Fostering an Engineering Entrepreneurial Mindset through the Engineering Problem-Solving Module in the Freshman Engineering Discovery Course

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***Abstract* – In order for new engineering students to clearly grab and be equipped with the philosophy of engineering problem solving, the *Freshman Engineering Discovery* course developed and currently running at the Marquette University – Opus College of Engineering provides an engineering problem-solving module session for four weeks in which students explicitly practice how to estimate and predict the engineering analysis results for real-life problems, while incorporating the elements included in the engineering entrepreneurial mindset defined by the 3C's of Curiosity, Connections and Creating Value. Instead of solving the well-defined problems through the engineering problem-solving module, the student teams (4-5 students per team) are asked to find, select and identify a problem from within the space (or campus) they live in. They are also asked to perform proper engineering calculations by following the engineering problem-solving steps and procedures to estimate and predict the amount of heat/energy transfer/loss from a system or region and the corresponding energy usage efficiency and costs. As a consequence, the students are able to experience and foster the engineering entrepreneurial mindset defined by the 3C's of Curiosity, Connections and Creating Value, in which they are curious about the environment where they live, gain insight through connections and information, and practice to create value by performing proper engineering calculations.**

Index Terms – engineering problem solving, fostering entrepreneurial mindset, freshman engineering

INTRODUCTION

According to the Wikipedia online directory [1], "*Engineering is the application of mathematics, empirical evidence and scientific, economic, social, and practical knowledge in order to invent, innovate, design, build, maintain, research, and improve structures, machines, tools, systems, components, materials, and processes.*" The Merriam-Webster online dictionary [2] defines engineering as: "*Engineering is the application of science and mathematics by which the properties of matter and the sources of energy in nature are made useful to people.*" Engineering is many things to many people. It involves analysis. To some it is all about problem solving. Many literatures and references [3]-[5] define engineering (or engineers) as a problem-solving activity (or problem solvers).

No matter the definition, what makes engineering distinct from sciences and other disciplines is that engineers design. Design is a process that begins with choosing what to design, how to configure the device or system, and determination of its dimensions and tolerances, materials, fabrication, manufacturing techniques, packing, rules for use of the product or system, and even its eventual disposal, recycling and reuse, among others [6]-[9]. In all elements of design, the engineer is in the role of decision maker. So a key element of design is decision-making. Through their decision-making, the engineer is manipulating nature to benefit at least a segment of society.

A key element of engineering is decision-making and since good decision-making demands good prediction, engineers (and engineering students) must be good at prediction. In designing a system, for example, the engineer must be able to predict the behavior of the system as a function of the design choices made regarding the system. In order to affect good prediction, engineers (and engineering students) invoke the belief that all laws of nature apply everywhere all the time, and it is the laws of nature that determines the system's behavior.

Here we see that in predicting the behavior of a system, the engineer faces two key questions: which laws of nature dominate the behavior of the system, and what mathematical and/or computational algorithm will enable enforcement of these laws with adequate precision? Predictions are never both precise and certain. Thus, engineers must deal properly with uncertainty, and they need mathematical and/or computational procedures to aggregate uncertainty estimates on components to an uncertainty estimate on the overall system.

Engineering problem solving (i.e., analysis and design) to predict or estimate the behavior of a system (or real-life problem) often is too abstract for most engineering students to grasp and comprehend in their minds during their college life as engineering students. Furthermore, most freshman (and even upper-level) engineering students consider studying engineering as simply limited to the ability of solving textbook-type (or virtual) problems, in which there are a set of solutions to the problems that the students expect to obtain, while being provided with somewhat clearly defined problem statements, the available and required information (or inputs), and the unknowns (outputs) to find by using a set of proper engineering fundamentals and the corresponding equations.

However, most real-life (engineering) problems are not clearly defined as described in the textbook-type problems. Furthermore, since most engineering analysis results are obtained by solving properly modified and/or simplified model equations derived from the given and available (sometimes complicated) physical laws or models involved in the problem, these results are only estimated or predicted outcomes which may or may not be close to real-life outcomes.

The currently running *Freshman Engineering Discovery 2* course developed at Marquette University – Opus College of Engineering provides the engineering problem-solving module session within the course content. Table I shows the overall structure and content/topics for the course, offered every second (spring) semester. The author's previous works [12]-[13] describe the details of how the *Freshman Engineering Discovery* courses have been run for more than the last five years.

TABLE I
FRESHMAN ENGINEERING DISCOVERY 2 – OVERALL COURSE STRUCTURE AND TOPICS

Engineering Computing with MATLAB® & Its Applications	Engineering Problem Solving Practice
	Engineering Design Process with Design Challenges/Projects
Team Design Challenge/Project – Poster Exhibition & Competition	

During the engineering-problem solving module session, the students are primarily introduced to simple engineering problem-solving steps while they study the selected topics - basic modes of heat/energy transfer (i.e., conduction, convection and radiation). After introducing the engineering entrepreneurial mindset defined by the Kern Engineering Entrepreneurial Network (KEEN) [10], this paper describes how the freshman engineering students practice and foster the engineering entrepreneurial mindset through energy-term team project.

ENGINEERING ANALYSIS ROUTE

Figure 1 shows the flowchart describing the various stages of the engineering modeling process. The analysis of any problem begins with a physical description of the real-life problem. This description usually constitutes some text and perhaps a few accompanying illustrations that describes the problem, along with other physical details and detailing geometries. In addition, the description will include what the goal of the analysis is and what is sought.

The second step in the analysis is to create a physical model from the available physical description. The creation of the physical model entails making important decisions on what physical phenomena need to be included. These decisions are driven not only by the goals of the study, but also the feasibility of including or excluding a certain physical phenomenon based on the resources and time available to complete the task. There are some (example) issues/questions that need to be addressed: (a) Is the problem steady or unsteady? (b) Is it sufficient to model the problem as isothermal, constant (material) properties, 2-D and linear behavior, among others? It should be noted that the answers to some of these questions may not be known beforehand, and one may have to explore the various possibilities.

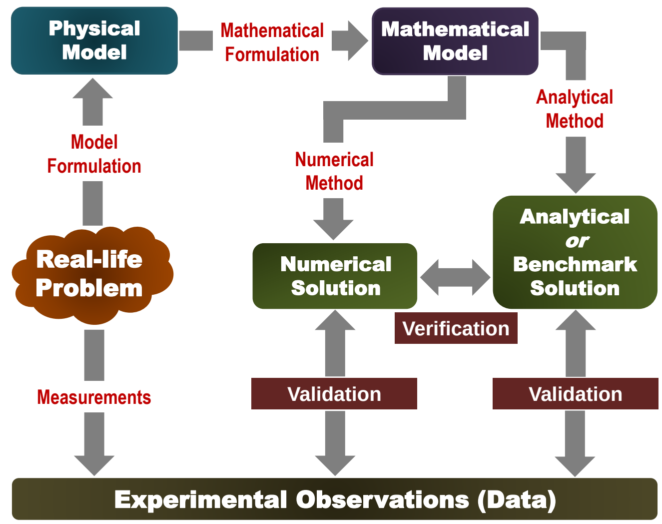


FIGURE 1
VARIOUS STAGES OF ENGINEERING MODELING PROCESS

Once the physical model has been created, the next step is to develop the mathematical model. Various types of mathematical models (or governing equations) can be selected, derived and simplified. Before selecting the solution method, one may have some of the following critical issues/questions about the model equations: (a) linear or non-linear, (b) 2-D or 3-D algebraic and/or ordinary (or partial) differential equations, (c) relevant (homogeneous or non-homogeneous) initial and boundary conditions, (d) regular or irregular model geometry, among others. As is the case of the physical model's development, the answers to these questions are often deeply rooted in state-of-the-art-knowledge in the field in question and requires formal education (or training) and experience. More often, poor decisions and associated uncertainties lead to discrepancies between the model's predictions and observed behavior.

Only a limited few (i.e., simplified) governing equations have closed-form analytical solutions. Most of these solutions can be obtained by solving the linear (and constant coefficient) equations with homogeneous initial and boundary conditions for a simple geometry. Irregular geometry, space or time dependent coefficients, nonhomogeneous boundary conditions and nonlinearities in the governing equation or boundary conditions, are some of the primary reasons why numerical solutions are warranted.

The numerical solution may have some discrepancies with the closed-form exact analytical solution to the governing equations (if available), and the degree of discrepancy is generally dependent on the numerical method being used.

Verification is the process of comparing the numerical solution of the governing mathematical model (algebraic or ordinary/partial differential equation, along with initial and boundary conditions) to a "well-established" (benchmark) solution of the same equations. The well-established solution means either a proven closed-form analytical solution or a solution obtained by a proven numerical technique, agreed upon by the community at large.

The process of quantitative comparison between the solution of the mathematical model and experimental observations is known as validation. Anytime a model has been created following the route sketched in Figure 1, there is an obligation to compare the predictions of the model with experimental data to ascertain that the results are meaningful and of practical value. Errors may have been introduced in developing the mathematical model from the physical model. Similarly, errors may also have crept in during the process of creating the physical model. Certain important physics may have been ignored. In order to trace back to the root of the discrepancy, the engineer must now reexamine every step of the modeling process. One may verify his code against a known benchmark solution, and rule out any possibilities of error in his code, but his validation study may fail.

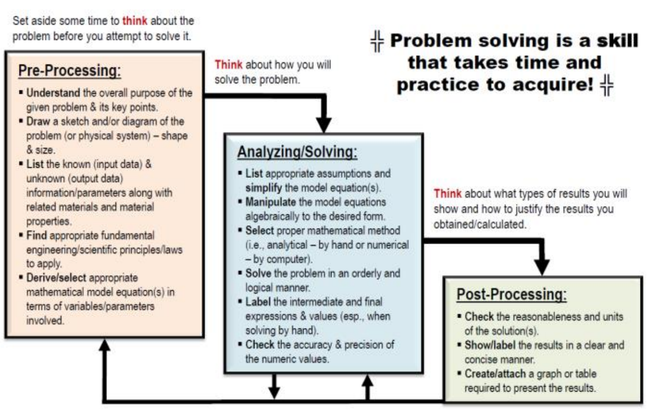


FIGURE 2
GENERAL ENGINEERING PROBLEM-SOLVING PROCEDURES

ENGINEERING PROBLEM-SOLVING STEPS OR PROCEDURE

Now it is clear to say that engineers (and engineering students) are problem solvers who are able to select and use proper scientific fundamentals and mathematical principles to analyze and solve a given problem under specific conditions and constraints involved. Generally speaking, depending on types and/or areas of (engineering) problems to solve, the engineering problem-solving method or strategy may vary or be different. However, the engineering problem-solving steps or procedure is similar to one another as long as a problem solver (or engineer) intends to consistently think about the problem, solution skill(s), and the expected result(s). Figure 2 shows the overall structure or diagram of a general engineering problem-solving procedure which consists of pre-processing, analyzing/solving and post-processing.

In order for the freshman engineering students to learn the engineering problem-solving procedure and technique more efficiently, this course properly selects the key elements shown in Figure 2 for the students to use as a guideline to solve sample engineering problems in class. Table II shows the engineering problem-solving steps for the students to use and follow to solve assigned engineering problems in the class.

TABLE II
ENGINEERING PROBLEM-SOLVING STEPS USED TO SOLVE SAMPLE ENGINEERING PROBLEMS IN THIS COURSE

1. **GIVEN/KNOWN:**
   - State briefly and clearly (in your own words) the information given.
2. **FIND/UNKNOWN:**
   - State the information that you have to find or solve.
3. **SKETCH/ (CONCEPTUAL) DIAGRAM:**
   - A drawing (or sketch) showing the physical situation with all quantities involved should be included.
4. **BASIC LAWS & PRINCIPLES:**
   - Give appropriate mathematical formulation of the basic laws and principles that you consider necessary to solve the problem
   - List of variables and constants related to (and involved in) the problem
5. **OBSERVATIONS & ASSUMPTIONS:**
   - List the simplifying assumptions that you feel (sometimes by experience) are appropriate in the problem
6. **ANALYSIS & NUMBERS:**
   - Manipulate (or simplify) the model equations algebraically to the desired form - appropriate to substitute numerical values
   - Select proper mathematical method (e.g., analytical by hand and/or numerical by computer)
   - Substitute (known and given) numerical values (using a consistent set of units) to obtain a numerical answer
   - Create/attach a graph/plot or table (if necessary) required to present the results
7. **CHECK & ESTIMATE:**
   - Check and estimate the answer (with the units, if appropriate) and the assumptions made in the solution to make sure they are reasonable
8. **LABEL:**
   - Label the answer (e.g., underline/highlight it or enclose it in a box)

In this course, the analogy between heat flow/transfer and electric current flow [11] has been introduced and used to practice the engineering problem-solving procedure or steps. After studying basic fundamentals on heat transfer such as heat conduction, convection and radiation with proper forms of thermal resistances, the students are able to consistently solve and analyze various types of energy and heat system example problems. Figure 3 shows the analogies between the heat and electric current flow, the temperature and voltage difference, and the thermal and electrical resistance. The expression for the thermal resistance can be obtained from the one-dimensional heat conduction equation based on Fourier's law. Figure 4 shows various thermal circuits or networks with different forms of thermal resistance corresponding to different modes of heat transfer used in the problem. Two basic Ohm's and Kirchhoff's laws are explicitly applied to obtain the local and overall thermal resistances in the heat transfer problem.

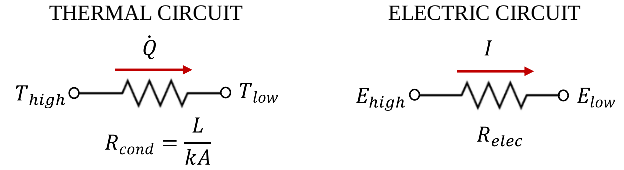
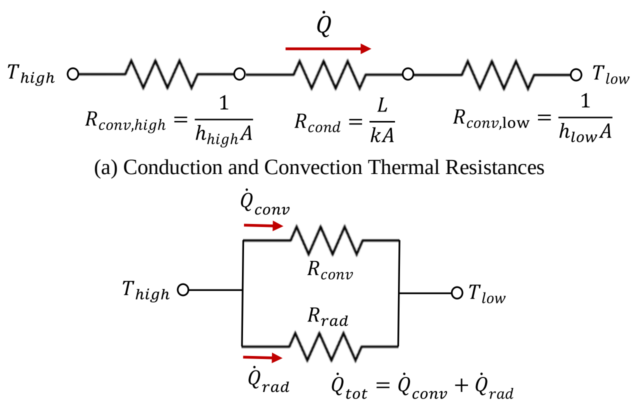


FIGURE 3
ANALOGY BETWEEN HEAT AND ELECTRIC CURRENT FLOW



(a) Conduction and Convection Thermal Resistances

(b) Convection and Radiation Thermal Resistances

FIGURE 4
VARIOUS THERMAL CIRCUITS WITH CONDUCTION, CONVECTION AND RADIATION THERMAL RESISTANCES

ENGINEERING ENTREPRENEURIAL MINDSET

There are a multitude of literatures and references that define and describe entrepreneurial mindset and/or entrepreneurship in different ways. Due to the similarity between definitions and the corresponding descriptions about entrepreneurial mindset obtained from various resources, in this paper, the entrepreneurial mindset defined by KEEN [10] is adapted and explicitly used for the students to build their engineering entrepreneurial mindset through the course design challenges/projects.

TABLE III
ENTREPRENEURIAL MINDSET DEFINED BY KEEN WITH 3C'S [10]

CURIOSITY	In a world of accelerating change, today's solutions are often obsolete tomorrow. Since discoveries are made by the curious, we must empower our students to investigate a rapidly changing world with an insatiable curiosity.
CONNECTIONS	Discoveries, however, are not enough. Information only yields insight when connected with other information. We must teach our students to habitually pursue knowledge and integrate it with their own discoveries to real innovative solutions.
CREATING VALUE	Innovative solutions are most meaningful when they create extraordinary value for others. Therefore, students must be champions of value creation. As educators, we must train students to persistently anticipate and meet the needs of a changing world.

Table III summarizes the entrepreneurial mindset defined by KEEN in which three keywords, 3C's (Curiosity - Connections - Creating Value) were created for educators to use/follow as a guideline in order to provide the students an entrepreneurial mindset.

It is also suggested that the students (properly educated/trained with the 3C's shown in Table III) must possess an entrepreneurial mindset coupled with engineering thought and action expressed through collaboration and communication founded on values. Table IV shows the expected student outcomes and example behaviors in order for them to properly practice and build the engineering entrepreneurial mindset [10].

Using the engineering entrepreneurial mindset defined and described in Tables III and IV, the freshman engineering students registered in the course, *Engineering Discovery 2*, perform the class energy term team project to practice engineering problem solving and eventually foster an engineering entrepreneurial mindset during the second semester of their first year in college.

TABLE IV
STUDENT OUTCOME AND EXAMPLE BEHAVIOR WITH ENTREPRENEURIAL MINDSET [5]

STUDENT OUTCOME	EXAMPLE BEHAVIORS
ENTREPRENEURIAL MINDSET	**CURIOSITY** DEMONSTRATE constant curiosity about our changing world EXPLORE a contrarian view of accepted solutions **CONNECTIONS** INTEGRATE information from many sources to gain insight ASSESS and MANAGE risk **CREATING VALUE** IDENTIFY unexpected opportunities to create extraordinary value PERSIST through and learn from failure
COUPLED WITH	
ENGINEERING THOUGHT AND ACTION	**APPLY** creative thinking to ambiguous problems **APPLY** systems thinking to complex problems **EVALUATE** technical feasibility and economic drivers **EXAMINE** societal and individual needs
EXPRESSED THROUGH	
COLLABORATION	**FORM** and **WORK** in teams **UNDERSTAND** the motivations and perspectives of others
AND	
COMMUNICATION	**CONVEY** engineering solutions in economic terms **SUBSTANTIATE** claims with data and facts
AND FOUNDED ON	
CHARACTER	**IDENTIFY** personal passions and a plan for professional development **FULFILL** commitments in a timely manner **DISCERN** and **PURSUE** ethical practices **CONTRIBUTE** to society as an active citizen

ENERGY TERM PROJECT WITH ENTREPRENEURIAL MINDSET

In order for the freshman students to practice solving real-life problems using the engineering problem-solving steps equipped with an engineering entrepreneurial mindset through the engineering problem-solving module session in the course, a number of student teams (4-5 students per team) work on the class energy term project for a two-week period with the theme of estimating energy/heat amount or usage, system efficiency and energy usage cost.

Each project team was asked to find and identify the problem (i.e., an energy system or region) from Marquette University campus, such as the dormitory, cafeteria, class room, library, etc. They explicitly perform proper engineering analysis to estimate/predict the amount of heat/energy loss from the selected system by using the engineering problem solving steps/process, along with the energy system efficiency and the corresponding energy/heat usage cost. Table V shows the guideline and rubric for the team energy term project in which three items of the 3C's defined for the entrepreneurial mindset are included for the students to recognize.

TABLE V
GUIDELINE AND EVALUATION RUBRIC USED FOR THE ENERGY TERM PROJECT

Project Evaluation Criteria & Equivalent Grade Point				
Poor [1]	Below Average [2]	Average [3]	Above Average [4]	Good/Excellent [5]

No.	Evaluation Items	Point
[1]	<u>**Clarity of Problem Statement (w/ Curiosity)**</u> • Selected/identified system and its (known/given) operating, environmental and geometric conditions • Sketches and/or (free-body) diagram of the system • List of parameters and/or unknowns involved in the problem	
[2]	<u>**Analysis Procedure (w/ Curiosity & Connections)**</u> • List of (properly) selected (scientific & engineering) fundamentals (laws & principles) used to solve the problem • Physical and mathematical model equation(s) involved • List of assumptions/approximations involved in the model equations • Final form(s) of model equation(s)	
[3]	<u>**Analysis Results (w/ Creating Value)**</u> • Amount of heat/energy loss from the system and the energy usages cost estimated/predicted. • Summary of the analysis results in tables and graphs • Checking out the reasonableness and feasibility	

*<u>Note</u>: Entrepreneurial mindset defined with the 3C's of curiosity, connections and creating value.

Table VI shows some of the students' works on the energy term project. It is apparent that the students (and their teams) are able to identify the problems/issues from their space or region within campus where they are able to access and obtain the required information related to the problem - which belongs to the first item of *Curiosity* in the entrepreneurial mindset. Once the project problem or topic is selected, the students find and use proper heat/energy fundamentals necessary to estimate the amount of heat/energy transfer from the system, along with appropriate operating conditions and constraints involved in the problems – which belongs to the items of *Curiosity* and *Connections* in the entrepreneurial mindset. The analysis results obtained by using the engineering problem solving procedure include the amount of heat/energy transfer, the system efficiency and the energy usage cost – which belongs to the item of *Creating Value* in the entrepreneurial mindset.

TABLE VI
ENERGY TERM PROJECT – SAMPLES OF STUDENTS' WORKS

Project Title	Problem Statement with Objective or Goal
CARPENTER TOWER HEAT TRANSFER	Performing an analysis of the heat loss and energy cost of one floor in M. Carpenter Hall, utilizing the data of the six coldest months of the year
HEAT LOSS FROM O'DONNELL	Calculating the amount of heat loss and the heat needed to be produced to maintain a comfortable temperature in O'Donnell Hall and estimating the corresponding yearly electricity cost of maintaining a proposed ideal temperature
CARPENTER DOUBLE HEAT COST	Estimating total amount of heat loss due to a number of windows, wall, and door and energy cost to maintain a temperature of 21°C in a standard Carpenter room when the hallway is 20°C and the outside is -7°C
CHILLIN' IN THE CHAPEL	Estimating the amount of heat loss from the Joan of Arc Chapel and the corresponding heating/energy cost to heat the chapel when it was in 15th century France
ENERGY LOSS IN A HUMPHREY AHLL ROOM	Estimating the amount of the net heat loss in a typical Humphrey Hall dorm room with using the thermal resistances of each 'resistor' (wall, air, window panes, etc.) and predicting the corresponding energy cost
EVANS SCHOLARS HOUSE BEDROOM HEAT LOSS	Estimating the amount of heat loss from AJ's room in the Evans Scholars House at Marquette University by using the engineering problem solving process and the corresponding heat usage cost for the 7 months of the year that the house is heated due to the cold Milwaukee weather.
HEAT LOSS OF THE ENGINEERING HALL ENTRANCE	Estimating the amount of heat loss for Engineering Hall entrance over 6 months while maintaining a room temperature of 23˚C maintained by ceiling heater
HEAT LOSS OF MCCORMICK	Estimating the amount of heat loss from one of the McCormick doubles and the base gas usage cost per month to heat McCormick.
HEATING COST OF AN ABBOTSFORD CORNER ROOM	Estimating the energy cost to heat an Abbotsford corner room during December by assuming a constant internal temperature of 21ºC and the daily average outdoor temperature in Milwaukee.
MCCORMICK HALL COMMON ROOM	Estimating the amount of total heat loss through the windows in a McCormick Hall common room and the corresponding energy utility cost each year

Each project team presents their work during the class hours. Engineering faculty/staff members and upper-level engineering students are invited to evaluate the students' project works using the evaluation rubric provided in Table V. Also, while a team presents their work, the remaining students (audience) in the class participate in evaluating the team's work. Depending on the size of class sections, minimum of 70 and maximum of 180 people (faculty/staff members and engineering students) participate in evaluating team energy term project presentations.

Figure 5 shows the (averaged) performance results of all project teams, in which the minimum and maximum evaluation grade points are shown for each evaluation item shown in Table V. It can be seen that a large gap between the maximum and minimum grade points for evaluation item #1 exists. Also the grade points for evaluation item #1 are relatively lower than those for evaluation items #2 and #3. This is due to the fact that many teams selected similar problems or topics (or buildings) for their energy term projects. However, the evaluation grade points for items #2 and #3 are relatively higher than item #1 because many teams confirmed using/applying the heat/energy fundamentals for the project work.

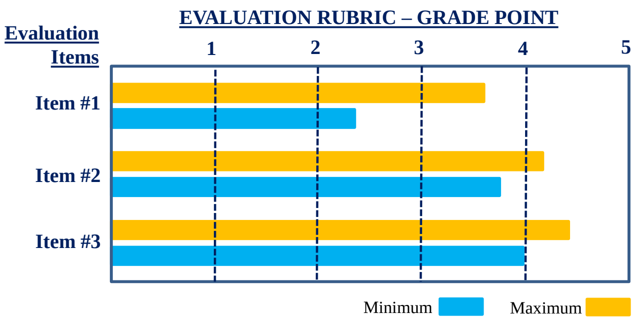


FIGURE 5
ENERGY PROJECT TEAM PERFORMANCE ANALYSIS RESULTS

SUMMARY AND CONCLUSIONS

In summary, the *Freshman Engineering Discovery 2* course developed and currently running at Marquette University – Opus College of Engineering provides the engineering problem solving session within the course content for the new engineering students to practice solving real-life problems, along with explicitly incorporating the elements included in the entrepreneurial mindset defined by the 3C's of Curiosity, Connections and Creating Value [10]. The students also experience and foster the engineering entrepreneurial mindset through the class energy term team project.

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