Freshman Engineering Discovery Courses at Marquette University – College of Engineering

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***Abstract* – The Freshman Engineering Discovery courses at Marquette University - College of Engineering provide freshman engineering students the vision to become an engineering student and an engineer in the future. The students are given a taste of engineering, while receiving guidance on how to think like an engineer and gain insight as to what an engineer does. In order to meet some of the course objectives, the students are asked to find proper and creative answers and solutions to various multi-disciplinary engineering environments and problems. As the semester progresses, the students will be asked to participate in various types of team/group projects (or challenges), which include individual and team responsibilities on assigned topics/tasks/works. Through the Freshman Engineering Discovery courses, the freshman engineering students are able to recognize the types of knowledge and skills necessary to succeed as an engineering student, discover their way towards the engineering disciplinary area of their interest, and layout their vision as a future engineer.**

Index Terms – engineering design process, engineering problem solving, engineering vision, freshman engineering discovery

INTRODUCTION

Marquette University - College of Engineering currently utilizes the Freshman Engineering Discovery courses started in 2008; which was designed for first-year freshman engineering students for the duration of two academic semesters. These two-semester long courses were originally prepared for the students in the mechanical, electrical, computer, civil and environmental engineering programs. Since the 2013 academic year, all freshman engineering students in the mechanical, electrical, and computer engineering programs have been required to take the courses.

The general goal of the course is to introduce freshman engineering students to engineering by immersing them in the experience of what it means to be an engineer through discovery-learning experiences: Discovery Learning refers to an array of classroom practices that promote students learning through guided and increasingly independent investigation of complex questions and problems, often for which there is no single answer [1].

The main objectives of the courses Freshman Engineering Discovery 1 and 2, offered respectively during the fall and spring semesters, are to give the new freshman engineering students a vision as a future engineer. In order to meet some of the course objectives, during the first semester the students are asked to find proper (guided and/or creative) answers/solutions on the given/selected various multi-disciplinary engineering environments and problems. The students will start recognizing and eventually following various engineering rules (e.g., engineering ethics, various graphics rules, team works, etc.) through course content during the first semester. As the semester progresses, the students will be asked to create and participate in a team/group project; which includes individual and team responsibilities on assigned work. This is the first step of discovery learning in which the students are able to realize and recognize where they are and what (and how much) they can do thus far as a freshman engineering student.

During the second semester, the students study and experience the following three subjects: *Engineering Computing with MATLAB*, *Engineering Problem Solving*, and *Engineering Design Process*. The students are able to extend and apply some of the knowledge, experience, and skills they have learned during (and before) the first semester as an engineering student within these subjects, with the exception of *Engineering Computing* which requires some degree of their concentration and mathematical manipulation skills.

During the *Engineering Problem Solving* module session, the students will try to solve various (pre-selected) engineering problems through the use of proper problem solving steps and team/studio discussions in order to find the required solutions or estimations. They will also participate in two different levels (or types) of engineering designs, called *Design Challenges*, which are team/group-based multi-disciplinary term projects for the students to work together with other teammates. The students will naturally learn how to work together, how to share responsibility on their final work, and even how to improve their engineering knowledge and skills in the future.

In order to present the students' hard work, poster exhibition events are held at the end of the each semester. The poster exhibition events give each group/team the ability to display and present their projects to other engineering students, faculty, and staff members. Through these project-based poster exhibition events it is believed

that the students are able to highlight what they have learned, the skills they have attained, and the final results of their teamwork, all of which will be a valuable experience as an engineering student.

FRESHMAN ENGINEERING DISCOVERY 1

This course is offered every fall semester, and consists of one lecture for one one-hour period (on Monday) and two lab classes (on Tuesday and Thursday) for a four-hour period per week. Table 1 shows the overall structure and contents of the course in which various types of class activities are included.

TABLE 1
FRESHMAN ENGINEERING DISCOVERY 1 - OVERALL COURSE STRUCTURE AND CONTENTS

Math Proficiency Test	
Engineering Graphics Fundamentals & Computer-Aided Design (CAD) Practice	Introduction to Engineering and Engineers & Multidisciplinary Department Module Sessions
Graphics & CAD Team Project – Poster Exhibition & Competition	

Math Proficiency Test

Since most engineering core courses require the engineering students to be able to use proper scientific fundamentals (laws and theories) and mathematical principles to solve and analyze a number of virtual, imaginary (from most engineering textbooks), and real engineering problems in various disciplinary areas and fields, all engineering students are required to take and study a series of science and math courses (such as physics, chemistry, biology, college-level calculus, linear algebra and differential equations among others) as prerequisite courses before taking and studying core engineering courses.

It was found that (at Marquette University - College of Engineering) most (entry-level) engineering students somewhat struggled with studying college-level math courses due primarily to their lack of explicit experiences in using/applying some of the basic mathematical principles to scientific and engineering problems during their high school education.

For this reason, all freshman engineering students registered in the Engineering Discovery 1 course are required to take the Math Proficiency Test prepared by Marquette University - College of Engineering. The topics for the test (selected from pre-calculus) are shown in Table 2.

TABLE 2
PRE-CALCULUS TOPICS USED FOR THE MATH PROFICIENCY TEST PROGRAM

1.	Arithmetic/Algebraic Operations
2.	Graph Recognition
3.	Inequalities
4.	Trigonometric Functions
5.	Exponentials/Logarithms
6.	Geometry
7.	Powers, Polynomials, and Rational Functions
8.	Series, Continuity, and Limits

In order for the new/incoming freshman engineering students to anticipate and prepare for the Math Proficiency Test, a study packet which includes more than 500 sample example problems in the pre-calculus areas shown in Table 2, are distributed to them before the semester starts.

Figure 1 shows the distributions of the test results (averaged for the last three years) normalized by the highest score in the area of the graph recognition. It can be seen that most freshman engineering students are relatively weak in the area of trigonometric functions. It is a commonly known fact that this weakness is primarily due to the (engineering) students' reliance on hand-held calculators to solve trigonometric function related math problems (without analyzing them) during their high school education.

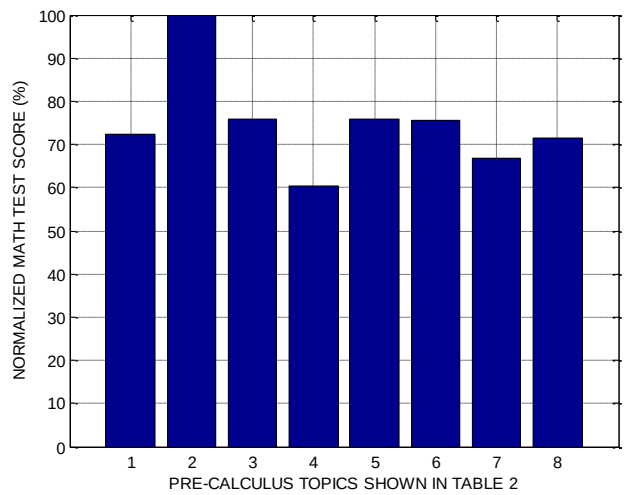

FIGURE 1
NORMALIZED MATH-PROFICIENCY TEST SCORE IN EACH AREA OF PRE-CALCULUS

The students who score below a passing score or grade are asked to retake the test (until they pass) in order to improve their basic math skills during the first semester of their freshman year.

Introduction to Engineering and Engineers

As shown in Table 1, the freshman students are asked to use and follow a set of rules and guidelines to experience and taste what engineering is about and what an engineer does, through various class and lab activities such as Fermi's problem solving exercises, scientific/engineering (US and SI) unit systems and their usages, and various types/kinds of engineering problems in different engineering disciplinary areas through department module sessions.

For the department module sessions, the representative faculty members from each engineering department (biomedical, civil and environmental, electrical and computer and mechanical engineering at Marquette University - College of Engineering) provide the students an overview of their departments and area of practices, along with appropriate research works and activities. Through this

type of department module session, the students are able to recognize the multidisciplinary perspectives of engineering disciplines. Table 3 lists sample topics and class activities for the department module sessions for this course.

TABLE 3
SAMPLE TOPICS AND CLASS ACTIVITIES FOR THE DEPARTMENT MODULE SESSIONS

Department	Topics & Class Activities
Biomedical	Measuring and analyzing electrocardiogram (ECG) and blood pressure
Civil and Environmental	Introduction to vehicle traffic analysis/control, airport EMAS (Engineering Materials Arresting System), and beam stain and stress intensity
Electrical and Computer	Designing, assembling and testing electronic digital dice game
Mechanical	Introduction to hand sketch technique, bicycle principles, cantilever beam deflection fundamentals, and flow pressure fundamentals using manometer

Engineering Graphics Fundamentals and Computer-Aided Design (CAD) Practice

It is a well known fact that modern engineers and engineering students are able to visualize a real and virtual (or conceptual) object by properly using the selected commercially available CAD software. For the Freshman Engineering Discovery courses at Marquette University - College of Engineering, the CAD software Unigraphics (UGS®) NX has been used. Other CAD software, like SolidWorks® and AutoCAD®, are also available for the engineering students to use.

Many CAD software specific textbooks and reference books are available in the market, in which most of them show and introduce the basic methods about how to use the software to create/generate sample 3D models shown in the book. This pedagogical point of view, a method-oriented approach introduced and shown in most CAD books, has a significant drawback because of a limited number of example/sample exercise problems for the readers or students to practice. Furthermore, it seems impossible to include/show all options available in the CAD software.

In order for the (especially entry-level) engineering students to learn and practice the CAD software more efficiently, a project-oriented approach has been developed by the author and used for this course [2]. This approach allows students to create a 3D solid model during the first day of the lab class, and consequently they are able to create new 3D models (every time they practice the CAD software) by using the method and/or routines that they have used to create previous 3D solid models.

In this course, the project model, Gear Pump System with 7 independent components, has been selected and used for the students to create all components/parts every time when they practice the CAD software, and assemble them to create a complete assembly Gear Pump system.

While the students practice the CAD software to create 3D solid models, they study about how to generate professional drawing documents in which the detailed information about the model should be included. In this course, special class sessions are provided for the students to study engineering graphics fundamentals such as orthographic projection views and dimensioning and tolerancing (GD&T) based on the American Society of Mechanical Engineering (ASME) and American National Standard Institute (ANSI) standards.

CAD Team Project Poster Exhibition and Competition

After practicing UGS NX CAD software to create assigned virtual individual components/parts, assembly models, and corresponding document drawings shown in the course textbook, the students are asked to create 3D solid CAD models of selected real objects such as a stapler, hand-held calculator, and electric hand dryer, among others. For this work the students measure the required dimensions of the assigned objects, create their own hand sketches and 3D solid models, and compare the final model with the real object to evaluate their CAD models.

This type of assignment helps students use and apply their CAD skills and engineering graphics fundamentals learned during class hours. Also, they are asked to discuss with other classmates in order to find/discover a better way/approach or strategy for creating the complete model.

After the real object modeling practice mentioned above, the students are asked to set a team or group (about 20 students per team). Each team member is assigned to create 4 to 5 components/parts of the machine assigned to the team. All team members measure the geometric dimensions of the parts/components of the machine, create hand sketches (with orthographic projection views) of the components, and create 3D solid models and document drawings. Sample machines used for this team CAD project are bicycle, floor scrubber, fork lift, drill press, single and double cylinders, among others.

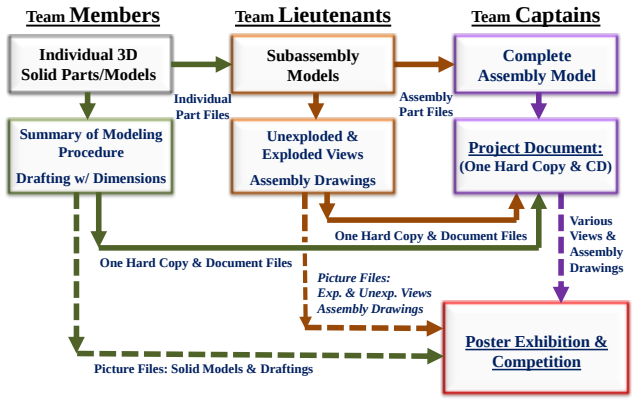

FIGURE 2
ORGANIZATION CHART FOR FRESHMAN STUDENTS GRAPHICS/CAD TEAM PROJECT POSTER EXHIBITION AND COMPETITION

In order for the design team/group to efficiently work together, depending on the assigned machine, each team selects two team leaders, called captains, and four to six small group leaders, called lieutenants. Figure 2 shows the team organization chart and how they work together. The

role of the small group leaders (i.e., team lieutenants) is to create subassembly models using the component models created by each team member, and pass them on to the team captains to create the complete assembly model of the machine.

Through the team project, the students naturally learn how to work together and recognize how important each team member's role is. After a period of about 4 weeks of project work, each team submits their final CAD project report while simultaneously creating project posters in which the overall CAD project procedure and intermediate and final views of the model should be included.

During the poster exhibition, usually scheduled during the last week of the semester, engineering faculty and staff members are invited to judge their posters. The winning teams receive the accomplishment certificate from the representative of college of engineering.

Undergraduate Student Teaching Assistants (TAs)

One of the peculiar aspects of the Freshman Engineering Discovery courses at Marquette University - College of Engineering is to hire and use a number of selected former freshman engineering students (who successfully finished the Engineering Discovery courses) as course teaching assistants (TAs). There are two main purposes for hiring the undergraduate student TAs. First, since they successfully went through the freshman engineering discovery courses during their first year as engineering students, they can efficiently use their knowledge and experiences to help and even teach the new freshman engineering students. Second, direct feedback from the TAs (i.e., the former freshman students) about the Freshman Discovery courses can be obtained and used to improve the course contents and the class and lab activities. Through a regular weekly TA training meeting provided by the course instructor, the course TAs are trained and instructed to assist the classes and arrange TA office hours to help the students after the class hours.

An additional advantage (i.e., engineering education point of view) in hiring and using the undergraduate student TAs is to reeducate them about the fundamental aspects of engineering and being an engineer. While helping and teaching the freshman courses, the TAs reuse and repeat (or practice again) the basics that they studied during their freshman year, strengthening their vision as an engineering student, and ensuring them to be better engineering students.

ENGINEERING DISCOVERY 2

This course is offered every spring semester, consisting of one lecture for one one-hour period (on Monday) and two lab classes (on Tuesday and Thursday) for a four-hour period per week. It requires the course, Engineering Discovery 1, as a prerequisite. Table 4 shows the overall structure and content of the course in which various class activities are included.

TABLE 4
FRESHMAN ENGINEERING DISCOVERY 2 – OVERALL COURSE STRUCTURE AND CONTENTS

Engineering Computing with MATLAB & Its Applications	Engineering Problem Solving
	Engineering Design Process with Design Challenge/Project #1
	Engineering Design Process with Design Challenge/Project #2
Team Design Challenge/Project – Poster Exhibition & Competition	

Engineering Computing with MATLAB®

The software MATLAB® is one of the most widely used programming language for college-level students in the fields of engineering and science because of its advantageous features such as no requirement for compilation procedures to run the program or code, and various built-in functions and libraries available for technical calculations.

Since most freshman engineering students registered in this course have never used the MATLAB before (i.e., during their high school education), it is pivotal to provide a well-structured and consistent way and material for them to learn and use the MATLAB. There are a number of introductory level MATLAB textbooks and references available for students to study and learn the MATLAB. However, according to this author's experience in teaching the engineering software like MATLAB, it was found that using textbook-type books are not quite proper and useful for the lab-oriented class of this course.

For this reason, with others such as self-study guides and sample example problems, this author developed the MATLAB lab manual [3] for freshman engineering students (or entry-level college students) to use and practice the MATLAB during the lab class hours. The MATLAB lab manual guides the students on how to properly enter MATLAB commands and codes (partly) shown in the manual in order to produce the numerical and graphical results required, while giving the students the opportunity to compare their results with the result obtained by the instructor. Also during the lab class hours, the students practice justifying their logic or strategy (i.e., algorithm) for programming MATLAB to solve various types of example problems.

After practicing the MATLAB basics and the corresponding programming algorithms, the students start using/applying the MATLAB basics (i.e., commands and codes) to solve some useful engineering and scientific problems by using proper numerical methods (introduced in the MATLAB lab manual) such as solving system linear equations, interpolation and curve fitting, solving nonlinear equations and numerical integration and differentiation. These numerical methods or techniques are very useful for the students in their study of engineering courses.

Engineering Problem Solving

It is said that engineers 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 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 3 shows the overall structure or diagram for general engineering problem-solving procedure which consists of pre-processing, analyzing/solving and post-processing.

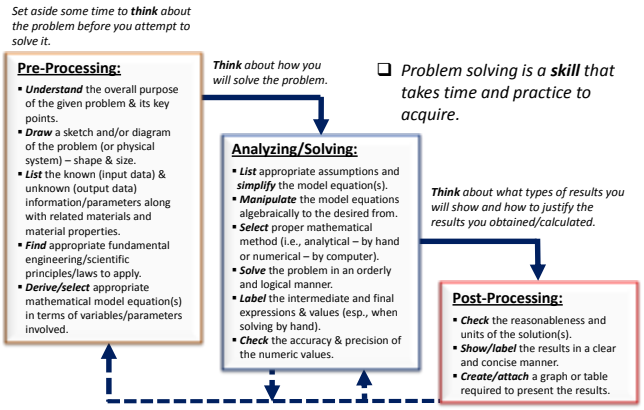

FIGURE 3
GENERAL ENGINEERING PROBLEM-SOLVING PROCEDURES

TABLE 5
ENGINEERING PROBLEM-SOLVING STEPS USED TO SOLVE SAMPLE ENGINEERING PROBLMES IN THIS COURSE

1. **GIVEN:**
   - State briefly and concisely (in your own words) the information given.
2. **FIND:**
   - State the information that you have to find or solve.
3. **SKETCH/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 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 3 for the students to use as a guideline to solve sample engineering problems in class. Table 5 shows the engineering problem-solving steps for the students to use and follow to solve assigned engineering problems in the class.

In this course, the analogy between heat flow/transfer and electric current flow has been used to practice the engineering problem-solving procedure or steps. After introducing 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. In conclusion, most students are able to continuously use the engineering problem-solving steps to solve different types of engineering problems in other engineering disciplinary areas.

Engineering Design Process with Team Design Challenges

Design is the process of creating a product or system to satisfy a set of requirements that has multiple solutions by using any available resources [4] - [6]. The design process is the method of devising innovative solutions to problems that will result in new product or system. Based on various references related to the engineering design process, the following simple traditional six steps of engineering design process as shown in Figure 4 has been used for the freshman engineering students to use and follow in this course. It can be seen that each step can be recycled as needed.

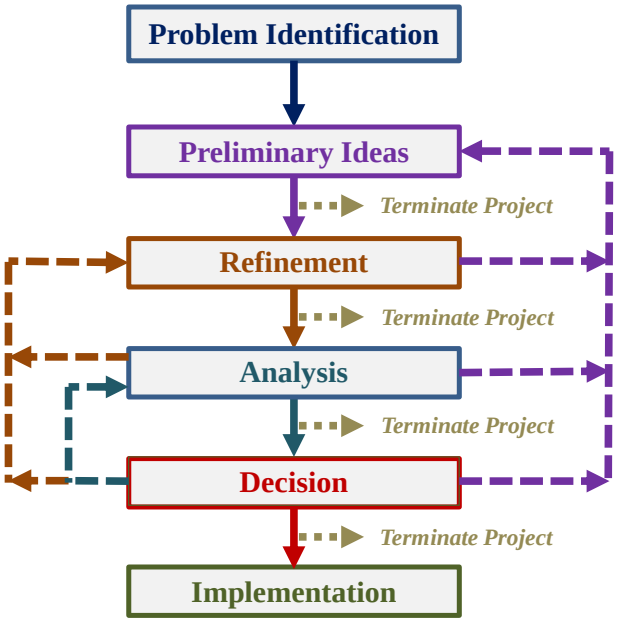

FIGURE 4
TRADITIONAL ENGINEERING DESIGN PROCESS/STEPS USED IN THIS COURSE

In order for the freshman engineering students to practice the engineering design process in this course, two different types of design challenges/projects are given to them. Each design challenge has different themes. The theme used for the design challenge #1 relates to an issue in the students' first-year college campus life. Table 6 shows the topic for the design challenge #1 and the guideline for the students to follow and finish the project within a 4 week period.

TABLE 6
OVERALL THEME AND GUIDELINE USED FOR THE DESIGN CHALLENGE/PROJECT #1

OVERALL THEME:
"Analyzing & (Conceptually) Designing (Innovative/New/Useful) Energy Efficient System/Devices Using/Selecting Any System/Devices/Facilities Available in MU Campus"

DESIGN GUIDELINE:
- Identifying & selecting the problems/issues of a system
- Performing a basic/proper engineering (energy) analysis of the selected objects
- Generating/creating new concepts/ideas and the corresponding hand sketches
- Selecting/refining/finalizing idea/concept
- Developing system working principles
- Creating physical system (3D solid) models

Before initiating the design challenge/project #1, the students are asked to make a design team of 6 to 8 people. Each team selects team leaders, such as one team captain and one team secretary. The main role of the team captain is to lead and moderate the team project and its progress, while the team secretary schedules and records the team project progress and intermediate and final project results.

The overall performance of the team's works is evaluated by the final team project report and team oral presentation during the class hours. The engineering students, faculty and staff members are invited to evaluate and judge their presentations.

After finishing the design challenge/project #1 activity, the students are asked to regroup their design teams for the design challenge/project #2, to be performed for a period of 6 weeks. The open-ended type design challenge/project has been used in this course in order for the freshman engineering students to have an opportunity to open their eyes to view, taste and experience various engineering applications. Table 7 shows the overall theme, potential project areas/topics, and design guideline used for the design challenge/project #2 of this course. Through the open-ended design challenge/project #2, the students use, follow, and practice the engineering design process again shown in Figure 4.

The overall team performance of the team's design challenge/project #2 is evaluated by the final team project report and team design project posters to be displayed during the event, *Freshman Engineering Students Design Challenge/Project - Poster Exhibition and Competition*, usually scheduled during the last week of the semester. The engineering students, faculty/staff members, and industry people are invited to evaluate and judge their design works. The winning teams receive the accomplishment certificate from the representative of college of engineering.

TABLE 7
THEME, POTENTIAL AREAS/TOPICS AND GUIDELINE USED FOR THE DESIGN CHALLENGE/PROJECT #2

OVERALL THEME:
"Developing/Designing the System/Device Related to the Energy & Water Sustainability"

POTENTIAL PROJECT AREAS//TOPICS:
- (General) energy and water Savings
- Water production/maintenance/purification/etc.
- Renewable energy (solar, wind, tide, geothermal, etc.) system device
- Water and thermoelectric power interdependency
- Fuel resources/supply (fossil, biomass, nuclear, etc.)

DESIGN GUIDELINE:
- Identifying the global water & energy related issues
- Generating concepts (or ideas) - potential solutions
- Developing an innovative solution – system or device & considering its impact on the energy/water issues
- Designing/developing system/device & its working principle(s) with some degree of entrepreneurial aspect to the products/system
- Developing virtual (UGS NX) models and building & testing (small-scale) prototype (mock-up) system/device
- Finalizing the design project – report, presentation & poster

In conclusion, through the *Freshman Engineering Discovery* courses, the freshman engineering students are able to see and layout their vision as an engineering student (and future engineer), realize the types of knowledge and skills necessary to succeed as an engineer, and discover their way towards the engineering disciplinary area of their interest.

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