Innovative Conceptual Engineering Design (ICED) Epic Challenge Program

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Course Key Aspects Overview

This course was designed to impact science, technology, engineering, and math (STEM) with each of the following components: "Epic" challenge, student agency, ICED Methodology, the importance of failure, team diversity, mentors, and low cost per student.

"Epic" Challenge

The Innovative Conceptual Engineering Design (ICED) Epic Challenge program was conceived by Dr. Charles Camarda, NASA Astronaut and Senior Advisor for Engineering Development in the Engineering Directorate at NASA Langley Research Center. Through his Epic Education Foundation, Dr. Camarda proposes "Epic" challenges that need to be solved. "Epic" challenges are designed to fit the following criteria:

1. Very complex without an existing or known solution
2. Multi-disciplinary in nature and involves the expertise of multiple disciplines for a solution
3. Time critical or has some sense of urgency which helps impart a healthy tension
4. Grave importance to the interests of the Agency (like NASA), company, nation, or world
5. Has a real or perceived competitive adversary
6. Has a "design" nature (open-ended and, thus stimulating to the imaginative/creative side of the brain)
7. Problem solution would have far-reaching benefits for the quality of life on Earth, exploration, and/or better understanding of the unknown.

These attributes of an "Epic" challenge help motivate students of all ages and sustain a life-long interest in STEM education.

Student Agency

While the 'Epic' challenge is presented to the students they are able to choose what part of this complex mission resonates with them and work to solve that part of the problem. Henri Holec's (1981) defines autonomy as 'the ability to take charge of one's learning.' Students autonomy is a key aspect for motivating students because they get to make choices about their learning. In the Epic Challenge course, student groups choose the specific part of the "Epic" challenge they want to solve. Each "Epic" challenge has a very wide range of specific problem which students get to explore and settle up what interests them.

ICED Methodology

The students are asked to follow Dr. Camarda's Innovative Conceptual Engineering Design (ICED) Methodology often referred to as ICED methodology which is a phenomenon-based learning (PhBL) strategy. Figure 1 provides an overview of the ICED Methodology providing the students with the "Epic" challenge. First, the students' imaginations and interest are peaked. Students are provided the top-level, overall program/mission goals which allow the student to visualize the end goal and recognize that a systems approach is required. Students are then asked to think critically, interrogate, and then define what they think the problem really is. This method of learning is reversed from what is typically done in a classroom according to Bloom's Taxonomy which would have students memorize vocabulary and then put them into a context so that students can understand and apply it to a real-world scenario (Figure 2). Rather than having students start with the knowledge and comprehension domains, we start student engagement at the application domain. These "Epic" challenges have allowed us to pull in people who are not typically interested in science and engineering but may have an interest in graphic design and history for example. These students' imaginations are captivated by the possibilities and they are given the freedom in the class to pursue any aspect of the "Epic" challenge that they see that is worth researching and developing a solution to the problem.

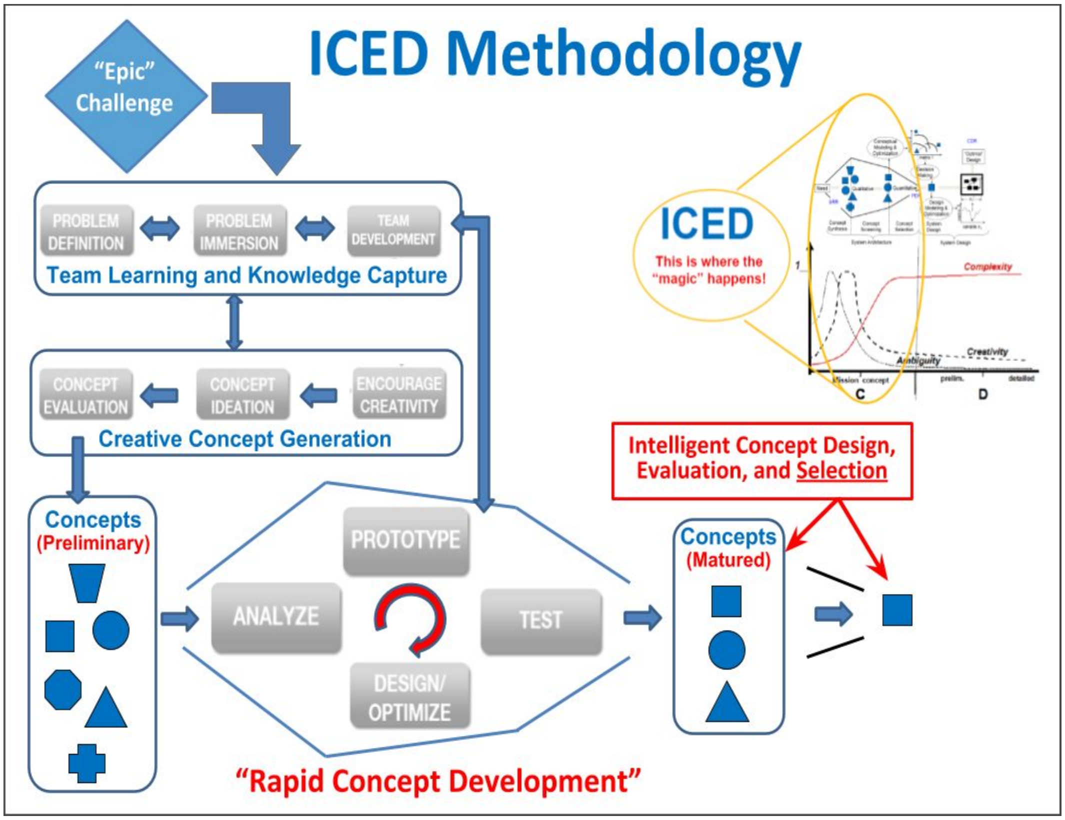

Figure 1. The Innovative Conceptual Engineering Design (ICED) Methodology as conceived by Dr. Charles Camarda. This image is available at https://goo.gl/EgFH1p

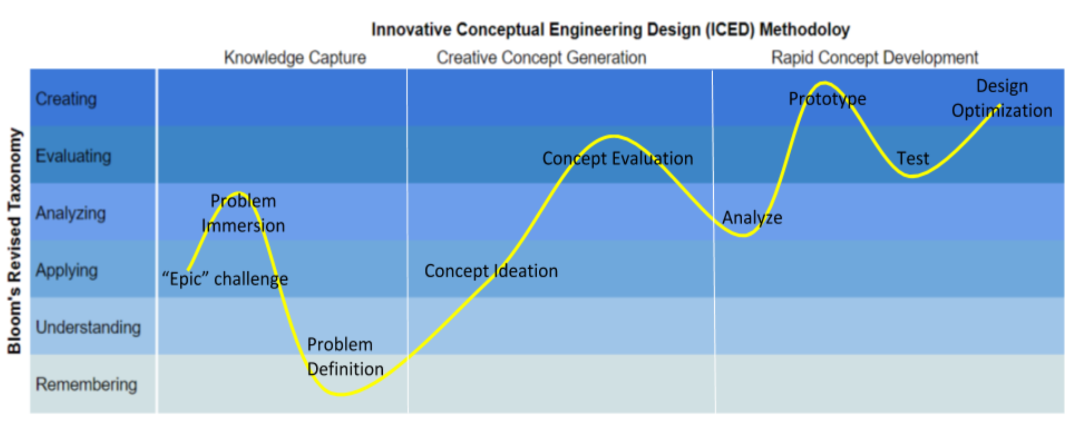

Figure 2. ICED Methodology & Bloom's Revised Taxonomy Roller Coaster. This image is available at https://goo.gl/3DhrRV

Importance of Failure

The program's motto is "Fail Small, Fast, Early, Cheap, and Often." We teach students the importance of failure and that not all failures are the same. Students learn that there is a way for them to fail that can lead to learning and even success because it is by failing that we learn most effectively. All too often a string of successes can hide fatal flaws in a system and Dr. Camarda uses the Columbia accident incident in 2003 to illustrate that point. Students learn that certain types of failure are critical to success and integral to innovation (Figure 3). Dr. Jack Matson, in his book "Innovate or Die," calls this type of failure "intelligent fast failure."

While emphasizing the importance of failure, it is critical to also create a psychologically safe environment so students feel safe to fail and learn from their failure. All too often our students are afraid to fail. The "smart" students tend to avoid it at all costs while the "not-so-smart" students just refuse to try because they are so paralyzed by their fear of failure. This program is designed to mitigate those fears and create a safe environment so that not only the kids who are innovative can join in but also those with a fear of failure.

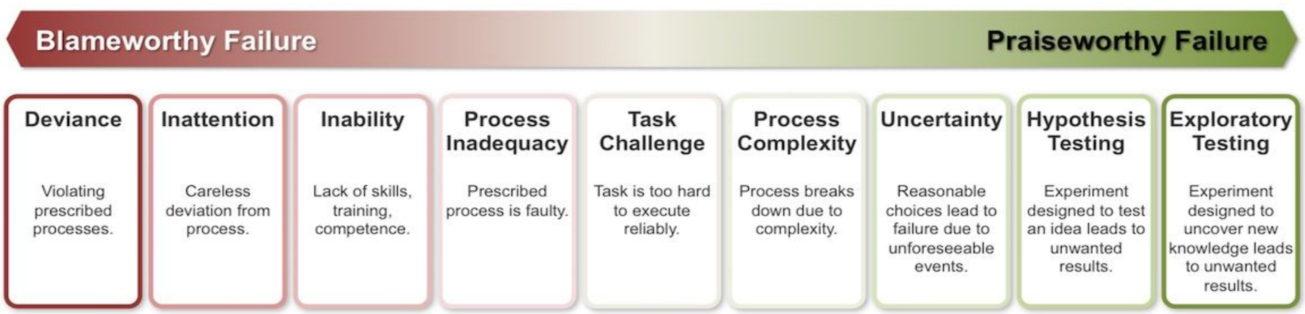

Figure 3. A Spectrum of Failure as proposed by Amy Edmondson ("Reasons for Failure," Harvard Business Review, April 2011). Image source https://www.pocketbook.co.uk/wp-content/uploads/2016/06/failure-edmondson.jpg

Team Diversity (Teamology)

This program emphasizes designing as a diverse team where members have different backgrounds with very different knowledge bases, cognitive skill sets, leadership styles, personality types, and decision-making preferences. These differences can be an advantage and disadvantage. This program employs Teamology, a program designed at Stanford which results in the construction and organization of effective teams (https://web.stanford.edu/group/designx_lab/cgi-bin/mainwiki/index.php/Teamology). In other words, students who favor the analytical/logical/structured side of their brain (the left hemisphere) are teamed with students who prefer to work with their artistic/creative/innovative right hemisphere to make a powerful team. Team members are selected to ensure a diversity of thought, capability/skill, experience, culture, outside interests, etc. to maximize creativity and innovation. These diverse teams often take more time to coalesce but according to Douglass Wildes' "Teamology: The Construction and Organization of Effective Teams" 75% won awards vs only 25% won awards when the teams were randomly selected. Therefore, a diverse team is a much stronger team. Team development is a big focus at the beginning of the year. As a result of the Teamology survey, every member knows their strengths and their essential contribution to the success of the team. We have found great value in these types of diverse teams and the students find that they are more productive working together than on their own.

Mentors

Teams focus on very specific and technical problems and learn that no single teacher or person knows all the information. So mentors are very important in helping support diversity and they do so in a couple of ways. Firstly, Dr. Camarda opens a wide network of experts from around the globe. These experts are not only diverse in knowledge and skills but as well as their cultural background and gender. Secondly, students are encouraged to reach out to subject matter experts that they have identified through their research.

Students are always shocked to find out that these subject matter experts are doing research all over the world. It can happen that one day they are writing Germany and the next they could be corresponding with England or the USA. Each time they get a written response they light up because an expert took interest in them and this really helps with retaining student interest and keeping their drive to solve this problem going. Through these interactions, the students are taught about the particular culture that the person comes from because it often shapes how they interpret the person's response and how they should also respond back to that person. The students learn through these positive experiences that diversity is a wonderful thing and a great asset when trying to solve these complex problems.

Low Cost

The Epic Challenge program has been operating for over 10 years in providing innovative educational programs for students of all ages (K-20) and young professionals entering the engineering field. Industry, government, and academic partnerships in the U.S. and Finland have proven the effectiveness of the proposed programs which make use of technology to drastically reduce program cost by several orders of magnitude (over 100 times) and demonstrated scalability to reach every student with access to the internet. Typical costs per student of existing educational programs range from $1,500 to over $3,000 per student as compared to proven results for the Epic Challenge program of less than $15 per student and estimates of less than $1 per student by scaling using the collaborative virtual platform and hybrid physical/virtual instances of the program. Estimates are based on 6-years of experience developing programs in the U.S. reaching over 3,000 students and 2 years of experience in Finland scaling from 25 to 250 students in one year using SOA virtual platform and education technology.

At Northbridge High School, we run the program on $600 or less each year for supplies. The ICED Epic Challenge program costs nothing to join or participate but the students get access to mentors and fellow schools.

Program Outcomes: How the Lesson/Activity Supported "*Growing STEM in Our Communities"*

One of the key features of this program is that student reach out to mentors in the local in the local community or global and seek their advice. This builds a relationship between the institutions. We have also have brought in local members from the community to speak with our students about their job and taken our students to see their workplace.

Massachusetts English Language Arts Standards
Reading **RCA-ST.11–12.1 -** Cite specific textual evidence to support analysis of science and technical texts, attending to important distinctions the author makes and to any gaps or inconsistencies in the account.

RCA-ST.11-12.2 - Determine the central ideas or conclusions of a text; summarize complex concepts, processes, or information presented in a text by paraphrasing them in simpler but still accurate terms.

RCA-ST.11-12.3 - Follow precisely a complex multi-step procedure when carrying out experiments, taking measurements, or performing technical tasks; analyze the specific results based on explanations in the text.

RCA-ST.11-12.4 - Determine the meaning of general academic vocabulary as well as symbols, notation, key terms, and other domain-specific words and phrases as they are used in a specific scientific or technical context

RCA-ST.11-12.5 - Analyze how a text structures information or ideas into categories or hierarchies, demonstrating understanding of the information or ideas.

RCA-ST.11-12.6 - Analyze an author's purpose in providing an explanation, describing a procedure, or discussing an experiment in a text, identifying important issues that remain unresolved.

RCA-ST.11-12.7 - Integrate and evaluate multiple sources of information presented in diverse formats and media (e.g., quantitative data, video, multimedia) in order to address a question or solve a problem.

RCA-ST.11-12.8 - Evaluate the hypotheses, data, analysis, and conclusions in a science or technical text, verifying the data when possible and corroborating or challenging conclusions with other sources of information.

RCA-ST.11-12.9 - Synthesize information from a range of sources (e.g., texts, experiments, simulations) into a coherent understanding of a process, phenomenon, or concept, resolving conflicting information when possible.

RCA-ST.11-12.10 - Independently and proficiently read and comprehend science/technical texts exhibiting complexity appropriate for the grade/course.

Writing

WCA.11-12.1 - Write arguments focused on *discipline-specific content*.

- **a.** Introduce precise, knowledgeable claim(s), establish the significance of the claim(s), distinguish the claim(s) from alternate or opposing claims, and create an organization that logically sequences the claim(s), counterclaims/critiques, reasons, and evidence.
- **b.** Develop claim(s) and counterclaims/critiques fairly and thoroughly, supplying the mos relevant data and evidence for each while pointing out the strengths and limitations of both claim(s) and counterclaims/critiques in a discipline-appropriate form that anticipates the audience's knowledge level, concerns, values, and possible biases.
- **c.** Use words, phrases, and clauses with precision as well as varied syntax to link the maj sections of the text, create cohesion, and clarify the relationships between claim(s) anc reasons, between reasons and evidence, and between claim(s) and counterclaims/critiques.
- **d.** Establish and maintain a style appropriate to audience and purpose (e.g., formal for academic writing) while attending to the norms and conventions of the discipline in which they are writing.
- **e.** Provide a concluding statement or section that follows from or supports the argument presented

WCA.11-12.2 - Write informative/explanatory texts, including the narration of historical events, scientific procedures/experiments, or technical processes.

- **a.** Introduce a topic and organize complex ideas, concepts, and information so that each new element builds on that which precedes it to create a unified whole; include text features (e.g., headings), graphics (e.g., figures, tables), and multimedia when useful to aiding comprehension.

b. Develop the topic thoroughly by selecting the most significant and relevant facts, extended definitions, concrete details, quotations, or other information and examples appropriate to the audience's knowledge of the topic.

c. Use varied transitions and sentence structures to link the major sections of the text, create cohesion, and clarify the relationships among complex ideas, concepts, or procedures.

d. Use precise language, domain-specific vocabulary and techniques to manage the complexity of the topic; convey a knowledgeable stance in a style that responds to the discipline and context as well as to the expertise of likely readers.

e. Establish and maintain a style appropriate to audience and purpose (e.g., formal for academic writing) while attending to the norms and conventions of the discipline in which they are writing.

f. Provide a concluding statement or section that follows from and supports the information or explanation provided (e.g., articulating implications or the significance of the topic).

WCA.11-12.4 - Produce clear and coherent writing in which the development, organization, and style are appropriate to task, purpose, and audience.

WCA.11-12.5 - Develop and strengthen writing as needed by planning, revising, editing, rewriting, or trying a new approach, focusing on addressing what is most significant for a specific purpose and audience.

WCA.11-12.6 - Use technology, including current Web-based communication platforms, to produce, publish, and update individual or shared writing products in response to ongoing feedback, including new arguments or information.

WCA.11-12.7 -Conduct short as well as more sustained research projects to answer a question (including a self-generated question) or solve a problem; narrow or broaden the inquiry when appropriate; synthesize multiple sources on the subject, demonstrating understanding of the subject under investigation

WCA.11-12.8 - When conducting research, gather relevant information from multiple authoritative print and digital sources, using advanced searches effectively; assess the strengths and limitations of each source in terms of the specific task, purpose, and audience; integrate information into the text selectively to maintain the flow of ideas, avoiding plagiarism and overreliance on any one source and following a standard format for citation.

WCA.11-12.9 - Draw evidence from informational texts to support analysis, interpretation, reflection, and research.

WCA.11-12.10 - Write routinely over extended time frames (time for reflection and revision) and shorter time frames (a single sitting or a day or two) for a range of discipline-specific tasks, purposes, and audiences.

Speaking

SLCA.11-12.1 - Initiate and participate effectively in a range of collaborative discussions (one-on-one, in groups, and teacher-led) with diverse partners on discipline-specific topics, texts, and issues, building on others' ideas and expressing their own clearly and persuasively.

a. Come to discussions prepared, having read and researched material under study; explicitly draw on that preparation by referring to evidence from texts and other research on the topic or issue to stimulate a thoughtful, well-reasoned exchange of ideas.

b. Work with peers to promote civil, democratic discussions and decision-making, set clear goals and deadlines, and establish individual roles as needed.

c. Propel conversations by posing and responding to questions that probe reasoning and evidence; ensure a hearing for a full range of positions on a topic or issue; clarify, verify, or challenge ideas and conclusions; and promote divergent and creative perspectives.

d. Respond thoughtfully to diverse perspectives; synthesize comments, claims, and evidence made on all sides of an issue; resolve contradictions and critiques when possible; and determine what additional information or research is required to deepen the investigation or complete the task.

SLCA.11-12.2 - Integrate multiple sources of information presented in diverse formats and media (e.g., visually, quantitatively, orally) in order to make informed decisions and solve problems, evaluating the credibility and accuracy of each source and noting any discrepancies among the data.

SLCA.11-12.3 - Evaluate a speaker's point of view, reasoning, and use of evidence and rhetoric, assessing the stance, premises, links among ideas, word choice, points of emphasis, and tone used.

SLCA.11-12.4 - Present information, findings, and supporting evidence, conveying a clear and distinct perspective, such that listeners can follow the line of reasoning, alternative or opposing perspectives are addressed, and the organization, development, vocabulary, substance, and style are appropriate to purpose, audience, and a range of formal and informal tasks.

SLCA.11-23.5 - Make strategic use of digital media (e.g., audio, visual, and interactive elements) in presentations to enhance understanding of findings, claims, reasoning, and evidence and to add interest.

Massachusetts Science & Engineering Practices

1. Define a design problem that involves the development of a process or system with interacting components and criteria and constraints that may include social, technical, and/or environmental considerations.
2. Develop and/or use a model (including mathematical and computational) to generate data to support explanations, predict phenomena, analyze systems, and/or solve problems.
3. Plan and conduct an investigation, including deciding on the types, amount, and accuracy of data needed to produce reliable measurements, and consider limitations on the precision of the data.
4. Apply concepts of statistics and probability (including determining function fits to data, slope, intercept, and correlation coefficient for linear fits) to scientific questions and engineering problems, using digital tools when feasible.
5. Use simple limit cases to test mathematical expressions, computer programs, algorithms, or simulations of a process or system to see if a model "makes sense" by comparing the outcomes with what is known about the real world.
6. Apply scientific reasoning, theory, and/or models to link evidence to the claims and assess the

extent to which the reasoning and data support the explanation or conclusion.

7. Respectfully provide and/or receive critiques on scientific arguments by probing reasoning and evidence and challenging ideas and conclusions, and determining what additional information is required to solve contradictions.
8. Evaluate the validity and reliability of and/or synthesize multiple claims, methods, and/or designs that appear in scientific and technical texts or media, verifying the data when possible.

Massachusetts High School Technology/ Engineering Curriculum Framework

HS-ETS1-1. Analyze a major global challenge to specify a design problem that can be improved. Determine necessary qualitative and quantitative criteria and constraints for solutions, including any requirements set by society.

HS-ETS1-2. Break a complex real-world problem into smaller, more manageable problems that each can be solved using scientific and engineering principles.

HS-ETS1-3. Evaluate a solution to a complex real-world problem based on prioritized criteria and tradeoffs that account for a range of constraints, including cost, safety, reliability, aesthetics, and maintenance, as well as social, cultural, and environmental impacts.

HS-ETS1-4. Use a computer simulation to model the impact of a proposed solution to a complex real world problem that has numerous criteria and constraints on the interactions within and between systems relevant to the problem.

HS-ETS1-5. (MA) Plan a prototype or design solution using orthographic projections and isometric drawings, using proper scales and proportions.

HS-ETS1-6. (MA) Document and present solutions that include specifications, performance results, successes and remaining issues, and limitations.

Course Specific Learning Objectives

ICED Methodology

ICED.1 - I can describe the relationship of science and engineering

ICED.2 - I can describe the ICED Methodology and procedural steps

ICED.3 - I can identify the seven key themes of ICED

ICED.4 - I can explain in general how the ICED process can be used to solve a design problem

ICED.5 - I can describe the building-block approach to research, design, and problem solving

Team Learning

Team.1 - I can express my vision for future

Team.2 - I can state which cognitive modes I prefer and how they would benefit my team.

Team.3 - I can express my teams vision for the future.

Team.4 - I can describe important components for building and working in high-performing, effective teams.

Team.5 - I can identify and effectively address issues with poor team or individual team member performance

Team.6 - I can explain the various roles and duties of the team, for example: team leader, chief engineer, project manager, test engineer, analyst, etc.

Team.7 - I can develop and practice methods for both self and team assessment.

Team.8 - I can create a team contract which details how the team will work together on this project.

Knowledge Capture

Knowledge.1 - I can define a problem like an engineer with criteria and constraints.
Knowledge.2 - I can use and construct a functional decomposition
Knowledge.3 - I can effectively use academic research databases to increase my understanding of a topic.
Knowledge.4 - I can annotate an article for easier understanding and review
Knowledge.5 - I can create a concept map to make explicit the relationship between ideas/ concepts.
Knowledge.6 - I can develop and state a thesis statement for the project objectives.
Knowledge.7 - I can conduct a literature review in support of for the project objectives using a literature review matrix
Knowledge.8 - I can write a synthesis paper based on a literature review and thesis statement.
Knowledge.9 - I can identify subject matter experts that would be able to answer questions.
Knowledge.10 - I can write a subject matter expert (SME) in a professional manner.

Engineering Drawing

Drawing.1 - I can explain why engineers use practical drawing methods
Drawing.2 - I understand what a scale drawing is and make a scale drawing.
Drawing.3 - I can recognize the different types of engineering (e.g., orthographic, isometric, perspective and oblique) and state the pros and cons of each.
Drawing.4 - I can accurately represent an object in an engineering drawing.

Creative Concept Ideation

Ideation.1 - I can describe the techniques employed in effective brainstorming.
Ideation.2 - I can list the rules of brainstorming and explain how they relate to the techniques.
Ideation.3 - I can state the factors needed before beginning brainstorming and have demonstrated how to use them.
Ideation.4 - I can describe and practice, by experience, several methods for thinking creatively such as: Brainstorming, Brain Writing (6-3-5 Method), SCAMPER, and Ishikawa Diagrams (Fishbone Diagrams).
Ideation.5 - I can express my engineering problem creatively via song and/or interpretive dance.
Ideation.6 - I can describe and practice, by experience, the use of analogic thinking practices such as Biologically Inspired Design (BID).
Ideation.7 - I can describe and practice, by experience, the use of the Theory of Inventive Problem Solving (TRIZ).
Ideation.8 - I can analyze solutions with respect to criteria and constraints in an organized manner.
Ideation.9 - I can use a Pugh chart to select the best solution and develop it further.

Rapid Concept Development

RCD.1 - I can explain the usefulness of failure and ways to employ Intelligent Fast Failure (Fail small, fast, small, cheap, early and often).
RCD.2 - I can explain the importance of failure mechanisms and use them to predict types of failure based on analysis.
RCD.3 - I can validate the feasibility of the concept.

RCD.4 - I can provide information (e.g., materials, methods, type of data and how to how much data is needed to produce reliable results within limitations) to conduct a meaningful test.
RCD.5 - I can describe what a prototype is and explain why it is important in ensuring usability
RCD.6 - I can identify tools and safety rules for building prototypes.
RCD.7 - I can construct a scale model and/or prototype.
RCD.8 - I can use spreadsheets, databases, tables, charts, graphs, statistics, mathematics, and information and computer technology to collate, summarize, and display data and to explore relationships between variables.
RCD.9 - I can recognize patterns in data that suggest relationships worth investigating further.
RCD.10 - I can evaluate the prototype against criteria and constraints.
RCD.11 - I can determine an appropriate material for the final product.
RCD.12 - I can create and execute a plan for redesign.

Communication of Ideas

Communication.1 - I can conduct a live video conference with other students or subject matter expert to find out information or answer questions.
Communication.2 - I can design a slideshow in a professional manner
Communication.3 - I can compose a professional engineering report.
Communication.4 - I can communicate findings orally to an audience of both experts and non-experts in a professional manner.
Communication.5 - I can create and maintain a website and blog for our team
Communication.6 - I can use Explain Everything to produce a short video explaining a concept.
Communication.7 - I can design a research proposal poster to effectively convey and summarize the engineering project idea.
Communication.8 - I can present the finding in a symposium format to both experts and non-experts.
Communication.9 - I can present my findings in a 20-minute video presentation.