of their average scores on four graphics exams and one lab proficiency quiz. The results are presented in Table 7 and Figure 6. In **Exam 1, ITS students significantly outperformed AEV students** (22.18 versus 21.70, $p<.001$). **ITS students also significantly outperformed AEV students on Exam 2** (21.38 versus 20.04, $p<.001$) **and Exam 4** (22.94 versus 22.44, $p<.05$). On the contrary, **AEV students significantly outperformed ITS students on Exam 3** (18.87 versus 17.81, $p<.001$). In terms of

the **lab proficiency quiz, ITS students performed significantly better** than AEV students (13.41 versus 13.05, p<.05).
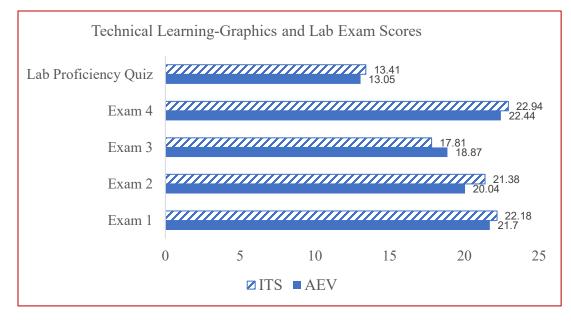

Figure 6. Technical Learning on Graphics and Lab Exam

Table 7. Comparisons between AEV and ITS on exams and lab proficiency

	AEV	ITS	P
Graphics Exam 1	21.70 (3.30)	22.18 (2.96)	0.03*
Graphics Exam 2	20.04 (4.17)	21.38 (4.44)	0.00***
Graphics Exam 3	18.87 (3.45)	17.81 (3.24)	0.00***
Graphics Exam 4	22.44 (3.61)	22.94 (3.62)	0.047*
Lab Proficiency Quiz	13.05 (2.50)	13.41 (2.51)	0.040*
N	411	427	

Note: Standard deviations in the parentheses. * p<.05; ***p<.001

Conclusions

This work models ways that students in large courses can engage in real-world problems at scale without compromising technical proficiency and diversity of student experiences. Based on the results presented above, we have found evidence to suggest that the integration of EML concepts into a first-year engineering course significantly improved student performance with respect to technical learning objectives, increased willingness to take risks, and increased social curiosity (as measured by Kashdans' 5 Dimensions of Curiosity instrument [4])– all while creating aptitude in EML-related competencies of creating connections and creating value. The increase in technical learning for the EML version of the course (ITS), was especially surprising given the short exposure time these students had to working directly with the Arduino microcontroller.

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