Incorporating an Entrepreneurial Mindset Competition into a Structural Analysis Course

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Abstract

Structural Analysis is a required course for junior civil engineering students. They learn the theory of the common methods of analysis of structures during the course; however, do not get to apply such methods to a hands-on project. The paper discusses a competition that provides the students with an opportunity to apply the concepts learned in the class through a hands-on experience on analysis, design, and fabrication of a balsa wood bridge. The project challenges the students to fabricate a wooden truss bridge that yields the highest load bearing capacity and weight ratio to win the competition. In addition, students get to improve their entrepreneurial mindset by applying Kern Entrepreneurial Engineering Network (KEEN) learning objectives on curiosity and creating value via investigating multiple truss bridge systems and selecting the superior design through NABC approach. The direct assessment was conducted by rubric evaluation and an anonymous survey was used for the indirect assessment of the project. The students' feedback indicated that they enjoyed the real-world application of the project and liked being able to learn how to analyze trusses using professional software and apply their learning to an actual design.

Introduction

Project-based learning (PjBL) has been widely used in engineering education. Several studies have shown the effectiveness of PjBL in terms of increasing understanding, motivating students, taking ownership, and helping to bridge the gap between the classroom and workplace by preparing students with skills such as leadership, team building, critical thinking, and problem solving [1, 2]. In this methodology, an assignment with multiple tasks is normally used to drive the students learning activities to produce a final product in the form of a design, model, and device or service that can be utilized in real world. PjBL is similar to problem-based learning (PBL) in terms of involving teams of students in open-ended and challenging assignments, which resemble the real-world situations as well as identifying solutions and reevaluating their methodology. The difference between the two approaches is that the PjBL covers a broader scope and may include several problems. In addition, PjBL focuses on the final product by applying or integrating previous knowledge while the emphasis of PBL is on the acquisition of new knowledge [3].

Currently universities are utilizing entrepreneurial-minded learning (EML) as well. Through EML students get to solve a problem in a fashion that creates value, which helps to create engineers to make an impact in the workplace [4, 5]. EML course modulus can be created by incorporating behavioral or complementary skills into student-centered pedagogy. Examples of such skills are demonstrating constant curiosity, exploring a contrarian view of accepted solutions, assessing and managing risk, evaluating economic drivers, examining societal and individual needs, understanding the motivations and perspectives of others, conveying engineering solutions in economic terms, identifying an opportunity, investigating the market, evaluating customer value and economic viability, protecting intellectual property, and validating market interest. Particularly, EML builds upon active pedagogies such as PBL by integrating curiosity, identifying opportunity, and creating value [6]. It is important to understand that entrepreneurship, in this context, is not necessarily about teaching students how to start a new business, but rather to develop the mindset of innovation necessary to recognize opportunities and make the most of them. EML is being promoted by Kern Entrepreneurship Education Network (KEEN) and implemented at many institutions. 3Cs of the entrepreneurial framework are defined as:

1. Curiosity. Students are encouraged to demonstrate constant curiosity about our world, and explore different solutions, which empowers them to investigate the rapidly changing world and motivates them to become life-long learners.
2. Make connections. Students integrate information from many sources to gain insight, assess, and reveal innovative solutions.
3. Creating value. Students get to create value by identifying unexpected opportunities and learning from failure to meet the needs of a changing world [6, 7, 8].

The main objective of the current paper was to introduce a EML project in the form of a competition to a structural analysis course to and investigate whether this could motivate and improve the performance of students and their understanding of concepts such as influence line or not. Such implementation of the EML project including the competition description, assessment criteria, observations of the instructor, and examples of student work are presented in the paper.

Competition Description

A structural analysis course is offered for junior civil engineering students at Ohio Northern University (ONU). Through the course students get to know typical loadings on structures, influence lines, deflections, and common methods of analysis for determinate and indeterminate structures. However, the students do not get to apply these concepts until they take design courses. Therefore, it was decided to assign a project competition so that the students can gain a better understandings of the fundamental concepts of the course and at the same time apply those concepts through a hands-on experience. The competition was implemented during the fall semester of 2018. The learning objectives of the competition were as follows:

- Draw influence line for truss members.
- Use a professional application software such as SAP2000 to analyze trusses.
- Develop a propensity to ask more questions, which is related to curiosity.
- Create solutions through analyzing different types of bridge trusses that meet stakeholders needs and craft a compelling value proposition tailored to specific stakeholders, which is attributed to curiosity as well as creating value.
- Meet commitments to the rules developed by the team and work with individuals with complementary skillsets, expertise, etc. to produce effective written reports.

The project competition is shown in Appendix 1. To increase the motivation of students, the competition was defined as a task from Ohio Department of Transportation (ODOT): ODOT has funded a timber truss bridge to be constructed over Maumee River in 2025. During the preliminary design stage, ONU is to investigate different possible prototype truss bridge systems to make a recommendation on the appropriate truss type based on cost, constructability, aesthetics, and strength. The design constraints on the model were defined as:

1- The length of the truss bridge must be 12 inches.
2- The maximum width (side-to-side) and depth (top to bottom) of the bridge must not exceed 4 inches.
3- An incrementally increasing load will be placed on the bridge deck through the apparatus at the material lab until the bridge is unable to resist any additional load. The load is applied by a 1.5-inch-diameter rod. A loading platform must be provided at the mid-span of the bridge. The platform must extend side-to-side the full inside width of the bridge. The length of the platform must not be less than 2 inches, and no more than 4 inches. The space above the loading platform must be completely unobstructed to allow for the insertion and removal of the loading rod.
4- A 2-inch cube must be able to pass through the inside of the truss model from end to end. This block is to represent a vehicle moving across, or through the bridge.
5- The bridge must be fabricated using Balsa wood sticks. The cross-sectional dimensions of any individual stick may not exceed ¼ inch by ¼ inch. The length of any individual stick may not exceed 6 inches.
6- Sticks can be joined using any type of glue.
7- Sticks can be joined, or connected, only at their ends. No stick can be continuous through a joint. No stick can attach to the middle of another stick. Gusset plates and pegs may be used to connect the sticks. The gusset plate thickness may not exceed 1/16 inch and neither the length nor width can exceed ¾ inch.
8- Lamination, or gluing members together in parallel, is only allowed for the surface of the loading platform.
9- Sticks cannot be coated, painted, or stained with any material that will add to the structure ability to resist an applied load.

The class consisted of 26 students. The students were asked to organize into groups of four to five. Each group was to represent a fictitious startup company in order to bring their consulting service to the market. The students had to select a name for their company and list the set of the rules and expectations for the team. Examples of such rules are shown in Appendix 2. The purpose of the rules was effective team work and communication among group members as well as a reminder of how to avoid the common pitfalls. The students were not evaluated on adherence to their own rules.

Stimulating the curiosity of students is one of the most important goals of any educator. If successful, the student will be motivated to continue to learn and explore the course material outside of the classroom and find connections with other information or applications. To stimulate the curiosity of students, Question Formulation Technique (QFT) was utilized. The QFT enables students to generate technical questions, which makes the process of problem solving easier and helps them to take ownership of materials and become self-directed learners.

It is important for a student to be aware of what they do not know and be able to articulate it in the form of a question [9]. Thus, each company was asked to submit a list of questions. The instructor served as the client to bridge the gap between the students and the DOT. Samples of such questions are listed in Appendix 3. The questions were answered and returned to each group. In addition, common questions were discussed and elaborated in the class to avoid any confusion because the stakeholder or client feedback is essential to understand what is deemed as valuable. All groups scored at least 90% on their questions. This was intended as a tool to encourage students to ask further questions, which was successfully achieved.

In addition, each company must pitch a written proposal to convince the client that the design is a suitable and cost-effective solution to the problem that is in some way unique and more advantageous than other companies. Each member of the team was required to investigate at least one unique bridge truss as a solution and identify the determinacy of that truss. Exploring multiple solutions further stimulates the curiosity of the students. The alternative designs were to be considered competing solutions to the problem. The selection of the final design should be based on <u>N</u>eed-<u>A</u>pproach-<u>B</u>enefits-<u>C</u>ompetition (NABC) approach. NABC framework developed by Stanford Research International to teach engineering students how to articulate value propositions. The framework highlights the market needs, solution approach, solution benefits, and competition dimensions of any created solution. The objective is to create a solution that delivers customer's value and need and is clearly greater than the competition's. The NABC framework starts with a clear articulation of underlying Need the idea addresses. What are the important customer and stakeholder needs? A need should relate to an important and specific user-client segment with the end customers clearly stated [10, 11]. Then, the Approach to meet the need is described. What is the unique approach and compelling solution for addressing the specific client need? This should be drawn or simulated to help convey the vision required. As the approach develops through iterations, it becomes a full proposal or business plan, which can include cost, staffing, deliverables, a timetable, etc. [10, 11]. The Benefits of the approach to the specific stakeholders must be highlighted and should demonstrate a favorable benefit to cost ratio. What are the client benefits of our approach? Each approach to a client's need results in unique client benefits, such as low cost, high performance, or quick response. Success requires that the benefits be quantitative and substantially better - not just different [10, 11]. Finally, the Competition should be analyzed to show how the idea improves upon the competing solutions [10, 11]. Why are our benefits significantly better than the competition? Everyone has alternatives. We must be able to tell our client why our solution represents the best value. To do this, we must clearly understand our competition and their value proposition and our client's alternatives [10]. Since students may not be familiar with the method, it is beneficial to show a video introducing the framework [12] and share an example of applying the method. A good example might be video on-demand, which was pitched to a cable broadcast company, circa 2006. Need was a $5 billion business opportunity for movie rentals, which the company did not have any market share at the time. Furthermore, customers do not like picking up and returning rentals as well as late fees. Approach was developing a system for the company to provide the customers with videos on demand using cable. This enables people to have access to all movies by using one of unused channels with the same price as video store rental, which means there will be no change to the system and no capital needed to be invested by the company. Benefits were market share of 20% and receiving $5 revenue per rental. In addition, the customers were not worried about late fees and could have the same experience as VCR/DVD without the need to return. The competition was online rentals, but they do not provide the customers with spontaneous rentals and sending videos back is not convenient [10]. In this project, Need was given with a well-defined problem. The problem was to build a prototype bridge. The Approach was limited through the design requirements such as the length and width of the truss, material, etc. The Competition was limited by requiring students to design alternative viable solutions and using the alternative solutions as the Competition. Each member of the group had to investigate a unique bridge truss. Finally, the Benefits were to be articulated through evaluation metrics considered in the design such as cost, aesthetics, strength, and ease of construction. An example of the evaluation metrics developed by students is shown in Appendix 5. While the aesthetics and ease of construction would be subjective, the cost and strength aspects can be quantified. Students were able to estimate the strength and cost of each bridge system via the Bridge Designer and SAP2000 software.

Direct Assessment

The following grading was used for the project:

1- Team charter- 5%: selection of a name for the company, listing the set of rules and expectations for the team, and submitting questions. The students were given a week to finish this task. Appendix 4 shows an example of the charter. All students scored at least 90% on their questions.
2- Written proposal- 70%: problem description, constraints, alternative solutions, determinacy of each alternative bridge truss, analysis of bridges using Bridge Designer and SAP 2000, selection of superior design through NABC approach, AutoCAD drawings for the selected design, influence line for members with the largest compression and tension forces in the selected truss bridge, and conclusions. The students were given three weeks to finish this task. The proposal was assessed through the evaluation rubric. Table 1 illustrates the rubric. An example of the proposal is shown in Appendix 5. All students scored at least 90% on Introduction & Problem Description and Constraints & Criteria sections. For the Analysis section, 15% scored at least 90% as well as between 75% and 90% while 70% scored 60% to 75% indicating the second objective on using a professional software to analyze trusses was met. 54% scored at least 90% and 46% scored 75% to 90% on Alternative Solution. On the Superior Design Selection based on NABC approach, 35% scored at least 90%, 19% scored 75% to 90%, 31% scored 60% to 75%, and 15% scored below 60%. This indicates that the objective on create solutions and craft a compelling value proposition was met. 35% scored at least 90%, 19% scored 75% to 90%, and 46% scored between 60% and 75% on Additional Analysis of Superior

Design (draw the influence line), which shows that the first objective was met. 70% scored at least 90%, 15% between 75% and 90%, and 15% below 60% on AutoCAD Drawings. For the Conclusions section, 35% scored at least 90% as well as 75% to 90% while 30% scored between 60% and 75%. Overall, 85% of students scored 75% to 90% and 15% scored between 60% and 75% on the written proposal. This indicates that the last objective was met.

3- Peer evaluation- 10%: team members were asked to evaluate their peers through rubrics on different skills such as working with others, attitude, time management, quality of work, contributions, and problem solving. The students were asked to submit their peer evaluation twice, one in the middle and the other at the end of the project. Appendix 6 shows the rubrics. All students scored at least 90% on this evaluation indicating the last objective was met.

4- Bridge competition- 15%: an incrementally increasing load will be placed on the bridge deck through the apparatus in the lab. The value of the maximum resisted load will be divided by the weight of the bridge. The company with the highest strength to weight ratio wins the competition. While the strength to weight ratio is not the case in real world, it was felt that this could be an easy indicator to identify the winner team. Figure 1 shows the bridges built by students. The students were given a week to construct their bridge model.

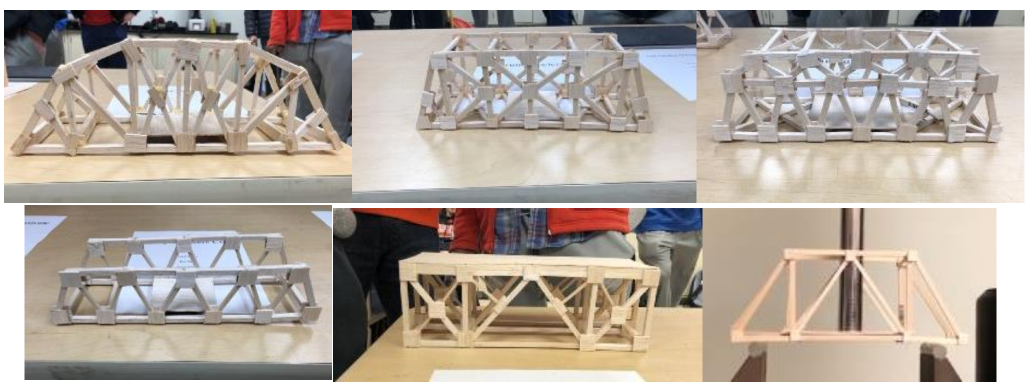

Figure 1. Bridge Models Built by Students

Table 1. Evaluation Rubric

Content						
	Excellent	**Above Average**	**Average**	**Marginal**	**Unsatisfactory**	**Pts**
Introduction & Problem Description	**5 pts** Provides excellent high-level description of problem: project importance and client need well-defined; outlines report	**4 pts** Provides good high-level description of problem: project importance and client need defined	**3 pts** Provides decent description of problem: some importance of the project and some aspects of the need established	**2 pts** Missing high-level description of problem: project importance and client need minimally or poorly addressed	**1-0 pts** Missing high-level description of the problem: project importance and client need not addressed	
Constraints & Criteria	**10 pts** Clearly & concisely identifies important constraints and criteria	**9-8 pts** Clearly identifies some important constraints and criteria	**7-6 pts** Identifies some constraints and criteria	**5-4 pts** Lacks in constraints and criteria	**3-0 pts** Severely lacks in constraints and criteria	
Alternative Solution	**10 pts** 4/5 alternatives presented and thoroughly considered.	**9-8 pts** 4/5 alternatives presented and sufficiently considered.	**7-6 pts** 4/5 alternatives considered and reasonably presented.	**5-4 pts** < 4/5 alternatives considered and/or 4/5 alternatives minimally/poorly presented.	**0 pts** No alternatives considered.	
Analysis	**15 pts** All alternatives expertly analyzed with SAP2000 and Bridge Designer; excellent presentation and analysis of results	**14-13 pts** All alternatives sufficiently analyzed with SAP2000 and Bridge Designer; good presentation and analysis of results	**12-10 pts** All alternatives fairly analyzed with SAP2000 and Bridge Designer; reasonable presentation and analysis of results	**9-6 pts** Not all alternatives analyzed; poor presentation and analysis of results	**5-0 pts** Analysis of alternatives is missing, is completely erroneous, or is incomprehensible.	
Superior Design Selection	**10 pts** Expertly describes the need; expertly describes the design approach; expertly articulates the benefits per cost; thoroughly justifies superior design over design alternatives through evaluation metrics	**9-8 pts** Describes correctly the need; describes correctly the design approach; articulates the benefits of the solution based on criteria; sufficiently justifies superior design over design alternatives through evaluation metrics	**7-6 pts** Describes mostly the need; describes the design approach; articulates some benefits of the solution; somewhat justifies the superior design over alternatives through evaluation metrics	**5-4 pts** Misses the main ideas of the need; describes aspects of the design approach; missing some benefits of the solution; marginal justification of superior design over alternatives through evaluation metrics	**3-0 pts** Poor discussion of need, approach, benefits, no selection of superior design	
Additional Analysis of Superior Design	**10 pts** Draws the influence line thoroughly for members with largest tension and compression force	**9-8 pts** Draws the influence line sufficiently for members with largest tension and compression force	**7-6 pts** Draw the influence line for members with largest tension and compression member with some errors	**5-4 pts** Draws the influence line for members with largest tension and compression member with significant errors	**3-0 pts** Influence line is missing, or is completely erroneous.	
AutoCAD Drawings	**10 pts** Thoroughly creates AutoCAD drawings for the superior design including elevation view, plan view, typical connection, and member schedule in a table.	**9-8 pts** Sufficiently creates AutoCAD drawings for the superior design including elevation view, plan view, typical connection, and member schedule in a table	**7-6 pts** Reasonably creates AutoCAD drawings for the superior design including elevation view, plan view, typical connection, and member schedule in a table	**5-4 pts** Poorly creates AutoCAD drawings for the superior design including elevation view, plan view, typical connection, and member schedule in a table	**3-0 pts** AutoCAD drawings miss few details; no AutoCAD drawings	
Conclusions	**5 pts** Concise summary of problem & solution; insightful discussion of redesign/lessons	**4 pts** Good summary; good discussion of redesign/lessons	**3 pts** Decent summary; some mention of lessons and redesign ideas	**2 pts** Poor summary; little mention of lessons or redesign ideas	**1-0 pts** Poor or no summary; no mention of lessons or redesign	

Discussion

An indirect assessment through an anonymous survey of the project was conducted by the instructor. 22 out of 26 students enrolled in the course submitted their responses. The survey asked students to rate each question on a scale of 1 (strongly disagree/none at all) to 5 (strongly agree/throughout most of the project). Table 2 shows the average of the results from the survey. For the entrepreneurial dimension, questions two, five, and six target creating value. Question 4 is related to curiosity and questions 1 and 3 target making connections. Questions 10 and 11 target the communications skills on the technical aspect of the project. Students overwhelmingly agreed that the project motivated them and gave them a better understanding of addressing customer's needs and using critical thinking skills to find solutions. Students found that they improved a myriad of skills including analyzing truss systems by SAP2000, drawing influence lines, report writing, and overall communication, not only with each other, but with their client.

Table 2. Survey Results

Dimension	No	Survey Question	Average Rating
Entrepreneurial	1	The real-world application motivated me to do my best work	4.3
	2	Create value for a customer or stakeholder	3.7
	3	Integrate information from many sources to gain insight	4.1
	4	Apply critical thinking to ambiguous problems	4.4
	5	Examine a customer's needs	4.4
	6	Convey engineering solutions in economic terms	4.4
Technical	7	Identifying the components of a bridge truss	4.5
	8	Analyzing truss systems by SAP2000	4.4
	9	Drawing the influence line for a truss member	3.9
	10	Reporting the solution to a customer	4.4
	11	Work with your team	4.9

Figure 2 displays the relative frequency for each survey question. For question 1, 50% of students strongly agree and 32% agree that the real-world application of the project motivated them while 14% were neutral and 5% disagreed. The project goal on creating value for a customer was successful as over half of students (64%) agreed, 23% were neutral, and 14% disagreed. 41% of students strongly agreed and 36% agreed that they could integrate information from multiple sources to gain insight. 18% were neutral and 5% disagreed. Survey question 4 asked whether students applied critical thinking throughout the project. As shown in Figure 2, 50% strongly agreed, 41% agreed, and 9% were neutral. Students overwhelmingly (81%) reported integrating information from many sources while 19% were neutral and none disagreed. According to the results for survey question 6, over 80% of students agreed that they were able to convey engineering solutions in economic terms throughout the project. 14% were neutral. Students strongly (52% strongly agreed and 43% agreed) agreed that they improved their skills on identifying the components of a bridge truss (question 7) while 5% were neutral. 90% of students (52% strongly agreed and 38% agreed) found that the project improved their skills in analyzing truss systems by SAP2000 (question 8) and 10% were neutral. The project successfully improved students' skills on drawing the influence line for a truss member (question 9) as 24% strongly agreed and 52% agreed. 10% were neutral and 14% disagreed. Questions 10 and 11 evaluated the communications skills. Over 90% agreed that the project successfully enhanced their skills on writing effective reports and reporting the solution to the customer while 10% were neutral and 5% disagreed. Similarly, 91% strongly and 9% agreed that the project helped them to improve their skill on working with their peers.

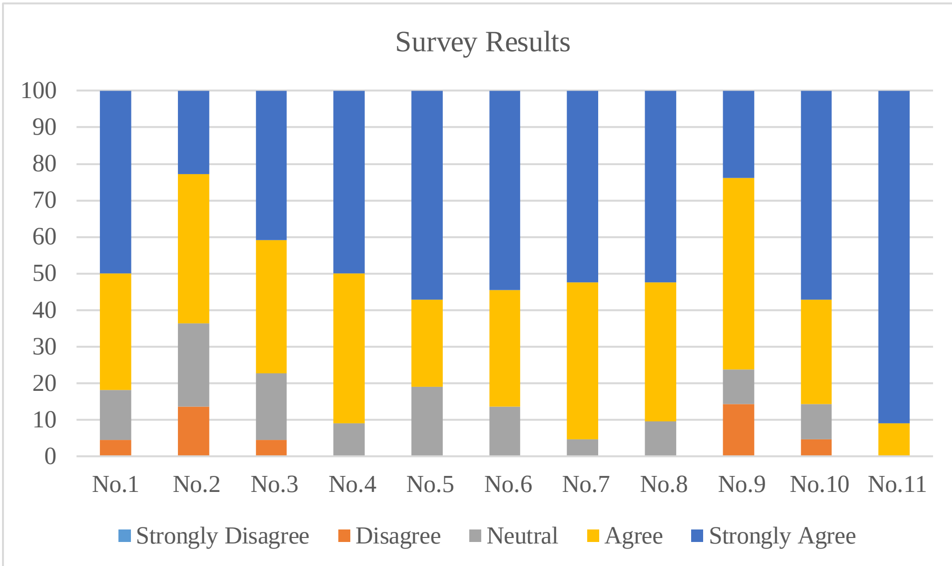

Figure 2. Relative Frequency for Each Survey Question

As seen in the Table 2 and Figure 2, the project was successful in targeting both technical and entrepreneurial skills of students and was well received by them. This is in accordance with the direct assessment of students work as 85% of students scored 75% to 90% and 15% scored between 60% and 75% on the written proposal.

Based on the results of the open-ended feedback portion of the survey, students found the project competition as a fun and creative way to learn about trusses and were excited about the competition to test their design. They also liked the hand-on experience and being able to learn how to analyze the trusses in Bridge Designer and SAP2000 and apply what had learned to an actual design. The students enjoyed the real-world application and appreciated the opportunity for creativity. The students were given approximately a month to finish the project. Based on student feedback and the quality of work submitted, it is recommended to assign the project competition in the middle of semester since students are normally overwhelmed with other projects and exams at the end of the semester. Furthermore, it is recommended to give an additional week on the written proposal of the project. It was felt that it will be easier for students if the project is broken down into several milestones with specific deadlines.

In author's opinion, influence line is one of the most challenging and difficult concepts for students to understand. In order to see whether the project was helpful for students to understand the importance of influence line and how to apply the concept in the design of bridges, the results of this group of students were compared to students from previous year who were not exposed to any project competition. This was done through giving a similar influence line problem on the final exam. The group with project consisted of 26 students and the other consisted of 27 students. Figure 3 displays the comparison of the two groups. Blue is corresponding to scoring of 90% or better, orange 75% to 90%, grey 60% to 75%, and yellow below 60% of the total points. 35% of the group with the project scored 90% or more while 7% of the other group scored the same. For the group with the project, 3% of the students scored 75% to 90%. The percentage for other group was 26%. This shows that the project was mostly beneficial to the students scoring at least 75%. It seems that these students were able to take ownership of the project and understand the concept very well to improve their score. 30% of the students with no project scored 60% to 75% while 31% of the other group scored within the same range. For below 60%, the percentage for the group with the project and the other group were 31% and 37%, respectively. This shows that these students were able to learn more from peers and improve their performance. In addition, the average score on this problem and overall for the group with the project was 16% and 5% higher, respectively while both groups had approximately similar average scores on midterm exams.

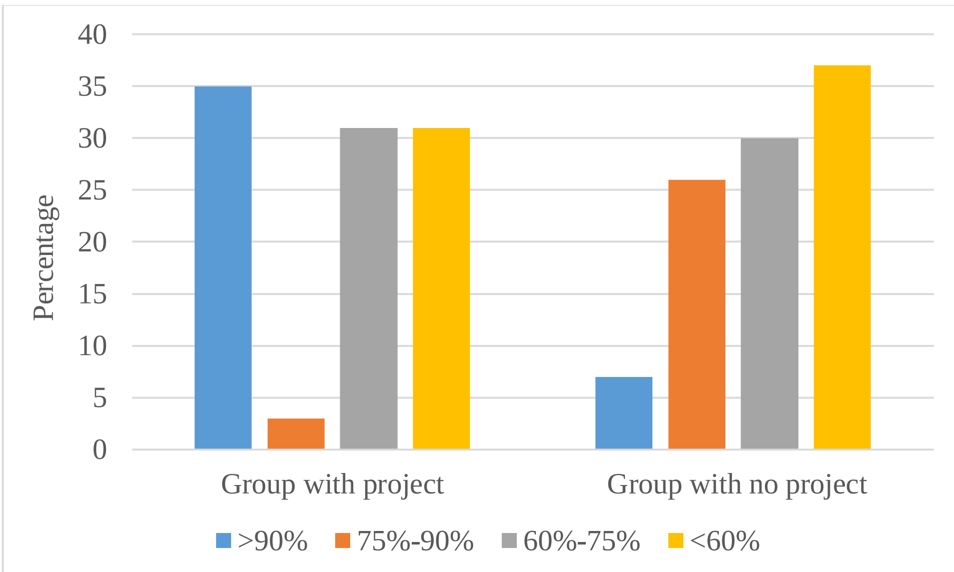

Figure 3. Comparison of Two Groups of Students

Summary and Conclusions

The paper describes an implementation of EML in structural analysis course. The students were assigned a project competition to design a prototype balsa wood bridge truss for ODOT. Based on students' feedback and observation of the instructor, the project competition based on the framework discussed herein can expose students to EML effectively and improve their performance.

Acknowledgements

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Appendix 1

Project Overview:
Students should organize into groups of four to five to design and build a balsa wood bridge that is applied to the underlying design problem described below. Each group represents a fictitious startup company in order to bring your consulting service to the market. Each company must pitch a proposal in an effort to convince the client that the design is a suitable, and cost-effective solution to the problem that is in some way unique and more advantageous than other companies.

Problem Description:
ODOT has funded a timber truss bridge to be constructed over Maumee River in 2025. During the preliminary design stage, ONU is to investigate different possible prototype truss bridge systems to make a recommendation on the appropriate truss type based on cost, constructability, aesthetics, and strength.

Design Constraints/Requirements:

1- The length of the truss bridge must be 12 inches.
2- The maximum width (side-to-side) and depth (top to bottom) of the bridge must not exceed 4 inches.
3- An incrementally increasing load will be placed on the bridge deck through the apparatus at the Mechanical Engineering material lab until the bridge is unable to resist any additional load. The load is applied by a 1.5-inch-diameter rod. A loading platform must be provided at the mid-span of the bridge. The platform must extend side-to-side the full inside width of the bridge. The length of the platform must not be less than 2 inches, and no more than 4 inches. The space above the loading platform must be completely unobstructed to allow for the insertion and removal of the loading rod.
4- A 2-inch cube must be able to pass through the inside of the truss model from end to end. This block is to represent a vehicle moving across, or through the bridge.
5- The bridge must be fabricated using Balsa wood sticks. The cross-sectional dimensions of any individual stick may not exceed ¼ inch by ¼ inch. The length of any individual stick may not exceed 6 inches.
6- Sticks can be joined using any type of glue.
7- Sticks can be joined, or connected, only at their ends. No stick can be continuous through a joint. No stick can attach to the middle of another stick. Gusset plates and pegs may be used to connect the sticks. The gusset plate thickness may not exceed 1/16 inch and neither the length nor width can exceed ¾ inch.
8- Lamination, or gluing members together in parallel, is only allowed for the surface of the loading platform.
9- Sticks cannot be coated, painted, or stained with any material that will add to the structure ability to resist an applied load.

Project Deliverables, Grading, and Due Dates:

1.) Team Charter (5%)

- Finalize your team members and select a name for your team/company. List the set of rules and expectations for your team. Some examples of rules may be proper preparation and attendance at group meetings, honest communication when conflicts arise, etc. Each team member must sign the sheet thereby indicating acceptance to comply with the rules and expectations. In addition, submit a list of questions related to this project that demonstrates your curiosity while express your interest in the project.

- Note: This set of rules and expectations is for your use and benefit. The instructor will make a copy and return it to you.
- **Due:** Friday, November 9, 2018

2.) Written Proposal (70%)

- Producing alternative design solutions is a beneficial step in the engineering design process. For this project, your alternative designs will be considered competing solutions to the problem. Each solution must be viable (i.e., meet the constraints set forth in the problem statement) and unique (one cannot be a trivial modification of the other!). Each member of the team is required to investigate at least one different bridge truss as a solution and identify the determinacy of the truss (must have 5 different trusses if you are a team of five).
- In addition, it is required to analyze each bridge truss with a load of 10 lbs applied at the loading platform using SAP2000 and submit the results indicating the members in tension and compression with the corresponding forces. Refer to the following website to download the bridge analysis software for guidance on configuration of the element of the bridge and a tutorial that will help you learn how to use the software for first time users:
  http://bridgedesigner.org/download/
  http://bridgedesigner.org/tutorial/
- The bridge trusses should be compared through an evaluation metrics. An example of the selection of the bridge truss might be based on the following criteria: Aesthetics/Creativity, Cost, and Ease of Construction.
- Based on the table, teams are required to select the bridge truss for construction and testing. Additionally, should justify the weighting factor for each criterion and also how each bridge truss is rated based on the given criteria. The Bridge Designer software should be used to determine the Strength to Weight Ratio and the Cost of each bridge truss. For ease of Construction and Aesthetics/Creativity, the teams can come up with their own method for rating the bridge trusses.
- For the selected bridge truss, draw the influence line for the member with the largest compression force as well as the member with the largest tension force. May use SAP2000 to analyze the bridge to find the member forces and draw the influence line.
- For the selected bridge truss, create a full-scale drawing in AutoCAD. The drawing should include an elevation view, plan view, and a detail drawing of a typical connection. Members in the truss should be numbered and these members should correspond to the numbers shown in a table as shown below. The table should indicate the tension and compression members, their corresponding lengths and cross-sectional dimensions.

ID	Member Type	Length	Cross-sectional Dimensions	Quantity Required

The written product proposal should include the following:

- **Introduction section** that motivates the underlying problem, briefly describes the approach to the solution.
- **Problem Description section** that describes the problem and identifies the design constraints and evaluation metrics.
- **Alternative Solutions and Analysis section** that should describe each design alternative, the determinacy of each bridge truss, SAP2000 results, the approach to advocate for the superior design alternative, the selected bridge truss, the influence lines for tension and compression members, and AutoCAD drawings. The member forces of each solution should be provided with indication of compression or tension. Be sure that all plots and figures are embedded within the proposal (not as attachments). Use NABC approach to advocate for the selected bridge truss. The approach should be emphasized, as well as the benefits per cost compared to the design alternatives. It is also necessary to clearly restate the underlying need and identify based on the evaluation metrics why the preferred design is selected.
- **Conclusion section** that briefly summarizes the problem and the selected bridge truss. Summarize the critical aspects of the approach and benefits that make it (the superior solution) better than the alternative. Describe the lessons learned from the design and implementation process of the project.

- **Due:** Friday, November 30, 2018

3.) Bridge Construction (15%)

- Each team should construct their selected bridge truss using balsa wood and the AutoCAD drawing based on the members listed in the table. Scott Cottle, our technician, can aid you in troubleshooting.
- **Due:** Wednesday, December 5, 2018

4.) Competition

An incrementally increasing load will be placed on the bridge deck through the apparatus at the Mechanical Engineering material lab. The value of the maximum resisted load will be divided by the weight of the bridge. The team with the highest strength to weight ratio wins the competition and receives bonus point.

Thursday, December 6, 2018

5.) Peer Evaluation (10%)

Two rubric evaluations are conducted. Failure to complete the peer reviews by the deadline will result in zero score for the peer evaluation portion of the project.

- **Due:** Wednesday, November 28, 2018 & Wednesday, December 5, 2018

Appendix 2
Examples of rules set by students:

- Put cell phones on quiet and do not have other distractions, such as Facebook, Twitter, Snapchat, or Instagram, open during team meetings.
- Inform other team members if you will be late to a meeting.
- Complete things in a timely manner.
- Give good and honest feedback
- Have open and honest communication
- Utilize technology for communication
- Do thorough work
- If you are late, you have to bring snacks to the next meetings
- Be productive
- Ask questions when confused or need an expansion on the subject manner
- Be accountable for individually assigned tasks
- Members must be receptive to any new ideas, and remain objective during any criticism given or received
- Members must not be afraid to fail when testing a new idea.

Appendix 3
Examples of questions asked by students:

- Does the bottom of the bridge have to be solid all the way across or can it be open?
- Which criteria in decision matrix does the client care about most?
- Is there a budget?
- Are outside personnel allowed to be contacted for help in brainstorming ideas for the bridge design?
- Is there a limit to the amount of gusset plates and pegs the team is allowed to use?
- Does the vehicle passing through the bridge have to do so in a straight line?

Appendix 4
An example of the team charter:

Team Charter
Company Name: The Girder Design Co.
Members: [redacted]

Team Rules and Expectations:

- Members must attend all group meeting, unless a valid excuse is given and preapproved by the other members of the group.
- Members must come to meetings with all expected work completed prior to meeting time.
- Members must be on time when meeting with the group.
- Any and all ideas or discrepancies should be brought to the attention of the group in an effective and constructive manner so a resolution can be more efficiently reached.
- Members must be receptive to any new ideas, and remain objective during any criticisms given or received.
- Members must not be afraid to fail when testing a new idea.

Member Signatures:

X [redacted]

X [redacted]

X [redacted]

X [redacted]

Project Relevant Questions:

1. Are outside personnel (ie: professional engineers or designers) allowed to be contacted for help in brainstorming ideas for the bridge design?
2. Will the group be able to test their bridge with weight before their design is complete?
3. Is there a limit to the amount of gusset plates and pegs the team is allowed to use?
4. What increments will the weight be added by?
5. Can the team attach the bridge to a flat surface, to serve as a base?
6. Does the "vehicle" passing through the bridge have to do so in a straight line?

[redacted]

Appendix 5

An example of the written proposal:

Baby Breakers Co.
Written Proposal
By: [redacted]

Introduction

The company, Baby Breakers Co., was tasked to design and build a timber bridge. Baby Breakers Co. is a start-up company bringing their consulting service to the market. This proposal is an effort to convince that the design chosen is a suitable and cost-effective solution to the problem. This design is unique and more advantageous than any other company.

Problem Description

ODOT has funded a timber truss bridge to be constructed over the Maumee River in 2025. During the preliminary design stage, Baby Breakers Co. is investigating 4 different possible prototype truss bridge systems to make a recommendation on the most appropriate truss type based on cost, constructability, aesthetics, and strength.

The timber truss bridge prototype design constraints are:

- Bridge length no less than 12 inches and width no greater than 4 inches
- A block 2 in. x 2 in. x 2 in. must be able to pass through the entire bridge
- The bridge must be made of balsa wood
  - Cross section no greater than 1/4 in. x 1/4 in.
  - Individual member may not exceed 6 in.
- Any glue can be used to attach members
- Members can only be connected at ends
- Gusset plates and pegs may be used to attach members
  - Gusset Plate thickness may be no greater than 1/16 in. and length/width cannot exceed 3/4 in.
- Lamination/gluing of members in parallel is only allowed for surface of loading platform
- Members cannot be painted, stained, or coated to aide in structural ability to resist load

Baby Breakers Co. will evaluate each truss design based on the criteria listed below using a decision matrix. The team will rate each truss on a 1-4 scale, where 1 is the least preferred option and 4 being the best preferred option.

The decision matrix evaluations matrix:

- Cost - 35%
- Aesthetic/Creativity - 15%
- Strength to Weight Ratio - 30%
- Ease of construction - 20%

These evaluation metrics were each given this specific weighting factor for a reason. The team spoke with the client, and the client said the cost was most important to them. The cost deserves the highest weighting factor. The strength to weight ratio received the second highest weighting factor because the project has a competition aspect of which can hold the most weight while also being the lightest bridge. The ease of construction was given the third highest weighting factor because the team needed to be able to easily construct the bridge because there is a close deadline for the project and it needs to be completed by the set date. The aesthetics and creativity received the lowest weighting factor because the team did not think that it was the most important factor in the project. The truss bridge can look as cool and interesting as it wants, but if it doesn't have the necessary strength, then the truss bridge is pointless. These were the reasons for the selection of each weighting factor for each evaluation metric.

<u>Alternative Solutions and Analysis</u>

Each truss bridge below is shown in three forms. In *Figures 1, 4, 7, and 10* the truss bridge in the bridge designer software is shown. In *Figures 2, 5, 8, and 11* the basic drawing in SAP 2000 is shown. In *Figures 3, 6, 9, and 12* all member forces are shown using SAP 2000.

- *Flatten Triangle Truss Bridge*

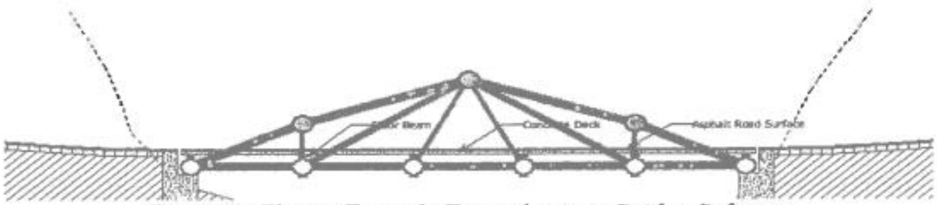

Figure 1: Flatten Triangle Truss shown in Bridge Software

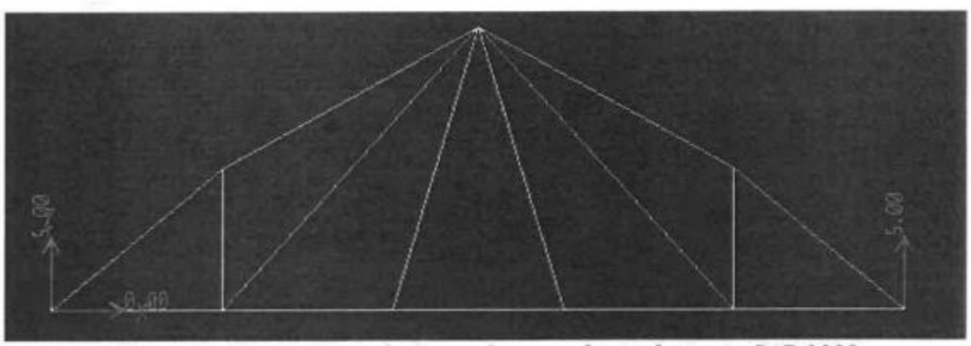

Figure 2: Flatten Triangle Truss shown as basic design in SAP 2000

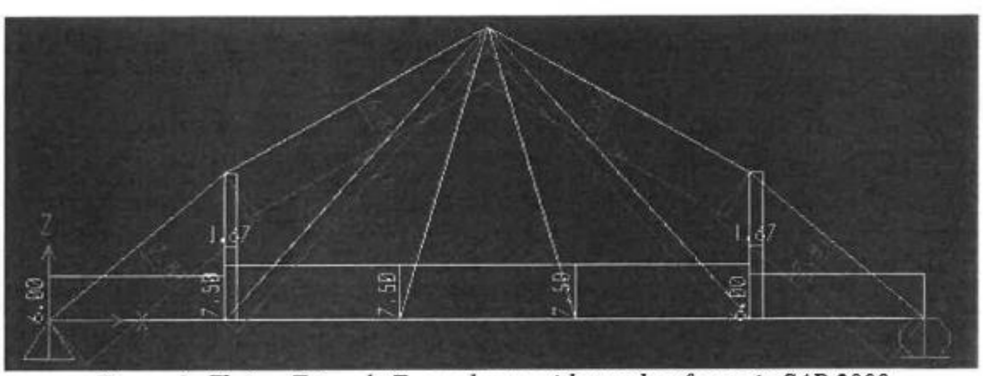

Figure 3: Flatten Triangle Truss shown with member forces in SAP 2000

- *Howe Truss Bridge*

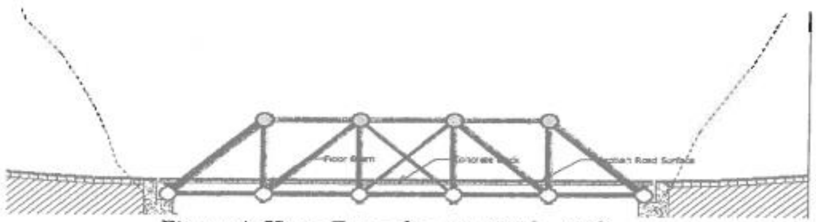

Figure 4: Howe Truss shown in Bridge Software

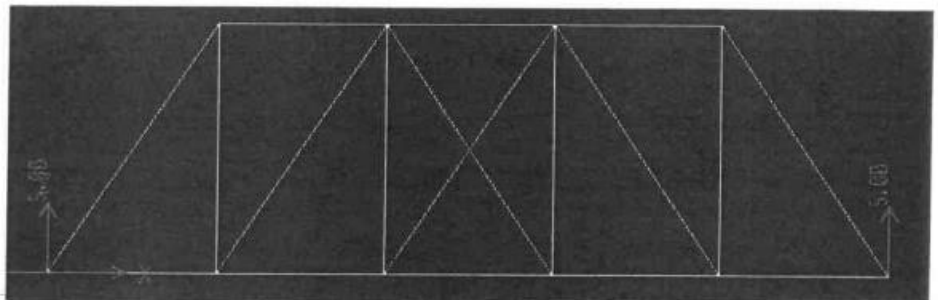

Figure 5: Howe Truss shown as basic design in SAP 2000

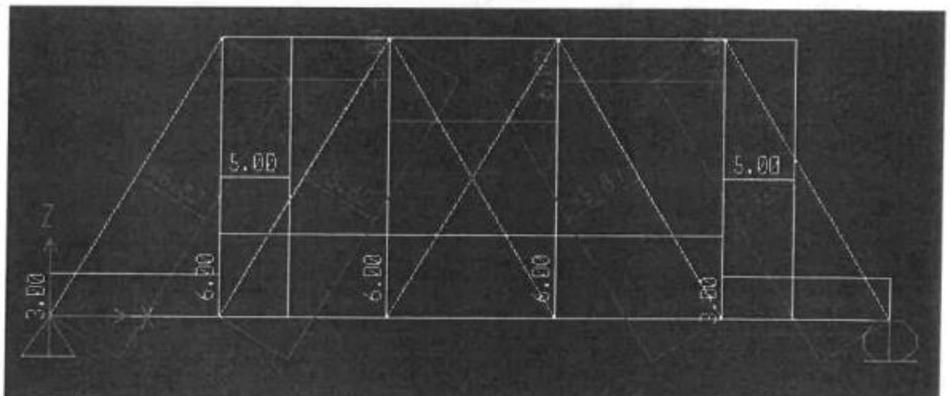

Figure 6: Howe Truss shown with member forces in SAP 2000

- Warren Truss Bridge

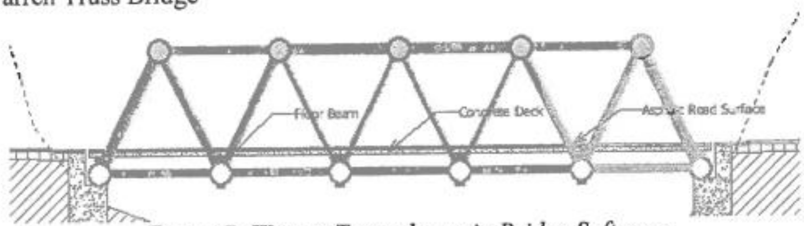

Figure 7: Warren Truss shown in Bridge Software

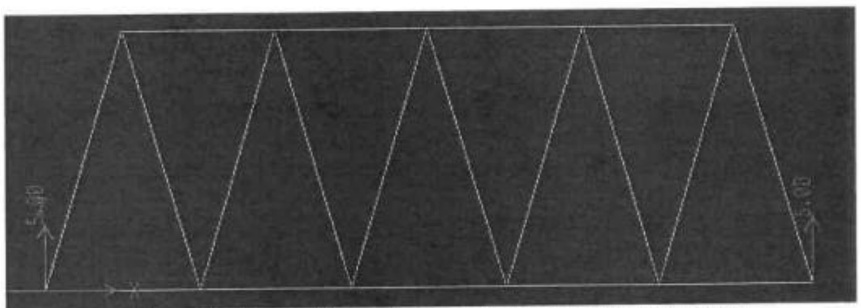

Figure 8: Warren Truss shown as basic design in SAP 2000

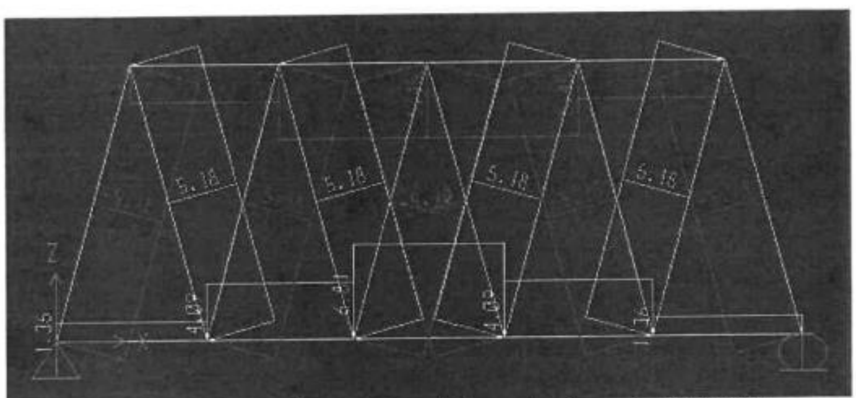

Figure 9: Warren Truss shown with member forces in SAP 2000

- X Out Truss

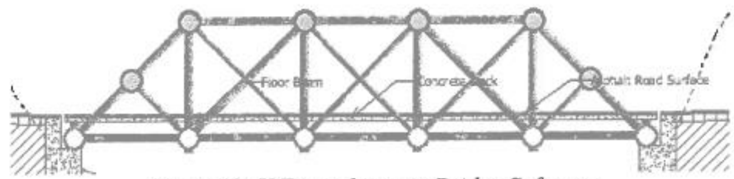

Figure 10: X Truss shown in Bridge Software

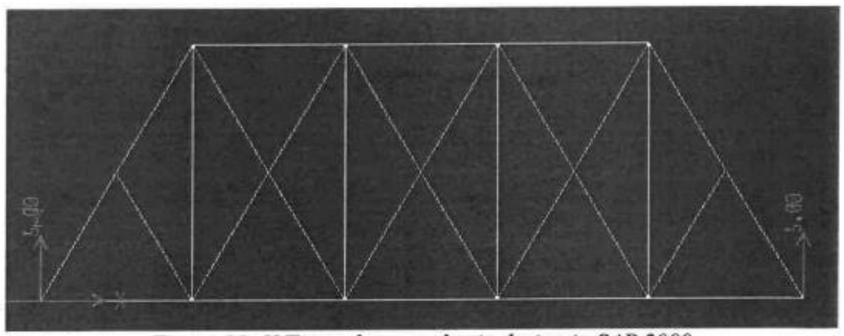

Figure 11: X Truss shown as basic design in SAP 2000

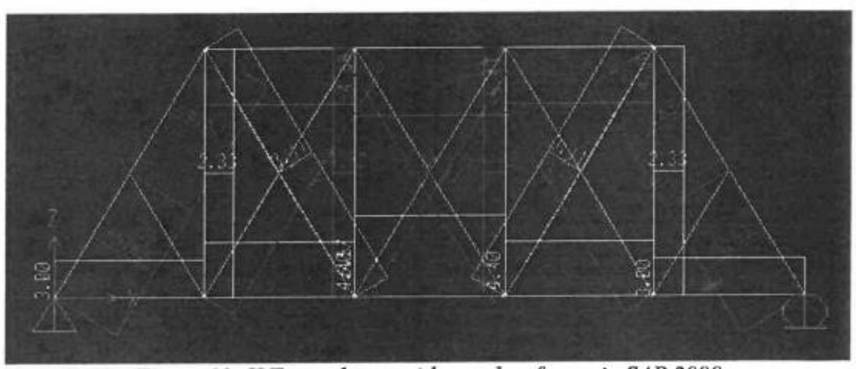

Figure 12: X Truss shown with member forces in SAP 2000

The decision matrix is shown in, *Table 1,* below. The selected design was the Warren Truss Bridge. The X Out Truss came in second with 2.95 rating, the Howe Truss came in third with a 2.4 rating, and the Flattened Triangle came in last with a 1.65 rating.

Table 1: Decision Matrix

Criteria	Weighting Factor	Warren Truss Bridge	Howe Truss Bridge	Flattened Triangle Truss Bridge	X Out Truss Bridge
Cost	35%	2	3	1	4
Aesthetics	15%	2	1	4	3
Strength to weight ratio	30%	4	2	1	3
Ease of construction	20%	4	3	2	1
Total	100%	3	2.4	1.65	2.95

The Warren Truss is shown below in *Figure 13,* as an exploded AutoCAD drawing. All values in the drawing are in inches. The overall length is 12 inches and the overall width is four inches. The height is 2.4 inches. The typical connection includes a ¾ in. by ¾ in. gusset plate with 4 members connected. All connections were attached using Balsa Glue.

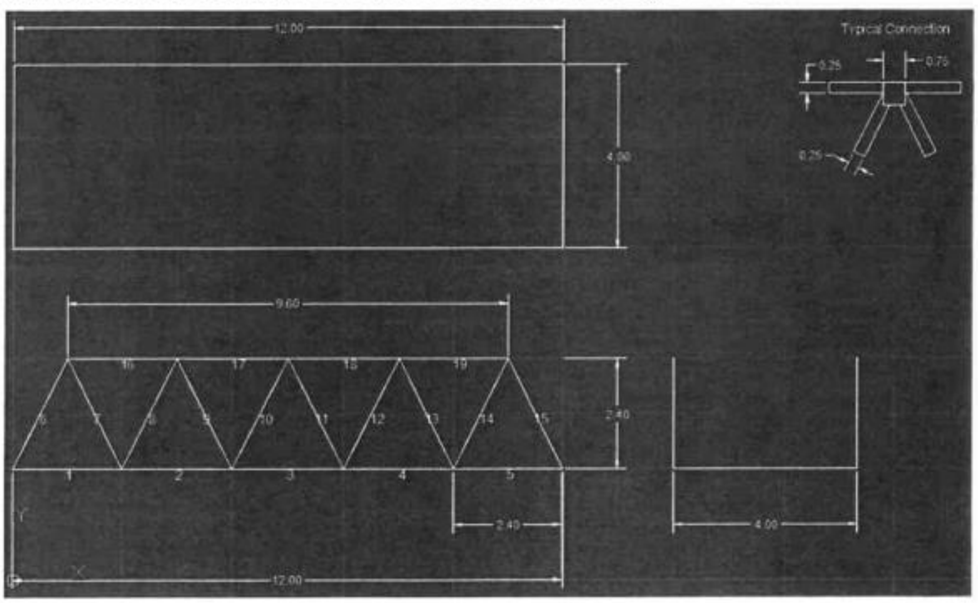

Figure 13: AutoCAD drawing of Warren Truss

Table 2 below shows the numbered members in *Figure 13* above. This table indicates tension or compression within the members, their corresponding length and cross-sectional dimensions.

Table 2*: Member properties*

ID	Member Type	Length	Cross-Sectional Dimensions	Quantity Required	Tension/Compression
1	Balsa Wood	2.4	1/4.	1	T
2	Balsa Wood	2.4	1/4.	1	T
3	Balsa Wood	2.4	1/4.	1	T
4	Balsa Wood	2.4	1/4.	1	T
5	Balsa Wood	2.4	1/4.	1	T
6	Balsa Wood	2.68	1/4.	1	C
7	Balsa Wood	2.68	3/16.	1	T
8	Balsa Wood	2.68	3/16.	1	C
9	Balsa Wood	2.68	3/16.	1	T
10	Balsa Wood	2.68	1/4.	1	C
11	Balsa Wood	2.68	1/4.	1	C
12	Balsa Wood	2.68	3/16.	1	T
13	Balsa Wood	2.68	3/16.	1	C
14	Balsa Wood	2.68	3/16.	1	T
15	Balsa Wood	2.68	1/4.	1	T
16	Balsa Wood	2.4	1/4.	1	T
17	Balsa Wood	2.4	1/4.	1	T
18	Balsa Wood	2.4	1/4.	1	T
19	Balsa Wood	2.4	1/4.	1	T

In *Figure 15,* the influence lines for compression and tension members are illustrated. The member with the highest compression is shown first, and the member with the highest tension is shown second.

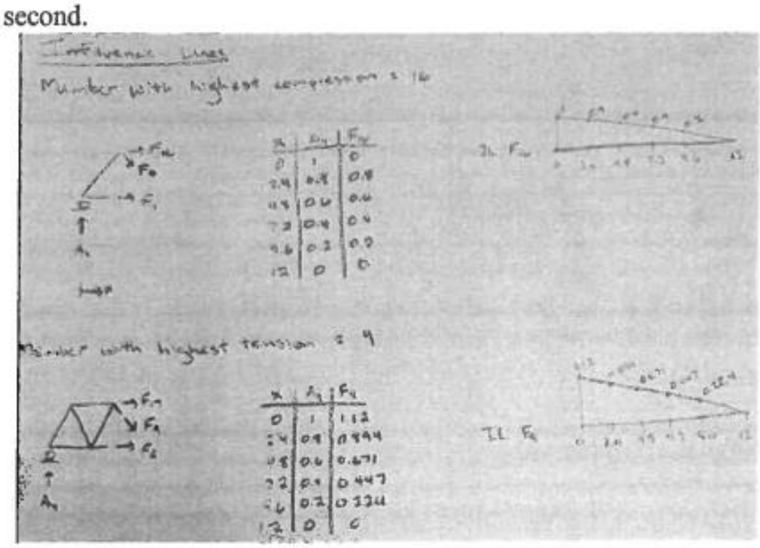

Figure 15: Influence Lines

Analysis of Selection

The NABC approach will be used to advocate for the selected bridge truss, the Warren Truss. *N* stands for "need". What is the underlying need the idea addresses? The underlying "need" the idea addresses is that the design chosen is a suitable and cost-effective solution to the problem. The problem being to construct a prototype truss bridge that is cost effective, easily constructible, aesthetically pleasing, and strong. *A* stands for the "approach". The unique idea for addressing the need is each member of the team formulating their own design, and then inputting those designs into a decision matrix to decide which is the best one. The Warren Truss bridge is simple yet effective. It is made up of 9 isosceles triangles on each side. Each triangle is 2.4 inches tall and 2.4 inches wide. The entire truss is 4 inches wide, 12 inches long, and 2.4 inches tall. This truss is unique because it is simple. It utilizes simple isosceles triangles to make a structurally sound truss bridge. The *B* stands for "benefits per cost". The benefits per cost of this design are high. Although the Warren Truss was at a higher cost, the strength to weight ratio proved to be the best by far. The strength to weight ratio and the ease of construction were both rated the highest for this truss. The cost of the Warren Truss was not that far off from the second lowest cost, the Howe Truss. All these factors should motivate this to be chosen as the selected design. That is exactly how the team rationalized it. Finally, the *C* stands for "Competition". The competing designs are the Howe Truss, the Flattened Triangle Truss, and the X Out Truss. The X Out Truss came in a close second to the Warren Truss. The deciding factor was the "Ease of Construction." The Warren Truss received the highest rating of a 4 and the X Out Truss received the lowest rating of a 1. That was what made the Warren Truss stand out from the X Out Truss. Both were close in strength to weight ratio and cost. The Warren Truss stands out from the Howe Truss and the Flattened Triangle Truss because the strength to weight ratio was much higher, and the ease of construction was much higher as well. What makes this design stand out from the rest is that it is simple, yet the strongest. The Warren Truss was chosen because it exceled above all other competing ideas.

Conclusion

Baby Breakers Co. is investigating 4 different possible prototype truss bridge systems to make a recommendation on the most appropriate truss type, based on cost, constructability, aesthetics, and strength. The team's final decision on the best design was the Warren Truss. The Warren Truss was chosen because of its high ratings in strength to weight ratio and ease of constructability which gave it the overall highest rating. It is better than the other alternatives because of the reason previously state and it is close in cost to the two designs ahead of it. The overall cost is not too far off the lowest costing truss. Therefore, the Warren Truss is the superior and chosen design. There were many lessons learned from the design and the implementation process of the project. During the design phase the team was able to learn to use a new software, the Bridge Designer. This was very helpful in testing truss ideas and the overall evaluation of different trusses. Also, during the design process, the team refreshed their abilities on SAP 2000. This program is very helpful to analyze different structures. Being able to utilize this type of software can be helpful in future aspirations in pursuit of a job in structural engineering. The team was also able to learn and utilize the NABC approach to show how and why the design chosen was superior to the competing designs. This approach is not only useful in the engineering world, but across all fields. The NABC approach can help determine which ideas are most useful and can show how the chosen design excels. All in all, as shown in the decision matrix and explained through the NABC method, the Warren Truss is the best solution to the problem statement given.

Appendix 6

Collaborative Work Skills: Teamwork Evaluation

Team Name: ____

Evaluation of: _____________________________ Evaluated by: __________________________

Directions: **Complete a teamwork evaluation for each member of your team. Circle the description in each category that you feel best describes the behavior or performance of the person you are evaluating. These confidential reviews are to be used by your instructor as an aid in determining your individual and group teamwork scores. Do <u>not</u> discuss how you have scored each other. Confidentiality is needed to ensure scores reflect performance and not personal relationships among team members.**

CATEGORY	**4**	**3**	**2**	**1**
Working with Others	Almost always listens to, shares with, and supports the efforts of others. Tries to keep people working well together.	Usually listens to, shares, with, and supports the efforts of others. Does not cause "waves" in the group.	Often listens to, shares with, and supports the efforts of others, but sometimes is not a good team member.	Rarely listens to, shares with, and supports the efforts of others. Often is not a good team player.
Focus on the task	Consistently stays focused on the task and what needs to be done. Very self-directed.	Focuses on the task and what needs to be done most of the time. Other group members can count on this person.	Focuses on the task and what needs to be done some of the time. Other group members must sometimes nag, prod, and remind to keep this person on-task.	Rarely focuses on the task and what needs to be done. Let others do the work.
Attitude	Never is publicly critical of the project or the work of others. Always has a positive attitude about the task(s).	Rarely is publicly critical of the project or the work of others. Often has a positive attitude about the task(s).	Occasionally is publicly critical of the project or the work of other members of the group. Usually has a positive attitude about the task(s).	Often is publicly critical of the project or the work of other members of the group. Often has a negative attitude about the task(s).
Time-management	Routinely uses time well throughout the project to ensure things get done on time. Group does not have to adjust deadlines or work responsibilities because of this person's procrastination.	Usually uses time well throughout the project, but may have procrastinated on one thing. Group does not have to adjust deadlines or work responsibilities because of this person's procrastination.	Tends to procrastinate, but always gets things done by the deadlines. Group does not have to adjust deadlines or work responsibilities because of this person's procrastination.	Rarely gets things done by the deadlines AND group has to adjust deadlines or work responsibilities because of this person's inadequate time management.
Quality of Work	Provides work of the highest quality.	Provides high quality work.	Provides work that occasionally needs to be checked/redone by other group members to ensure quality.	Provides work that usually needs to be checked/redone by others to ensure quality.
Contributions	Routinely provides useful ideas when participating in the group and in classroom discussion. A definite leader who contributes a lot of effort.	Usually provides useful ideas when participating in the group and in classroom discussion. A strong group member who tries hard!	Sometimes provides useful ideas when participating in the group and in classroom discussion. A satisfactory group member who does what is required.	Rarely provides useful ideas when participating in the group and in classroom discussion. May refuse to participate.
Problem-solving	Actively looks for and suggests solutions to problems.	Refines solutions suggested by others.	Does not suggest or refine solutions, but is willing to try out solutions suggested by others.	Does not try to solve problems or help others solve problems. Let others do the work.