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Combining Problem-Based Learning with the KEEN's Framework for Entrepreneurially Minded Learning in a Fluid Mechanics Course: Pilot Implementation

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Abstract

This paper describes the implementation and the results of problem-based learning (PBL) pedagogy infused with the Kern Entrepreneurial Engineering Network's 3C's in a senior level Advanced Fluid Mechanics course within the Mechanical Engineering Technology (MET) program. The work, a close collaboration between engineering and education faculty, aligns with the New Research Areas (National Engineering Education Research Colloquies 2006), ABET Criteria for Accrediting Engineering Technology Programs, and the KEEN 's Framework for Entrepreneurially Minded Learning.

The four-credit senior level course has lecture (three credits) and lab (one credit) components. It is the second in the fluid mechanics sequence and covers topics like pipeline systems, pump selection, and flow of air in ducts.

During the fall 2021 term, several new problem-based learning exercises were introduced in the curriculum to cover fluid flow through pipeline systems and pump selection theories. The first exercise asked the students to design a pump storage hydropower system able to satisfy a list of specific design requirements, including selecting a feasible pump and estimating the costs associated with implementing the proposed design. Afterwards, the students were asked to blind peer review and to grade all the designs except their own. The second exercise asked students to draft a paper about creativity in the HVAC industry, and a third exercise involved the design and analysis of a class II pipeline system. The students were also asked to analyze the economical and societal impact of their design based on the selection of three materials for their pipeline systems.

Preliminary assessment results support the continued use of these PBL and the integration of entrepreneurial mindset learning content. The evidence shows students developed an understanding of technical content while developing an entrepreneurial mindset. These outcomes satisfy the latest ABET student learning outcomes and support students' preparedness and readiness for the workforce.

Introduction

Several scholarly works examined the role of problem-based pedagogies (PBL) in higher education as a general pedagogical method (Barron et al., 1998; Cheney, 2004; Fosmire & Macklin, 2002). Others provide strategies for integrating PBL in engineering courses to expand hard and soft skills (Hsieh & Knight, 2008; Cioc et al., 2020, 2021). In all instances, the authors found that their PBL pilot implementations were more effective in knowledge transfer, participation, and interest, than a traditional lecture-based approach to instruction. The inclusion of an entrepreneurial mindset learning (EML) and promoted by the Kern Entrepreneurial Engineering Network (KEEN), into PBL, courses, and curriculum, further support engineering students' readiness for the engineering profession (Gerhart & Melton, 2016; Liu et al., 2017; Mynderse et al., 2015).

The KEEN 3C's framework has led to the increased integration of EML activities into engineering education (EE) coursework (Bosman, 2019). Hence, added focus on the evaluation of these pedagogical practices and related student learning outcomes, including the development of the means to assess EML growth in engineering students remains a priority (Li, et al., 2016)

The KEEN framework aligns with ABET quality assurance goals to prepare qualified engineers who can contribute their expertise in a global workforce (ABET, 2021). Therefore, the KEEN's mission and the ABET goals together provide a useful framework for considering, designing, implementing, and evaluating innovative engineering curricula and pedagogical best practices.

Research Methods and Procedures

This paper describes the implementation and evaluation of EML activities added to a learning module and to a Project Based Learning (PBL) activity part of that learning module. The pedagogical practices discussed herein focuses on solving a real-world problem by integrating: i) a collaborative model with multiple socio-technological dimensions supported by cooperative learning, peer assessment, and communication (Jordan, 2018; Dym et al., 2003); and ii) a KEEN's 3C's approach incorporated into an existing learning module and project.

Study Site

The site for this Entrepreneurial Mindset (EM) integration study described herein is the Engineering Technology Department (ET) in the College of Engineering (COE) at the University of Toledo. The ET Department offers 5 ABET-accredited Bachelor of Science (BS) in engineering technology programs, one of them being BS in Mechanical Engineering Technology (MET). Due to the COVID pandemic, the enrollment in the program decreased, and as of January 2022, there are 184 students enrolled. This student body is comprised of traditional students (37.0%), transfers (22.3%), internationals (4.3%), and non-traditional students (36.4%). The substantial number of transfer and non-traditional students brings a variety of engineering skills and lifelong learning experiences to the MET program.

The Course

The Applied Fluid Mechanics course (MET 4100) is an upper division core course in the MET program and the second in the sequence of fluid mechanics coursework, following Fluid & Hydraulic Mechanics (MET 2050). This four-credit hour (ch) course consists of a 3ch lecture and a 1ch laboratory. During the Fall 2021 semester, the course was offered as a face-to-face (F2F) on campus. To increase the accessibility to the lectures for those students not able to attend them in person due to COVID issues, the authors developed the course more like a blended experience than a F2F course, using the Blackboard platform to post lectures, course materials, instructional aids, and assignment submissions. Simultaneously, all the lectures were conducted synchronously through Blackboard Collaborate Ultra and recorded for later viewing. During the fall 21 semester, there were 29 students enrolled in it.

The course focuses on the applications of the basic principles of fluid dynamics, including series pipeline and parallel and branching pipeline systems, open-channel flow, pump selection, flow measurement, drag and lift, flow of air through ducts, etc., and it was structured as follows:

- Twelve learning modules, covering the topics listed above.
- Eleven weekly assessments, each valued at 50 points.
- One comprehensive project-based learning exercise, valued at 100 points.
- Two problem-based learning exercises, each valued at 50 points, and subject of this work.
- Six laboratory exercises, one discussed herein, and each valued at 50 points, plus another two pre-labs exercises, each valued at 25 points. The pre- and lab exercises were either hands-on experiences in the Fluid Mechanics Laboratory, or computer simulations using the Tahoe Design HydroFlo Academic software, good for piping system design. All simulations were done in the ET Department's computer labs or using Virtual Lab (VLab).
- Several extra credit opportunities taking various forms during the semester, including asking questions as part of four Muddiest Points sessions.

Problem-Based Learning Exercises – Examples

Pump Storage Hydropower (Assignment #5)

The students were asked to design and select a pump, part of a hydropower storage system, able to meet a client's location (see Appendix 1). The main condition was to create an excel file to work as a fluid flow simulator; two weeks were assigned for the completion of this exercise. The students were also given the option of either working alone, or as part of a group. Once the solutions were gathered by the instructor, the solutions were posted anonymously on Blackboard, and the class was asked to evaluate all the project both for style of presenting the excel file, and for correctness of the calculations. This exercise was valued at 100 points, out of which 25 points were given for the peer review exercise. The students' scores were considered when calculating the final grade for this exercise. For the peer review exercise, the students received instructions and a score sheet, and each student was instructed to provide at least three ways in which the solution can be improved (see Appendix 2 for details).

Creativity in HVAC Industry (Assignment #10)

The students were asked to draft a short article covering the history of HVAC, including the energy and societal impact of each innovation. They were instructed to focus on: a) *Past*: the history of HVAC; innovations that changed HVAC; b) *Present*: HVAC today; c) *Future*: HVAC trends; innovations that will change HVAC forever. In addition, the students were instructed to work in groups of three, and to adopt a jigsaw model for group work strategy, namely, to split the tasks, research your topic, and share the knowledge you gained with your team. Once the article was submitted, as before, it was evaluated by the classmates, instructed to identify the best three articles (first place, second place, and third place). The criteria for peer review were separated into a) Use of Content; b) Critical Thinking; c) Organization; and d) Mechanics (see

Appendix 3). The "best article" received an additional 10 extra points, while the second and third place received 5 extra credit points. The students responded positively to the assignment.

Pipeline Systems (Laboratory #3)

This exercise was done during a session of laboratory, in a computer room, and using HydroFlo software installed on university's computers. At the time the students received this assignment, they did not use the software before, and part of the laboratory lecture was a brief introduction of the software's capabilities. The exercise asked the students to create an excel file able to solve a given textbook problem. Once done, they were asked to investigate an additional two scenarios, in which elements from the textbook's problem are changed in terms of pipe material and valves. In the end, the students were asked to compare the three scenarios from an economical and societal impact and to make a recommendation for implementation.

Assessment Instruments

Direct Assessments

The scores the students received for the above-mentioned problems constitute direct assessment instruments. The investigative nature of these problems fits perfectly with this KEEN EML framework. Both exercises require the students to be i) curious about the given subject, to investigate it on their own, to find credible sources for information, ii) to make connections, and not only between the content knowledge learned during the course, but also between the assigned topic and the society, for example, and iii) to create value, by creating new simulation tools, able to be used for solving similar problems, and by thinking of new HVAC applications.

Indirect Assessments

This collaborative work between two engineering faculty and one educational faculty has the goal of improving both the technical and soft skills, and to evaluate entrepreneurial learning in a senior level fluid mechanics course. Two indirect assessments were implemented to assess the efficacy of the course and the blending of EML into the course: a 76-question engineering knowledge and skills survey and an end of course evaluation.

Engineering Knowledge and Skills Survey. The 76-questions survey was developed by the authors based on existing in-house survey(s) (Cioc et al., 2020, 2021) and the addition of EML sub-scales. The content of the EML sub-scales were influenced by assessments developed by the Arizona State University (EM@FSE 2.0 aq Indicators, 2016) and Ohio Northen University (2020). The students reported their engineering-related skills, including entrepreneurial mindset, problem solving, communication, and collaboration.

Three entrepreneurial mindset sub-scales detailed focused on the students' ability to: make connections between courses and to real-world contexts (three questions, $\alpha = .74$); create value with new and existing products (four questions, α = .83); and consider the consequences of their choices (four questions, α = .87). Two additional sub-scales related to communication and collaboration skills also informed student learning outcomes: interpersonal collaboration (seven questions, α = .85) and the use of ideas and feedback (four questions, α = .75). Responses were based on a five-point rating scale: 1=strongly disagree; 2=agree; 3=neither agree nor disagree; 4=agree; 5=strongly agree. Paired two-tailed *t* tests were performed to assess pre-course and post-course differences.

End of Course Evaluations. The university-driven end of course evaluations included 13 statements, 10 university-level and three college-level. The university-level statements focused on student effort, students' performance expectation, motivation, support of learning needs, comfort with expressing own views, receipt of timely feedback, quality of feedback, fairness of grading, quality of the learning experiences, and instructor engagement with students. Responses were based on a 4-point rating scale: 1=strongly disagree; 2=disagree; 3=somewhat agree; 4=strongly agree. The college-level statements focused on instructor effectiveness, clear presentation of subject matter, and overall course quality. Responses were based on a 5-point rating scale: strongly agree, agree, neutral, disagree and strongly disagree. Summary results from both surveys are provided by the university the following semester.

Results and Discussions

Direct Assessments

The class scores for assignments #5 and #10 showed proficiency of the subject, with a class average of 91.4%, stdev. = 4. and 90.9%, stdev. = 1.6. Furthermore, the comments and the recommendations the students wrote for future improvements, some more in depth than others, demonstrate the level of commitment showed by the students for peer assessment, while contributing to improving the student's soft skills like written communication and evaluation of the ideas of others. A total of 25 students participated in the peer process for assignment #5 and 23 students for assignment #10. Regarding the laboratory exercise, 28 students submitted their work. The class average of 87.9%, stdev. = 4.6 are proof of the students mastering a new software and use it for solving real-life scenarios, but also of their ability to be curious, to make connections, and to create.

Indirect Assessments

Tables 1 and 2 describe the pre and post course self-reported entrepreneurial mindset of the MET 4100 students.

Table 1
Students' Pre-Course and Post-Course Entrepreneurial Mindset

	Mean	N	Std. Dev	*t*, *p*-value
Connections: Course Work and the Real World				
make connections between classroom and outside	3.88	24	.947	-1.430, .166
	4.17	24	.761	
make connections between courses	4.08	24	.881	-1.430, .166
	4.38	24	.824	
ask probing questions to clarify facts concepts	4.08	24	1.10	-1.187, .247
	4.33	24	.702	
Creating Value: Use New and Existing Products				
suspend judgement on new ideas	4.20	25	.816	**-2.064, .050**
	4.48	25	.770	
define potential markets new & existing products	3.84	25	.987	**-3.645, .001**
	4.40	25	.816	
define potential opportunities new & existing products	3.68	25	.988	**-4.272, <.001**
	4.40	25	.707	
describe how existing products can solve new problems	4.04	25	.841	**-3.161, .004**
	4.56	25	.583	
Connections: Consequences of Decisions				
identify potential ethical issues	4.13	24	1.03	-1.163, .257
	4.29	24	.908	
recognize the ethical considerations solutions	4.04	24	.806	**-3.412, .002**
	4.50	24	.780	
recognize professional considerations solutions	4.21	24	.833	**-2.326, .029**
	4.54	24	.588	
recognize social considerations solutions	4.08	24	.929	**-2.198, .038**
	4.50	24	.590	

Students on average reported growth in all areas of connections and creating value. Growth was strongest in the areas of creating value from new and existing products, as shown in bold fonts in Table 1. All post-course responses were significant in terms of suspending judgment on new ideas [$t(23) = -2.064$, $p=.050$], defining potential markets for new products [$t(24) = -3.645$, $p=.001$], defining potential markets for existing products [$t(24) = -4.262$, $p<.001$], and describing how existing products can solve new problems [$t(24) = -3.161$, $p=.004$]. Students also reported significant growth in their ability to recognize the ethical [$t(24) = -3.412$, $p=.002$], professional [$t(24) = -2.326$, $p=.029$], and social [$t(24) = -3.161$, $p=.004$] consequences of their decisions.

Table 2
Students' Pre-course and Post-course Communication and Collaboration

	Mean	N	Std. Dev	*t*, *p*-value
Interpersonal Collaboration				
manage formal communication	4.44	25	.712	-1.155, .260
	4.64	25	.638	
display empathy – peers' ideas and solutions	4.52	25	.586	-1.445, .161
	4.68	25	.557	
use positive communication tone	4.72	25	.614	.296, .770
	4.68	25	.557	
recognize peers' strengths: knowledge	4.20	25	1.000	-.204, .840
	4.24	25	.831	
recognize peers' strengths: communication skills	4.16	25	.688	-.625, .538
	4.24	25	.779	
recognize peers' strengths: collaboration skills	4.28	25	.678	-.272, .788
	4.32	25	.748	
recognize peers' strengths: problem solving	4.04	25	.841	-1.155, .260
	4.24	25	.723	
Use of Ideas and Feedback				
evaluate ideas of peers	4.44	25	.507	-1.549, .134
	4.64	25	.490	
accept critical feedback from instructors	4.64	25	.569	-1.000, .327
	4.76	25	.436	
integrate feedback from peers	4.48	25	.714	-1.072, .294
	4.64	25	.569	
take ownership of problems	4.48	25	.653	
	4.60	25	.645	-1.141, .265

Tables 3 and 4 present the results of the university and college course evaluation questions. The results also show a comparison between the MET 4100 students' responses with the ET department and college. Compared with the ET Department and the COE, the MET 4100 responses show an elevated level of agreement with each statement.

Table 3
End of Semester Course Evaluation Survey: University-level Statements

	MET 4100 respondents (n=6)	ET Dept. respondents (n=432)	COE respondents (n=2,508)
I put forth my best effort in this course	3.67	3.66	3.59
Expectations for performance were clearly communicated throughout the semester	4.0	3.45	3.37
The teaching strategies used to motivated me do my best work	4.0	3.13	3.03
The teaching approaches used supported my learning needs	3.83	3.19	3.08
The course provided a comfortable environment for expressing views and ideas	4.0	3.31	3.23
I received feedback on my work withing a reasonable timeframe	4.0	3.41	3.26
The quality of the feedback on my work helped my learning	4.0	3.17	3.07
The grading in the course fairly reflected the quality of my work	4.0	3.52	3.37
Overall, I had a good learning experience on this course	4.0	3.29	3.17
The instructor worked to make the course engaging for all students	4.0	3.22	3.18

Table 4
End of Semester Course Evaluation Survey: College-level Statements

	strongly agree MET4100 / ET / COE	agree MET4100 / ET / COE)	neutral MET4100 / ET / COE	disagree MET4100 / ET / COE	strongly disagree MET4100 / ET / COE
For overall quality, the instructor is an effective instructor	100% 59% 52%	none 15% 21%	none 10% 12%	none 7% 8%	none 9% 8%
I learned a great deal about the subject matter presented in this class	80% 57% 53%	20% 22% 27%	none 8% 11%	none 5% 5%	none 8% 4%
The overall quality of this course was excellent	100% 51% 45%	none 20% 23%	none 13% 16%	none 7% 9%	none 10% 7%

Conclusion

Infusing EML in various activities at a course level was successfully implemented during the fall 2021 semester. The students enrolled in the course, majority graduating during that semester, positively accepted EML related tasks, and from their pre-and post- self-evaluations of their skills, overall improved not only the content knowledge, but also the soft skills related to communication, collaboration, finding credible sources, curiosity, creativity, and not lastly creating value, as demonstrated by the exercises discussed herein. Limitations related to self-report and the limited student participation in the end of course evaluations are noted. While mixed, the results provide support for continued focus on EML integration that aligns with previous findings (e.g., Bosman et al., 2019; Gerhart & Melton, 2016; Seyed, 2020). The available student responses were positive and reflected their positive view of the PBL tasks including the EML components. Focused skills are critical to the preparation of qualified engineers and global workforce readiness (ABET, 2021; KEEN, n.d.). Therefore, the authors consider the results of this pilot implementation encouraging and plan to continue further course and project development as well as extending PBL and EML in additional courses.

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Appendix 1

Assignment #5
Pump Storage Hydropower: Part 1

Group Project

Objective:

The objective of this project is to design a pump storage hydropower system able to meet the client's location (California desert) and proposed design as shown in figures 1, 2, and 3.

Part 1: identify the required pump power, and select the pump.

Pump Storage Hydropower:

Pumped storage hydropower is a type of hydroelectric energy storage, consisting of two water reservoirs at different elevations that can generate power as water moves down from one to the other, passing through a turbine. The system also requires power as it pumps water back into the upper reservoir. The two reservoirs act similarly to a giant battery, storing power and then release it when needed.

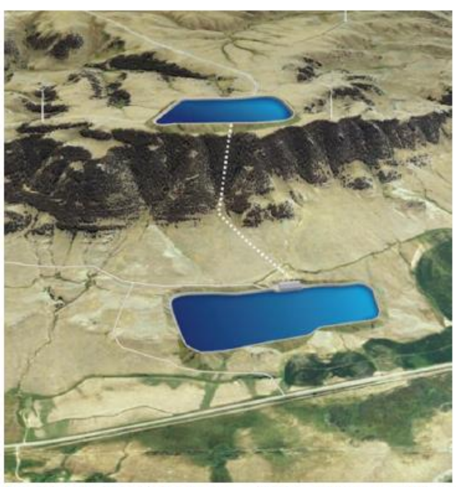

Figure 1: Aerial photo of the proposed location[1]

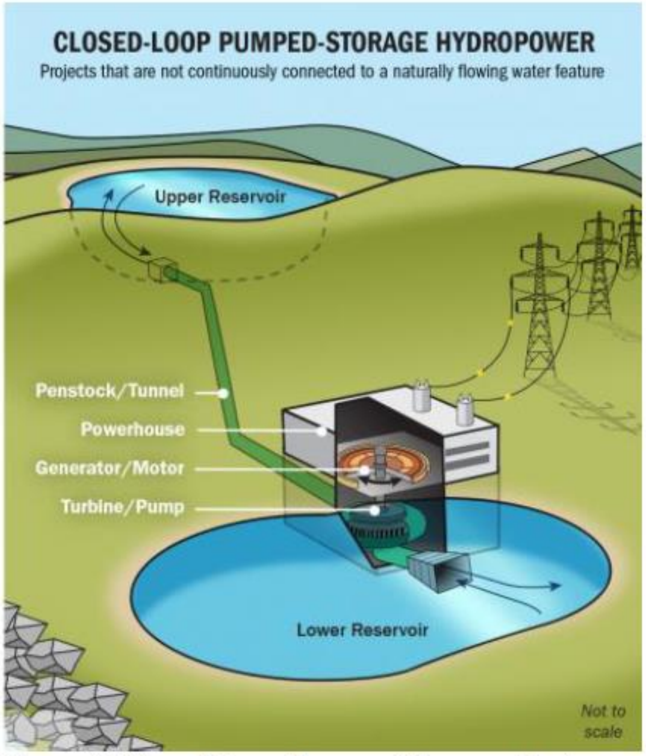

Figure 2: Closed-Loop Pumped Storage Hydropower[2]

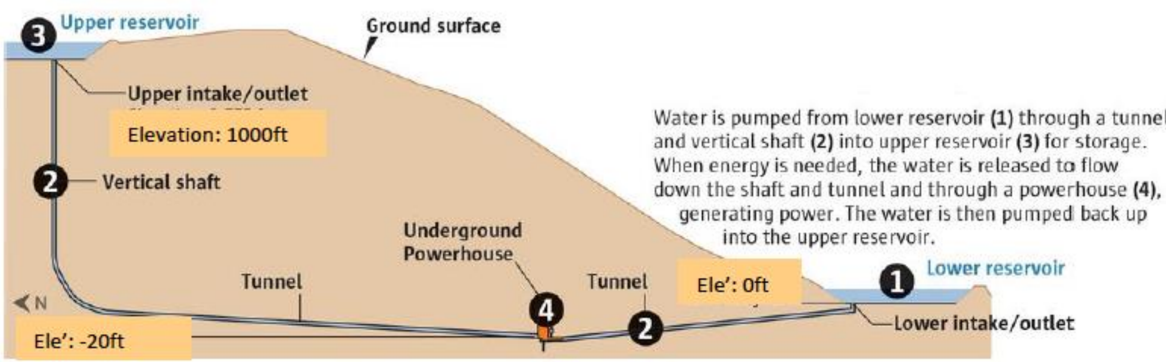

Figure 3: Proposed Design[3]

The following data is provided for the completion of this project:

- The pumping of water from the lower to the upper reservoir is done when outside average temperature is 100F.
- The flow rate is calculated as 2.5 ft^3/s
- The suction line is made of 24in schedule 40 steel pipes, totaling 500 ft.
- The discharge line is made of 20in schedule 40 steel pipes, totaling 3 miles.
- The suction line requires 50 standard elbows
- The discharge line requires 100 standard elbows
- The system requires a check valve ball type in suction and discharge lines
- Inward projected pipes are considered at the connection with each reservoir.

Results and Discussions:

1. Create an excel file to work as a __fluid flow simulator__ (meaning, that if one changes any of the given / input values, the final results update instantaneously), and calculate:
    a) Pressure at the pump inlet, in psi;
    b) Total head of the pump, in ft;
    c) Pressure at the pump outlet, in psi.
    d) Required pump input power, in hp, for an average pump efficiency of 78%.
2. Select the pump able to meet your system parameters.
3. Estimate the cost associated with this design.

Notes:

- Keep your fluid flow simulator for future assignments. Submit __one excel file per team__
- Once I collect all your solutions, I will post them on BB (nameless), and you will be asked to peer review / evaluate the competitive solutions presented by all the other teams, by **detailing the pros and cons of the presented work**. At that time, I will also post a grading sheet on BB. __This peer review component will be also included in this assignment grade and should be done by each group__. You will have an additional week to finalize the peer review.
- Afterwards, you will be asked to evaluate your team's contribution to the project.

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Assignment #5 Peer Review

Your name:________________

Please use the following 1 to 5 scale when grading each project. Do not evaluate your own project.

1 – strongly disagree	2 - disagree	3 - average	4 - agree	5 – strongly agree

	Teams								
	1	2	3	4	5	6	7	8	9
Project Style (20 points maximum)									
All the parameters are clearly labeled, including showing the units, if applicable.									
The data presented in the table is easy to follow.									
The visual effects, graphs and pictures, are visually pleasant and easy to read.									
Overall, the style is pleasant and appealing, making navigating the project very easy.									
Project Content (25 points maximum)									
All the given data, including data selected from tables, is correct.									
Formulas required to solve this project are clearly written either inside the cell or in an adjacent area making easy to understand the applied equations									
At least 90% of all formulas are correct and according to the theory.									
The project has no calculation errors.									
I recommend this project to be used as an analysis tool for future similar projects									
Total									

Use the space below to explain your grade and to list **at least 3 ways in which this project can be improved**.
Provide as much details as possible, so each team can improve their project based on your recommendations.

Team 1
Team 2
Team 3
Team 4
Team 5
Team 6

Appendix 3

Rubric Detail

Use of Content	**From 0 to 16 points** Limited integration of technical content into paper.	**17 to 25 points** Refers to a wide and appropriate range of technical content into paper.
Critical Thinking	**From 0 to 16 points** Understands key concepts and draws few conclusions about the evolution of HVAC systems. Articulately reflects ideas and approaches.	**17 to 25 points** The team shows deep knowledge of the technical content and make strong connections between past, present, and future of HVAC systems. The quality of work suggests extensive personal reflection on what the future might bring.
Organization	**From 0 to 16 points** Some organization; some logical progression of ideas, but not throughout the entire document.	**17 to 25 points** Very well organized; clear, logical progression of ideas.
Mechanics	**From 0 to 16 points** May have some grammar, punctuation, capitalization, and spelling errors that do not primarily interfere with comprehension; uses a variety of sentence structure, precise word choice; meets required length.	**17 to 25 points** No grammatical, punctuation, capitalization, and spelling errors that interfere with comprehension; uses a variety of sentence structure, precise word choice; meets required length.

Using the rubric detail above, read all the Groups' papers and grade them. Calculate the total; DO NOT grade your own. Do not use an interval of values;

Group Name	Use of Content	Critical Thinking	Organization	Mechanics	TOTAL
A					
B					
C					
D					
E					
F					
G					
H					
I					