The Future of Engineering Education
2024 Annual Conference & Exposition
Oregon Convention Center
Portland, OR . June 23 - 26, 2024
Paper ID #42203

Board 34: Equity Diversity and Inclusion (EDI) and Entrepreneurial Mindset Learning (EML) in Core Engineering Classes: A Case Study in Statics

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Equity Diversity Inclusion (EDI) and Entrepreneurial Mindset Learning (EML) in Core Engineering Classes – Case Study in Statics

1. Introduction

With the high demand on civil engineers as we invest more in infrastructure [1], it is paramount for engineering education to grow into a more inclusive and innovative practice to fulfill societal needs. While some progress has been made in introducing innovation during the first and fourth years of undergraduate education, the middle two years, burdened with core engineering courses, have seen limited change [2]. As we re-develop these courses, integrating "innovative entrepreneurship" in parallel with social ethics and EDI could be a great catalyst for positive change. Literature has shown its inclusive impact on the job market [3] and the economies of nations [4]. Education based on an entrepreneurial mindset relies on collaborations across disciplines, effective group work and productive communication [5], all pillars of inclusive education. It produces a breeding ground for innovative practices to tackle future designs relying on sustainability, equity, and inclusion. In this work, we use the Kern Family Foundation [6] definition of entrepreneurship as "initiatives that have long-term, systemic impact", and rely on the 3Cs to assess it: Curiosity, Connections and Creating value. This definition allows us to see the parallels between EML and EDI, and how their application together enriches civil engineering education.

Research has shown a very distinct link between sustainability and social equity, ethics and responsibility [7] [8] [9]. The NAACP hosted a retreat in 2019 titled: "Centering Equity in the Sustainable Building Sector Initiative". A finding was that the areas that are disaster-prone, where life expectancy is lower and energy is more expensive, are mostly under-represented minoritized (URM) community areas. Even with the great need, these clusters see the least amount of financial investments in sustainable solutions. This proves the need to educate engineers on linking "micro-ethical decisions" with "macro-ethical consequences" within the communities they serve [10]. One way to make this link is through project-based learning in EDI and EML.

In 2014, Atadero et al. ran a study on project-based learning in statics [11] showing that cultivating "inclusive engineering identities" within innovative curriculum practices has lasting outcomes on student retention and development. It has also been shown that project-based learning promotes the application of knowledge as opposed to simply the acquisition of knowledge [12]: In a case study, students in an introductory statics course were divided into two sections, one received a traditional statics course while the other intervention section completed three supplementary projects throughout the semester. While there was no statistically significant difference in standardized statics test scores between sections, data showed that students in the intervention benefitted more from these mixed methods of learning vs. a traditional lecture-based model. This was shown by measuring student autonomy and ability to solve complex problems in later years of their college experience. A similar study [13] showed increased ABET outcome achievement of programs as well as promotion of qualities associated with becoming a successful student and potential entrepreneur. Vaz and Quinn [14] even show that project-based and experiential, place-based, and community engaged learning is particularly impactful, and Nguyes et al. highlight the benefits specifically with minority students [15].

In this work, we present a case-study of a project-based application in a core engineering class in the second (sophomore) year, with heavy ties in EDI and EML. Students research the Federal Highway Act of 1956 and its effects on URM communities. They design and build a prototype steel truss to reconnect the communities severed by the discriminatory construction of highways through their once-thriving neighborhoods. As we present the details of this project implementation, we show the impact it has on students' academics as well as their personal growth. The end goal of the proposed work is for students to become empowered to innovate as they develop their technical skills, and design always with EDI principles.

2. The Federal Highway Act

The Federal Highway Act of 1956 built on previous proposals to connect the United States with a system of roads. During this time, a wave of migration of rural people of color started manifesting towards urban centers, particularly in the southern United States. As a result, African American communities sprawled out of their former confines into formerly white areas. Coupled with advances in the automobile industry, many middle to upper class white people opted to commute into cities instead of living there, which strained the transit system even more [16].

The introduction of the Federal Highway Act was not without opposition, particularly from wealthy urbanites. However, when developers realized that the Federal Highway Act would give them the ability to completely restructure the city centers by eliminating lower income housing, they allowed the act to pass.

Besides following federal regulations, all decisions regarding the routing of the interstate system were left to the states and local governments. There was a disconnect between the roles of the highway developers and urban developers because highway developers did not see issues such as relocation assistance or preserving the urban core as their responsibility. The highways routes were designed by local stakeholders who overwhelmingly sought to push minorities out of the city and physically cement redlining. In fact, the U.S. Department of Transportation estimates that 475,000 households and one million people were displaced between 1957 to 1977 [17].

In Nashville specifically, planners decided to put a curve in I-40, rerouting it through African American neighborhoods, to avoid a white developments [18]. This decision was made in a 1957 private meeting of white business owners. There was heavy opposition as a group called the I-40 Steering Committee won a restraining order in 1967 to halt the project because of racial discrimination. This success was temporary as the restraining order was ultimately shut down in federal court, but it gave solid proof that interstate routing was racially motivated [16].

There are hundreds of similar stories, with some of the most notable examples in Birmingham, the 15th Ward in Syracuse, Camden, New Jersey, and more. Although, some communities were able to resist destruction by campaigning their local government. One notable example is in Baltimore where 28,000 housing units were going to be destroyed in the predominantly African American West Side [18]. Ultimately, protests were able to halt construction.

The negative physical and social effects of the Federal Highway Act of 1956 are evident today in most cities throughout the United States, and currently there is an effort to remediate these effects. Many projects have already been completed, with one of the most common options being to put an enclosure, or “lid” over the interstate to reclaim the space and reconnect the parts of the city previously divided by roads. In 2021, a lid called the “Cap” was placed over I-579 in Pittsburgh and is home to Frankie Pace Park, which provides three acres of greenspace and connects the historically African American Lower Hill District. It stands as one of the largest green roof projects in the nation [19]. One such project has been proposed in Nashville over I-40 and would reconnect the Jefferson Street community.

These projects face many challenges largely related to garnering funding for city construction at such a scale. Heavy collaboration between state and local officials, as well as public approval is required for the planning and lifetime of the project. If local and state governments are not willing to provide the funding, it must be obtained through federal grants. However, these grants have an extensive list of requirements that are not always feasible for the scale of each project [20]. It is also important that this land is not developed solely as high-cost housing. Instead, there must be a focus on integrating communities through affordable housing, greenspace, and accessible amenities, in addition to physically reconnecting the communities.

The intricacies of the effects of the Highway Act and its lingering effects on disadvantaged communities and communities of color is one example that shows the importance of educating our students on understanding the core struggles their stakeholders face. Students must be aware of the short term and long-term consequences of their designs. They need to learn to make connections with the communities they serve so they can design an equitable and sustainable environment, not just a particular structure. Linking EML and EDI together is essential to engineering a better future for our world.

3. Application to Statics

Statics is typically taught as a lecture-based core engineering course, taken mostly by second year (sophomore) students in civil and mechanical engineering. In it, students apply the basic physics and math they learned in their first year to real engineering problems. They learn about forces, structural analysis (calculating internal forces in trusses and frames using the method of sections and the method of joints [21] to solve for unknown forces), as well as computing geometric properties such as center of gravity and moments of inertia. In previous years, students were required to complete two small computational projects worth 20% of their final grade. The rest of the grade distribution was split among midterms (40%), homework assignments (15%), in-class attendance (5%), and a comprehensive final exam (20%).

Discussions with previous cohorts of students supported research that the middle two years were mostly lecture-based, lacking hands-on activities and real-world applications. To remedy this, a final project with a lab component replaced the two small projects and final exam. This project was scaffolded over a few weeks throughout the second half of the semester. EDI as well as EML were main goals of the project: Students were to design and prototype a solution to reconnect a local community severed by the development of highways in the mid to late 1900s. This project was inspired by work done in 2019 by seniors from the Civil and Environmental Engineering Department at Vanderbilt University, under the mentorship of Prof. Lori Troxel. They worked with the Civic Design Center to design a cap to Interstate 40 around Jefferson Street to remedy the effects of the Highway Act on the community there [22].

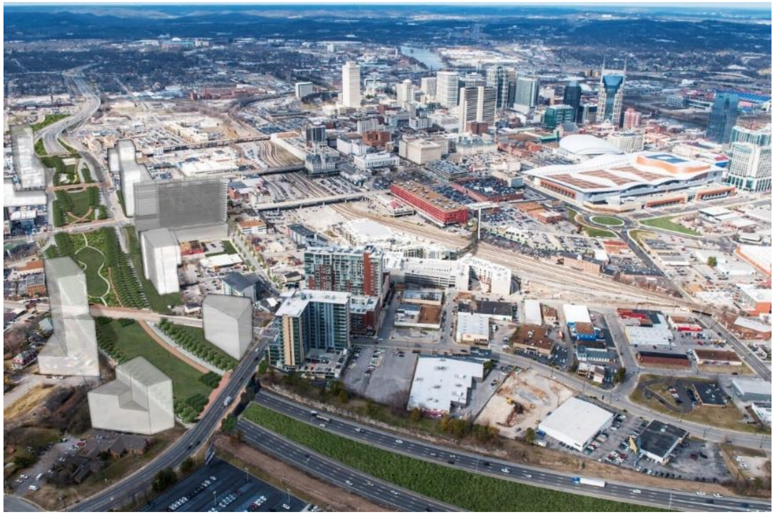

Figure 1: A visualization of a Midtown highway cap from the Civic Center website *[22]*

In an effort to connect the students with local projects in their community, the application design was a cap to Interstate 40 to reconnect the areas surrounding Jefferson Street in Nashville, TN. Jefferson Street was a thriving African American neighborhood that was decimated by the construction of Interstate 40 [23]. A final professional individual report was the main deliverable of this work. In its first section, students researched the Highway Act of 1956, its effects, and the current and future solutions proposed to remedy its impact. Each student wrote a 1-page essay on the subject.

Students were then given a truss design (Figure 2 below) and asked to find the internal forces for a given load P = 300lb using three different methods: Hand-calculations using the method of sections and the method of joints, and with the help of a commercial software they picked. This taught the students how to verify the commercial software calculation output to use in further steps.

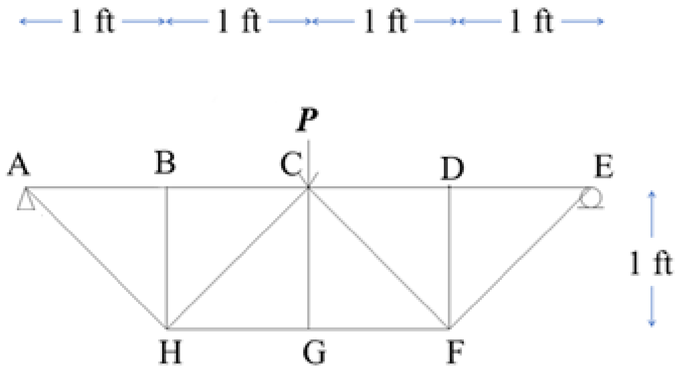

Figure 2: The prototype truss

Students then researched yielding in tension and buckling in compression, notions typically taught in mechanics of materials, a more advanced course for which statics is a pre-requisite (We assumed the slender elements in compression would buckle before they yield):

$$\frac{T}{A} \leq \sigma_y$$

where *T* is the tension in the elements, *A* the cross-sectional area and σ_y the material yield stress, and

$$C \leq \frac{\pi^2 EI}{(L_e)^2}$$

where *C* is the compression in the elements, *E* is the material's Young's modulus, *I* the moment of inertia and L_e the effective length of the elements. The students were introduced to basic code standards by using factors of safety for these failure calculations.

These failure mechanisms require the calculation of the centers of gravity and moments of inertia of the truss elements. Applying these simple equations, students were able to calculate the maximum load *P* their truss can carry and to predict its mode of failure.

At the same time as they were calculating their truss maximum load, students went in the structures lab and learned how to weld and manufacture a steel prototype of their structure. Each truss was built by 4 students (this is the only group work required of the students): Each welding station accommodated 2 students that completed half a truss, and they joined it with another half built by 2 other students to make their final structure. Typically, in the fall semester, 2 sections of statics are offered and have 35-40 students enrolled each, and in the spring semester, 1 section with about 30 students is offered. On average, 9-10 steel trusses were built per section of statics.

To accommodate the lab work, six 50-min lectures had to be freed. In the past, three review sessions were done before the midterms, and two project description sessions were needed for the smaller assigned projects. The review sessions were moved to out-of-class Q&A sessions, with the opportunity to watch previously recorded review sessions asynchronously. The project description lectures were not needed anymore. The final (6^{th}) lab session was used to test the truss and was added to the class time by moving the third midterm to the final exam slot after classes ended.

Figure 3: Student welding components of their prototype.

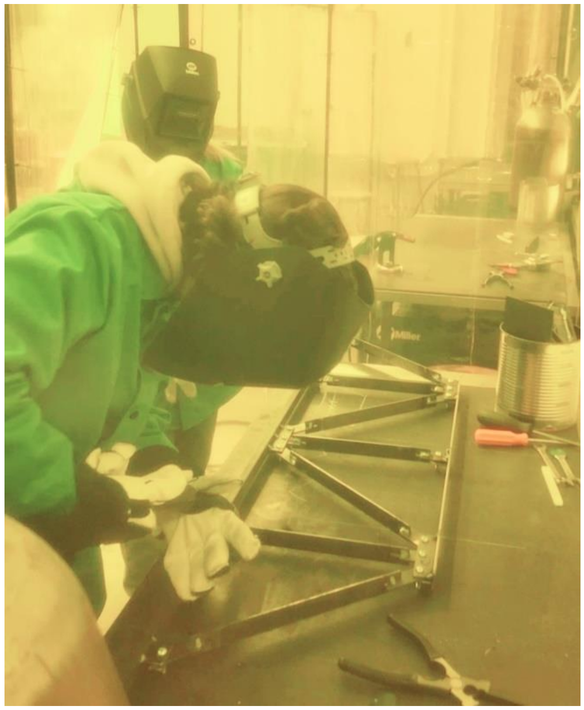

Figure 4: Student welding the prototype truss connections behind a protective screen.

Figure 5: Groups of students assembling the truss prototype.

As mentioned above, the trusses were tested in the lab and students were able to compare the predicted mode of failure with the lab experiment, observe sudden buckling, and discuss whether their results matched their predictions. This validation step taught students that hand calculations can vary from real life testing due to manufacturing processes, testing equipment, support assumptions, etc.

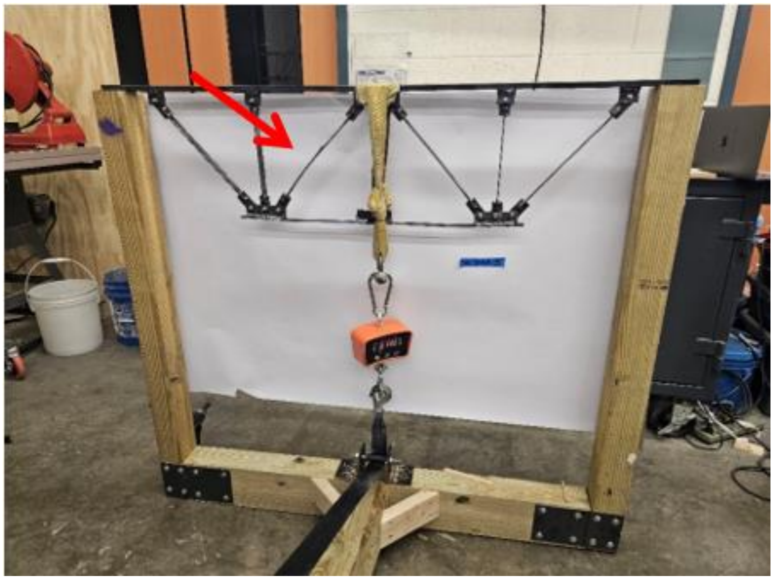

Figure 6: Test setup to mimic designed prototype: Elements show initial buckling failure.

The last calculation step for this project was designing the community space support itself: The structure was supposed to hold one landscaping area, one community building and one playground. The scaled resultant load from each was 200lb, 150lb and 100lb respectively. The students were tasked to apply these loads at different joints on the top of the truss and find the controlling load combination with respect to the buckling and yielding failures. One combination is shown in Figure 7 below:

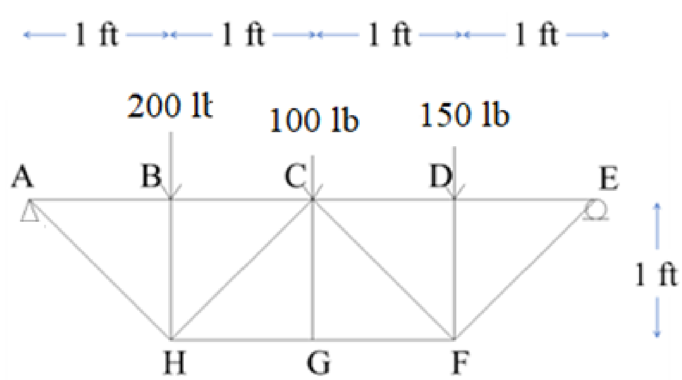

Figure 7: One combination of the load carried by the prototype truss.

The last section of the project required the students to write a letter to the community, their supposed client, that includes a brief historical context for the need to cap the interstate, the benefits of the projects they are proposing, a clear and concise explanation of the prototype design, and their recommendation regarding the load distribution on top of their truss. Students were also asked to write a brief reflection on this project in their report conclusion and how this exercise helps them be better engineers in the future.

This project allowed students to grow in three aspects: applying theoretical knowledge to real-life designs, connecting with their community/client, and finding innovative solutions to ongoing problems. It opened the door for students to research the effects of civil engineering infrastructure on communities and challenged them to be inquisitive about the diverse impacts of every future structure they design. Students were also taught to remedy problems created by previous generations of engineers using an innovative and inclusive approach. Students were assessed for their growth in EDI by:

- The diversity of their citations in the Federal Highway Act research section,
- The connections they create with the stakeholders in their letter to the community,
- The selection of the solutions they present to the community to safely optimize the use of the area above the bridge by the community: Is the community center close enough to the playground to allow the use of facilities easily? Are there any combinations that compromise the structural integrity of the bridge? Etc.

Students were assessed for their growth in EML in their final report by:

- Their ability to use a simple trade they learned (welding straight lines on a plate) and applying it to more complicated real-life truss welding without compromising the integrity of the truss,
- Their ability to research and apply new equations for a statics problem to calculate failure in elements (concepts learned in a more advanced mechanics of materials course),
- Their ability to learn and independently use a professional software to calculate their shear and moment diagrams,
- Their ability to look at test results that differ from their expected calculated results and use valid engineering reasoning to explain the disparity.

These student outcomes are assessed during the testing session in the lab as well as in the report they submit for their final project grade.

4. Cost and Preparation of Project

This project was developed by the author after attending a 2022 KEEN workshop: "Enhancing Diversity and Inclusion through EML", led by Erin Henslee, Lauren Lowman, and Michael

Gross from Wake Forest University. It was developed during the fall semester of 2022 and the first iteration was implemented in the spring semester of 2023.

This project was made possible by a generous donation from an alumnus of the civil engineering department (The Finfrock Company). One instructor (the main author) developed this project and implemented it over three semesters. During one of the semesters, another professor teaching an additional section of statics also implemented the same project without any modifications.

As mentioned before, each section of statics typically has an enrollment of 30-40 students. To optimize the experience of students in the structures lab and ensure the safety of all participants, undergraduate teaching assistants (TAs) were hired and trained in welding instruction. Online safety modules as well as in-person safety training were required of everyone working in the lab, as well as adequate personal protective equipment (closed toed-shoes, long sleeves, and pants, etc.). Ten welding stations were set up, and each welding station was used by two students at a time. When the number of students exceeded 20 in each section, the classes were divided into two sub-sections with half of the students in the lab and the other half in the classroom, and these sub-groups switched the next lecture.

Below is the breakdown of the cost of this project for the first two semesters that it was implemented. The first iteration (1 section with 30 students enrolled) was the most expensive because all the protective equipment, welding stations and testing equipment was purchased. During the second iteration (2 sections with 37 students enrolled in each), some additional core equipment was also purchased to cover the larger number of students in the lab. After that, the long-term equipment cost did not factor in the total cost of the class.

Table 1: Breakdown of cost over the first two iterations of the project.

	2023 Spring	**2023 Fall**
Long-term equipment (10 welding stations, PPE, tools)	$12,817	$3,422
Short-term lab materials (steel, hardware, welding gas)	$477	$723
Short-term TA salaries	$1,027	$2,350
Number of students	30	74
Short-term cost per student ((lab materials + TA cost) / number of students)	$50.13/student	$41.53/student

Once the project was completed, the steel trusses were recycled. Because of the change in material behavior after failure, these members cannot be used in building new trusses.

5. Project Deliverables and Assessment

In this project, students were required to write a professional report detailing their design steps. Professional formatting with the use of automated Word features was expected. It is worth noting that the instructor for this class is a licensed professional engineer in the state of Tennessee. The final grade was distributed as shown in Table 2 below (the grading rubric and other project specifics such as grading details are included in Appendix 1: Project specifics). In total, 30% of the student assessment was based on their research, including community area design and letter – which have clear ties to the EML definition of the 3Cs [6] – and 70% on their technical content.

Table 2: Report Grade Distribution

Section	**Grade out of 100pts**
Federal Highway Act research	10 pts
Preliminary Truss Design	35 pts
Calculating for Failure	10 pts
Building the Truss Prototype	10 pts
Comparing Calculations with Testing	10 pts
Designing the Community Area	10 pts
Conclusion and Letter to the Community	10 pts
Quality and Clarity of Report	5 pts

In their research of the Highway Act, students were assessed on how diverse their citations and sources were, and whether they captured the events leading to the construction of the highways well. The expectation was that students would explain the chain of events, but also show how the affected communities were resistant to these decisions as they unfolded. It is important to highlight the instances (albeit rare) where the communities were able to stop the act's implementation.

Special attention was given to the students' connection to their community as well as their ability to explain their design to a diverse audience. Students were instructed that their community members include engineering professionals as well as people with no engineering or construction background. The assessment took into consideration how sensitive the students' letter was to the plight of URM communities and how much engagement and feedback was solicited.

Framing this project within the Highway Act context not only allowed the students to be aware of the lingering inequities of civil infrastructure, but also pushed them to find creative solutions to this problem. The local context of the application allowed the students to see the effects of civil infrastructure right in their backyard. This amplified the connections the students made with the stakeholders in this example. Students reported the importance of this contextualization and how it helped them connect more with the community around Jefferson Street. Some URM students relayed that this project made them feel heard and allowed them to think of ways to engage better within their communities in their future careers.

The impact of this project on students was assessed with end of course evaluations. These surveys are anonymous and organized by the school of Engineering. The following were the results from the fall of 2023 evaluations (31 responses/37 students)– Please note that these evaluations were completed before the course ended, and before the final projects were finished:

- 81% of students strongly agreed that the instructor encouraged critical, original or creative thinking,
- 94% of students strongly agreed that the instructor helped them understand the core ideas and issues in this course,
- 97% of students strongly agreed that the instructor created a welcoming and inclusive classroom environment,
- 71% of students strongly agreed (and 26% agreed) that the course helped then appreciate the significance of the subject matter,
- 62% of students strongly agreed (and 36% agreed) that the course helped them consider connections between course materials and other areas of their personal, academic, or professional lives.

The authors are in the process of getting IRB approval for collecting more data on this project which includes demographics of students, quantitative data such as performance metrics, and qualitative data such as written responses from students using prompts related specifically to the Statics project and more generally to the course. These surveys would be completed by students after the submission of the final project.

6. Future Work

This project started as a part of the statics course, and, because of how well it was received by the students and the administration, it will become its own standalone lab course in 2025. The intention is to run this lab after students complete Mechanics of Materials and to add a materials and instrumentation section to it: As students test their structures, they can measure the strain on each element and compare the internal forces to their predicted values. This will allow more time in the lab to work on the trusses and more artistic freedom in building the prototypes.

So far, the largest cohort to do this project was that of the Fall of 2023, with 37 students in 2 sections, taught by 2 different instructors (the author being one of the two). The structures lab at our institution was able to accommodate up to 40 students per section easily for a total of 80 students (note that each section would be divided into two, with 20 students working in the lab at a time). For classes larger than 80 students, more sections would need to be offered at different times, and more welding stations would need to be equipped.

As mentioned earlier, the authors are working on getting IRB approval for data collection from the students to assess the effects of this project on their EML and EDI skills. The authors would like to see if this exercise increased the innovative thinking in students and developed their drive for social justice as they build their engineering paths in college.

The authors are also developing another version of this project using balsa wood as a more cost-equitable solution. Balsa wood is much cheaper than steel and does not require start-up equipment for welding (super glue is enough) or TA support. The framework will be similar, but the students will be able to build their own diverse prototypes using balsa. This allows adding more creative architectural aspects to the design of the project, but also the ability to work on these trusses outside of class hours (as part of a homework assignment) without straining the structures lab schedule. This balsa application will be shared with other engineering schools wishing to implement this in their curricula. The authors are also working on a less calculation intensive version of this project to share with local middle and high schools in a K-12 outreach effort to encourage STEM and social justice education.

7. Conclusion

The case-study presented in this manuscript implements a hands-on project infused with EDI and EML in a core class for civil and mechanical engineering degrees. It has a potential for growth in curiosity, connections and creating value within ethical design of civil infrastructure. Coupling EDI and EML in undergraduate education has great potential in developing ethical and socially conscient future engineers that will be able to tackle the complex problems facing our society.

Within a second-year core engineering class, students were able to calculate, build, and test prototype steel trusses to remedy the discriminatory effect of the Highway Act of 1956. This manuscript details the implementation steps of the project and the impact it had on student education. The authors present the work leading up to the implementation, show the real costs associated with the lab work, and share the feedback the students gave in the end-of-course evaluations they complete towards the end of the semester.

8. Acknowledgements

The authors would like to acknowledge the support of the Kern Family Foundation through the offered workshops and a fellowship that supported a portion of this work. They would also like to acknowledge the Finfrock company for their generous donation to the Civil and Environmental Engineering Department at Vanderbilt University that covered the initial cost of implementing this project.

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[27] S. Bonjukian, *Let's Bury I-5: An Urban Design Framework for Freeway Lids in Downtown Seattle,* University of Washington, 2015.

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Appendix 1: Project specifics

Expected length of report

The students followed an assigned formatting template for their reports. They submitted their documents in PDF version, 12pt text (14pt for titles), single spaced. Students had to use Word features to automate their figures/tables/equations numbering, and add an automated table to figures, table of tables, table of content and bibliography. Under these constraints, students had an average of 18 pages total in their reports.

Letter to the community:

Students were asked to write a letter to the community following this prompt:

"For this final step, you will gather the lessons learned from this project, and will write the community letter. Your letter should include:

- *A brief history explanation for the need to cap the interstate,*
- *The benefits of capping the interstate,*
- *The plan you have for developing the cap,*
- *A brief explanation of the impact the construction will have on the community, as well as the future impact of the project,*
- *A brief explanation of your design.*

Keep in mind that this letter is geared towards an audience that might not fully grasp engineering terms but can also be read by engineering members of the community. Make sure your letter shows connection with the community on multiple levels (examples can include but not restricted to societal, economic, artistic, historic and educational levels)."

Grading Effort:

This project was graded solely by the instructor. However, TAs could assist in grading by checking the calculations details for the method of sections, method of joints, and failure calculations for yielding and buckling.

Grading Rubric:

	Exceptional	Almost There	Needs some development	Requiring major edits
Federal Highway Act research (10pts)	Student shows understanding of subject, well written text, excellent references with diverse sources (9-10pts)	Student shows good understanding of subject, minimal errors, good references, could use more diverse sources (7-8pts)	Student doesn't show good understanding of subject, errors in text, references not diverse or very few sources used (4-6pts)	Student doesn't show understanding of subect, no references used (0-3pts)
Truss Design (35pts)	Excellent calculations and detailed procedure, no errors, excellent use of software (30-35pts)	Very good calculations and procedure, some small errors noted, software used with minimal explanations (21-29pts)	Calculations have some errors in them, software used incorrectly or missing explanations (11-20pts)	Calculations or software use are missing. Major errors present (0-10pts)
Building the prototype (15pts)	Students built the prototype together, learned how to weld, showed the progresswell in the report with pictures and sketches. (13-15pts)	Students built the prototype together, report shows some progress, could add more sketches/pictures to showcase lab work (9-12pts)	Students built the prototype with some difficulty, some details could be added to showcase the lab work, minimal explanations (5-8pts)	Prototype explanations missing or prototype not built/finished. No progress is shown, some errors in reporting (0-4pts)
Calculating for failure (15pts)	Students use the failure equations correctly, and explain their procedure in detail (9-10pts)	Students use the failure equations correctly but don't explain the procedure or results (7-8pts)	Students made mistakes using the failure equations (4-6pts)	Students didn't use the correct equations or major errors found in their procedure (0-3pts)
Comparing calculations with lab results (10pts)	Students interpret lab results correctly and are able to accurately explain the divergences and parallels between the experiement and the theory (9-10pts)	Students interpret lab results and compare them to the calculations well, some improvements or deeper discussions could be done (7-8pts)	Students struggle to link the experiment to the theory and make wrong assumptions to explain divergences and parallels (4-6pts)	Students fail to compare the experimental results to the calculations in a meaningful way or discussion missing (0-3pts)
Conclusion and letter to the community (10pts)	Students summarize their report very well. The letter to the community is empathetic and engaging, and explains the design in a language that the general public can grasp and benefit from (8-10pts)	Students summarize their report well, some more concise or clear wording might be needed. The letter to the community is good but could be improved for the audience to engage with (5-7pts)	Conclusion is lacking important information from the report. The letter to the community is generic and lacks connection to the audience (3-4pts)	Conclusion is not summarizing report or missing. Letter to the community missing or out of tune with the audience (0-2pts)
Quality and clarity of report (5pts)	Report is set up professionally, tables and images are captioned correctly and content is properly cross-referenced (5pts)	Report is mostly set up professionally, some tables and images are captionned correctly, and some content is properly cross-referenced (3-4pts)	Report has many non-cross-referenced material, report looks professional but not set up automatically (2pts)	Report is not professional and no cross-reference is available in text (0-1pts)

Figure 8: Grading Rubric for Project Report