# Integration of Entrepreneurial Minded Learning

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


## Abstract

Introduction

In collaboration with KEEN, a network of thousands of engineering faculty working to unleash undergraduate engineers so that they can create personal, economic, and societal value through the entrepreneurial mindset, The Ohio State University added multiple entrepreneurial minded learning (EML) elements to an existing first-year course. This paper represents the assessment findings from the spring 2019 implementation of the new curriculum.

Methods

A mixed methods quasi-experimental investigation was used 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, 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-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.

**Background**

Engineering education has traditionally focused heavily on technical skills, but in the past two decades, an increasing number of engineering education programs have come to recognize that technical skills should be coupled with an entrepreneurial mindset so that engineers can create extraordinary value for employers and society. For example, 47 universities and colleges in the United States have joined the Kern Engineering Entrepreneurship Network (KEEN), a network "dedicated to preparing undergraduate engineering students for success with the entrepreneurial mindset" [5]. Scholars have defined an entrepreneurial mindset as cognitive abilities and habitual ways of thinking that seek to discover opportunities and benefit from uncertainty [2], [3], [6]. Engineers with an entrepreneurial mindset would embrace and learn from, rather than avoid, uncertainty, which increasingly characterizes contemporary business and technological endeavors. Entrepreneurial education for engineers has led to an emerging body of literature on fostering and assessing entrepreneurially minded learning (EML) in engineering programs.

EML refers to "a pedagogical approach emphasizing discovery, opportunity identification, and value creation, while building on other active pedagogies such as problem-based learning" [7]. In addition to delivering knowledge and skills in traditional technical areas, EML provides students with opportunities to approach engineering problems and challenges by promoting curiosity, discovery, connection, and value creation. An EML curriculum cultivates an 'entrepreneurial mindset' (EM) among the students, helping them think like an entrepreneur.

To facilitate the transformation of engineering curricula, educational objectives of EML have been expressed through a series of extended KEEN Student Outcomes (eKSOs) [1]. These outcomes are based on three components of an entrepreneurial mindset: curiosity, connection, and creating value, which are often called the "3C's" [5]. It is believed that engineering students find success and personal fulfillment when they create extraordinary value through combining technical skills and an entrepreneurial mindset. Therefore, if educational institutions foster an entrepreneurial mindset among engineering students, they will:

- Demonstrate constant *curiosity* about the changing world and explore a contrarian view of accepted solutions;
- *Connect* information from many sources to gain insight and assess and manage risk; and
- Identify unexpected opportunities to *create value* and persist through and learn from failure [5].

In addition to the 3C's, engineering educators and researchers also seek to cultivate engineering thoughts and actions that express collaboration, communication, and sound character.

**Objectives**

In order to ensure the successful integration of the 3C's and extended KEEN Student Outcomes in the newly EM-integrated curriculum, the authors investigated first-year engineering students' learning of and engagement with the 3C's through a detailed assessment plan.

**Research design**

In a twenty-month pilot project, the curriculum was revised in the second course of a two-semester Fundamentals of Engineering sequence at The Ohio State University, and an assessment structure was created and implemented to evaluate students' demonstration of the 3C's and eKSOs as shown in Table 1. Of the two first-year courses, the second-semester course was chosen for revision due to its existing engineering design project, into which EML design principles could be incorporated. The EML curriculum allowed students to complete an open-ended Integrated Transportation System (ITS) project that provided students in large classes opportunities to discover and model customer needs and to undergo an entrepreneurial design process in order to provide value for those customers. 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 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. While both AEV and ITS labels were applied to the relevant sections in the course registration system, differences between the two curricula were not publicized before the semester began. The course descriptions provided in the registrar did vary between the versions and clearly stated that EML would be integrated to the ITS version of the course, however these descriptions are not directly viewable to students as they register for courses. Therefore, we expected students to have chosen the sections largely based on the timing of class meetings.[1]

[1] This expectation is partially supported by our qualitative study of student experience in the ITS 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. The primary differences between the ITS and AEV project curricula were in the project's introductory phase, milestones, and conclusion. No content was cut from the standard AEV course offering in the ITS adaptation, but the project was reframed using EML to provide a comprehensive project experience for students, starting with the identification of their own unique problem within transportation by considering design requirements from the users' perspective. Contrastingly, students in the AEV course built and tested their autonomous vehicles subject to a pre-defined set of criteria developed by the department. Their progression through the project was driven by the final objective of completing a run meeting all stated objectives, such as stopping for certain times and at certain locations. The ITS curriculum still integrated this type of hands-on modelling, but students designed and tested their vehicles within the context of the particular problem they sought to solve. The first seven lectures of the ITS course were created to guide students' formulation of their projects, with topics ranging from defining user pains and gains, conducting primary and secondary research, and creating a value proposition statement. After these EML lessons, the content shifted to what was taught in the AEV course, which centered around using the prototyping software and equipment presented to teams as their course lab assignments. A primary difference in this instruction was that students in the ITS course were responsible for identifying how this prototype played into their larger project, while students in the AEV course were just focused on getting the vehicle to run according to the provided requirements. The conclusion of the AEV project was successfully running the vehicle on the track, but running the protype successfully was not the primary objective of the ITS project. Instead, after creating their models and performing tests, students returned to EML content at the end of the course by identifying social and economic value created by their solutions. ITS students concluded the course with a technical design report and a pitch to hypothetical investors.

*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][2]. 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].

[2] The assessment team followed a consensus-building process in selecting the instrument for measuring curiosity. The eventual choice of the Five-Dimensional Curiosity Scale received full support in the team for its sound development process and for the prospect of conducting follow up, longitudinal studies of the students enrolled in this pilot study.

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. These assignments and reports were graded by undergraduate teaching assistants (TAs) who were trained to use the rubrics with example submissions similar to what would be expected from the real student submissions. These example submissions were created by a member of the team and graded by both the team and instructional team members to create baseline scores. The TAs graded the assignments, entering their scores into a quiz which provided them instantaneous feedback on if they were meeting our grading expectations. 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 | None | 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 |

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. In addition, exam 3 also covered dimensioning. 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. While student focus groups and instructor interviews were conducted, the focus of these was on course perception and curricula implantation and not on verifying our quantitative results.

## 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.

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.

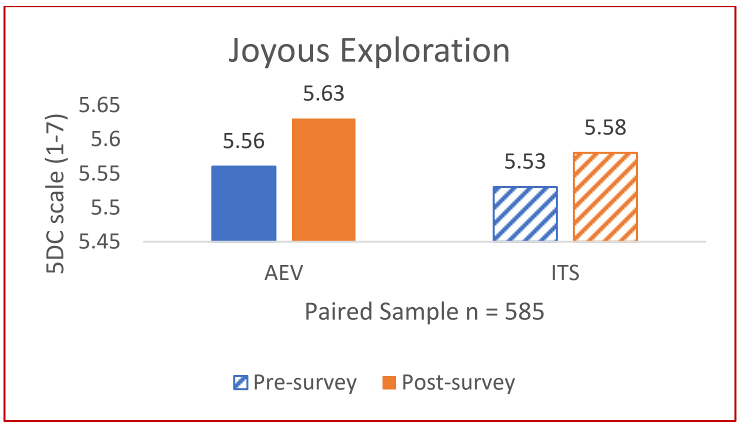


*Figure 1: Comparison of pre-post 5 Dimensions of Curiosities' Joyous Exploration Factor*

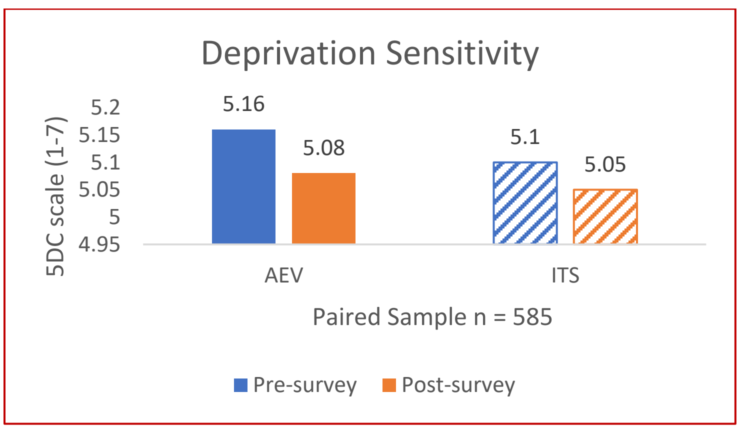


*Figure 2: Comparison of pre-post 5 Dimensions of Curiosities' Deprivation Sensitivity Factor*

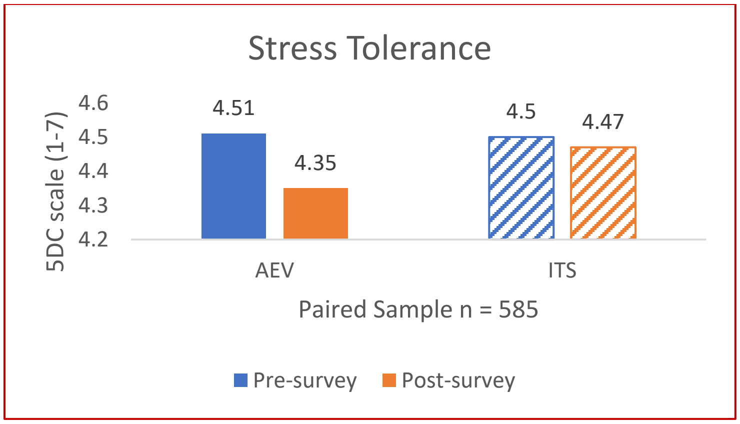


*Figure 3: Comparison of pre-post 5 Dimensions of Curiosities' Stress Tolerance Factor*

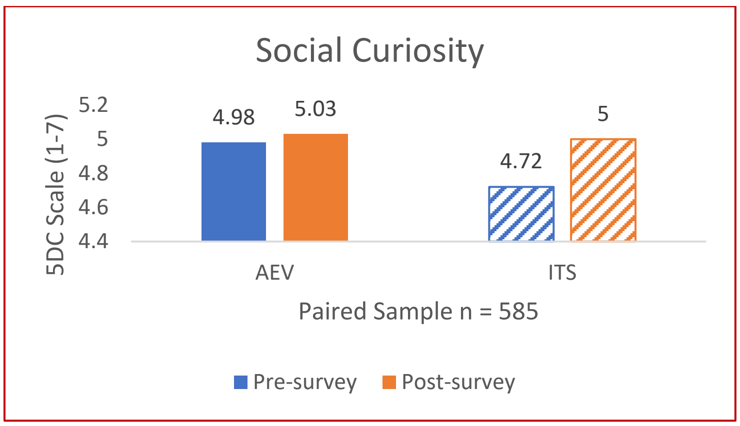


*Figure 4: Comparison of pre-post 5 Dimensions of Curiosities' Social Curiosity Factor*

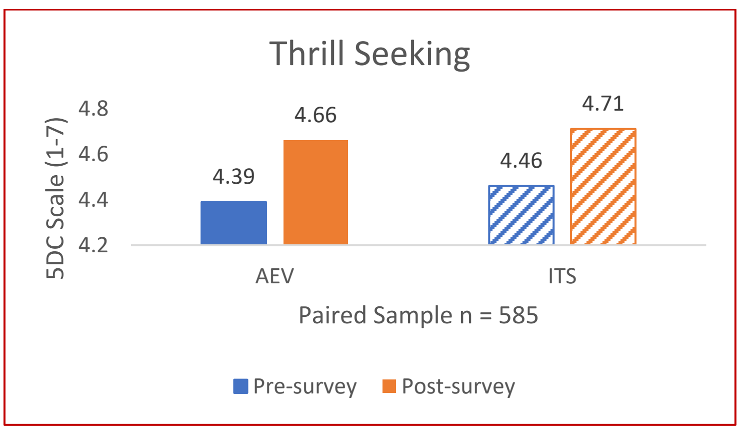


*Figure 5: Comparison of pre-post 5 Dimensions of Curiosities' Thrill Seeking Factor*

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.

*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)*
*(for Level B, success in last column is >75%; for Level I, success in last column is > 60%)*

| 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^ |
| **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)*
*(for Level B, success in last column is >75%; for Level I, success in last column is > 60%)*

| 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*
*(for Level B, success in last column is >75%; for Level I, success in last column is > 60%)*

| 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) where the main content of the exam was dimensioning. In terms of the **lab proficiency quiz, ITS students performed significantly better** than AEV students (13.41 versus 13.05, p<.05).

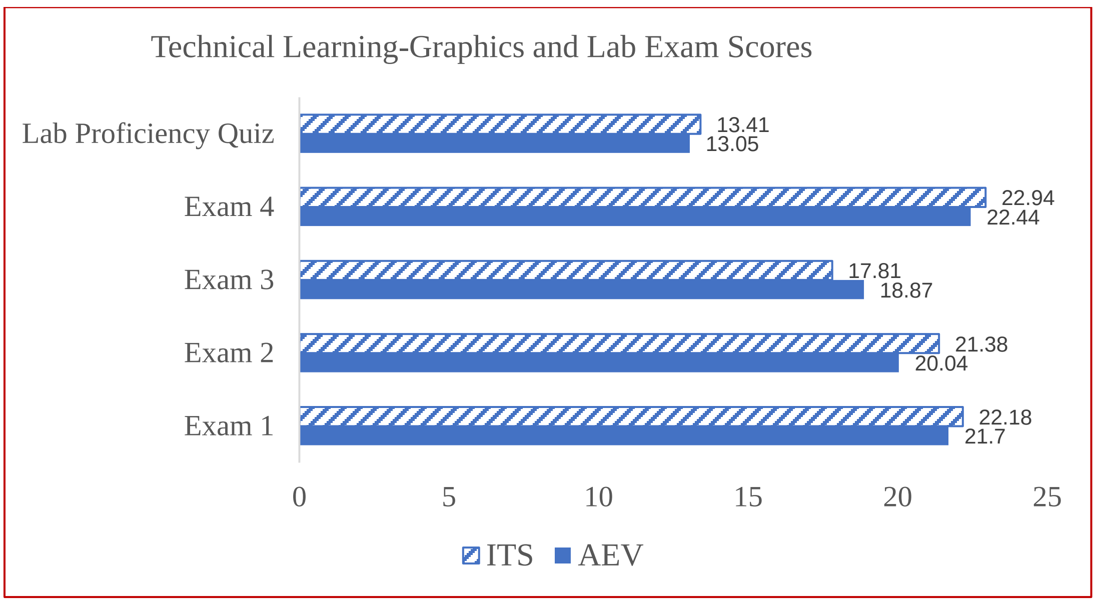


*Figure 6. Technical Learning on Graphics and Lab Exam*

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

| | AEV | ITS | P |
|---|---|---|---|
| **Exam 1** | 21.70 (3.30) | 22.18 (2.96) | 0.03* |
| **Exam 2** | 20.04 (4.17) | 21.38 (4.44) | 0.00*** |
| **Exam 3** | 18.87 (3.45) | 17.81 (3.24) | 0.00*** |
| **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. * $p<.05$; ***$p<.001$

## Discussion

The results from Kashdans' 5DC instrument indicated that the EML curriculum seemed to foster students' curiosity better than the standard curriculum. While both AEV and ITS fostered students' joyous exploration, social curiosity, acceptance of knowledge deprivation and thrill seeking, it was interesting to note that both versions of the course decreased students' stress tolerance. While the decrease was significant in the AEV sections, it was not in the ITS version of the course. It is possible that the grading of final deliverables of the course contributed to this result, as students in the AEV were receiving a grade directly related to their performance, while ITS students were rewarded for presenting their progression through the project. The stressors related to these final deliverables could have impacted how students took the assessment at the end of the term. We will continue to explore the validity of this explanation. If it were true, then, the results suggest that having a more stressful experience in a course without appropriate supporting structure does not increase, but rather decreases, students' ability to manage stress.

The assessment results demonstrated students' progression throughout the semester as they gained familiarity with the EML content. Earlier assessments indicated that students were not meeting the benchmark in several of the outcomes related to connection, however by the milestone reports students were demonstrating better understanding and application of the course material. We believe that the scaffolding of assignments and feedback on all assignments allowed students to develop over time.

The results from the exams were unexpected, as the authors had expected that with identical graphics instruction that the graphics exams 1-4 would be roughly equivalent. The authors had also expected that since the ITS students focused less on the hands-on portion of the project that their lab proficiency quiz results would be slightly decreased. However, the results indicate that graphics performance was generally improved and students' understanding of the project materials was increased with the EML curriculum being introduced. However, there are caveats to this conclusion as the groups were not compared prior to the term starting with a common graphics assessment so it is not clear if the groups came in with similar ability. The GPAs and spatial visualization scores of students entering the course were also not compared and could be used in further analysis to indicate the level of students entering both versions. It is also possible that the instructors played a role in these changes as well, as instructors only taught AEV *or* ITS sections.

**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.

**Future Plans**

As the results of this study have indicated that introducing EML into the first-year curriculum benefits student learning outcomes, the next step that our institution is working on is to integrate this content into our first semester course. This project has gained funding from the KEEN organization and faculty are in the preliminary stages of developing these course modifications. One of the main objectives of these changes would be to introduce EML content early in the first year to allow a gradual scaling up of EML concepts from stand-alone assignments to semester-long projects (in the second course). This approach would allow students to review this material over the course of their first-year experience to gain a deeper, long-lasting understanding.

We plan to do a longitudinal study on this same group of students and re-distribute the Kashdan 5DC instrument around their senior year to see if the changes were long-lasting.

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