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# Developing Cognitive Innovation Skills through a Problem Solving Approach in Science and Technology to Develop Solution Entrepreneurs

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# Developing Cognitive Innovation Skills through a Problem Solving Approach in Science and Technology to Develop Solution Entrepreneurs


## Abstract

The purpose of this paper is to describe an honors critical thinking/problem-solving course sequence. Highlighted is a first year general education critical thinking/problem solving course in science and technology taken by the science, technology and engineering majors during a special undergraduate honors science, technology, engineering, and mathematics (STEM) education experience. The target competencies are further applied throughout the students' subsequent academic major program of study. This sequence also incorporates opportunities specifically for entrepreneurially spirited honors students to provide them with an early experience in developing solution entrepreneurship. The sequence was built on the premise that collaboration by a variety of entities from across the spectrum of government, business, and social enterprise is needed to solve society's critical problems—particularly if we seek to create a new solution economy. A solution economy is one that has shifted away from a government-dominated economic model to one that is driven by new innovators who are closing the gap between what government provides and what citizens need.[1] These new innovators are called solution entrepreneurs. Crucial to this shift is the establishment of a growing cadre of entrepreneurs with a foundation of cognitive innovation skills, i.e., a new way of thinking about complex global problems in a solution economy.

This paper first defines cognitive innovation as identifying and applying mental models to develop a more integrative way of thinking about complex global problems while creating a solution economy. Secondly, examples of how critical thinking/problem-solving skills are applied to study complex global sustainability problems during the undergraduate general education experience are provided. Subsequently, examples of how students apply these skills during their major's course work, including the culminating Honors Thesis, are illustrated. It should be noted that while there are many other entrepreneurial skills, e.g., finance related ones, developed throughout this curriculum by students, this paper specifically focuses on critical thinking and problem solving skills necessary for the solution entrepreneur.[2]

Honors students begin their first year with a specific general education course designed to provide the foundation for critical thinking and problem solving. During the first half of the course, students engage in a variety of critical thinking learning experiences that teach them how to: develop analysis mapping for making decisions; use design heuristics; utilize comparative, ideological, deductive, and inductive reasoning; and understand the relationship between scientific inquiry and problem solving. During the second half of the course, students work in teams to apply these critical thinking skills to a complex global sustainability problem, investigating how a problem becomes a problem and exploring current solutions and projected future solutions. Relevant examples of how students apply these cognitive innovation skills within their academic major as they further develop their science, technology, and engineering knowledge are then provided. The culminating Honors Thesis then extends students' initial inquiry of the complex global sustainability problem they have studied and focuses effort on effective solutions.

Keywords: Cognitive innovation, solution economy, solution entrepreneur, critical thinking, problem solving, science, technology, engineering, and mathematics, general education (STEM)

## Introduction

With the exponential factoring of knowledge due to scientific and technological advances, solving complex global problems will require a different way of thinking than was used to create them. No longer are solutions bound within a discipline, science or technology. Instead, solutions require a highly integrated approach across many disciplines, sciences, or technologies. The purpose of this paper is to describe a critical thinking/problem-solving course sequence (Figure 1). Highlighted is a first year general education critical thinking/problem solving course in science and technology taken by the science, technology and engineering majors during a special undergraduate honors science, technology, engineering, and mathematics (STEM) education experience. These critical thinking/problem solving skills are further developed during students' subsequent program of study in their academic major. This sequence is also designed specifically for entrepreneurially spirited honors students by providing them with an early experience to developing America's next generation of solution entrepreneurs. The sequence is built on the premise that a variety of entities from across the spectrum of government, business, social enterprise must collaboratively team to solve society's critical problems. Only through such collaboration can the USA create a new solution economy. A solution economy is defined as a shift away from a government-dominated economic model to one that is driven by new innovators who are closing the gap between what government provides and what citizens need.[1] These new innovators are called solution entrepreneurs. Necessarily, this sequence establishes the critically needed foundation of cognitive innovation as it imbues a new way of thinking about complex global problems in a solution economy.

This paper will first define cognitive innovation. Cognitive innovation, for the purpose of this paper, is defined as identifying and applying mental models to develop a more integrative way of thinking about complex global problem for a solution economy. Secondly, examples of how critical thinking/problem-solving skills are applied to study complex global sustainability problems during the undergraduate general education experience will be provided. Subsequently, examples of how students apply these skills during their major's course work, including the culminating Honors Thesis are provided. It should be noted that while there are many other entrepreneurial skills developed throughout this curriculum by students, this paper specifically focuses on critical thinking and problem solving skills necessary for the solution entrepreneur.[2]

## Cognitive Innovation

Cognitive innovation, for the purpose of this paper, is defined as identifying and applying mental models to develop a more integrative way of thinking about complex global problem for a solution economy. This innovative way of thinking focuses on designing sustainability solutions by integrating and applying knowledge of how organic systems (systems of nature) work with human (technological) systems, the nexus between problem solving (deductive reasoning) and scientific inquiry (inductive reasoning). It also focuses on how relationships between two metabolisms, biological (cycles of nature) and technical (cycles of industry), provide an understanding of systems of nature, how phenomena in nature exist, and how humans think those environments ought to be. The concept deals with the integrative relationship of how science starts with a problem and is guided by theory and reflective experience, while technology results in solutions which in turn help generate new theories, a new way of thinking about complex social problems called naturalistic sustainability[3]. Not infrequently, the solutions in themselves generate subsequent downstream problems that also must be considered. Having students learn how to construct and use mental models is essential to develop a new way of thinking about complex social problems. Nature provides the best and largest laboratory for people to create mental models by imitating and emulating nature's systems.

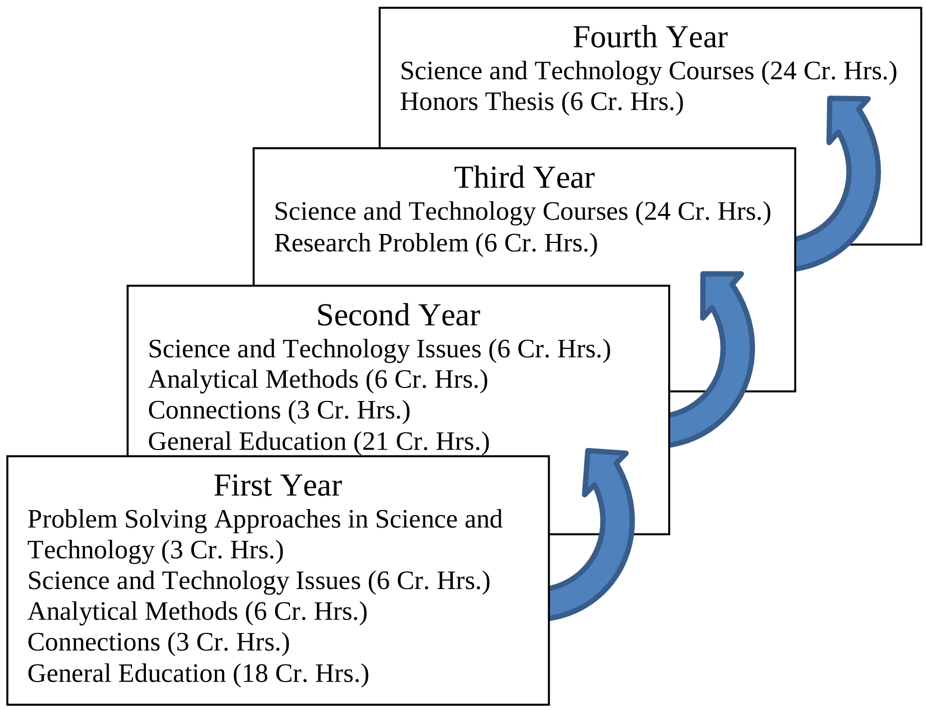



*Figure 1.* Critical thinking/problem-solving curriculum sequence for STEM honors students.

**Introduction to Critical Thinking and Problem Solving**

One of the university's five required general education clusters focuses on developing foundational skills in reasoning, writing, and oral communication. To address this cluster, during the freshman year, STEM major students take a critical thinking and problem solving course entitled *Problem Solving Approaches in Science and Technology*[4]. The primary goals of this honors general education class are to develop students' critical-thinking and problem-solving skills in science and technology, especially through written and oral communication, and to demonstrate how these thinking and problem-solving processes are applicable to other disciplines. This undergraduate general education course provides an introduction to critical reasoning concepts and practices in science and technology by focusing on: 1) a conceptual and practical understanding of thinking and reasoning, 2) applied thinking and problem-solving skills, 3) a liberal opportunity to practice in methodologies taught, and 4) careful assessment and evaluation of results. Students are required to demonstrate basic competency in applying critical thinking skills to real world global problems, other disciplines, and effectiveness with idea-generating scenarios.

The goal of this course is to promote the **initial development** of problem-centric habits of mind. These habits of mind are introduced during the initial critical thinking/problem-solving course as a life-long pursuit. Students begin building a foundation for the habits of mind during this course and continue to enrich them as they move through their program of studies. They continue to build their habits of mind skills as they move through their career path. These habits of mind have students:

1. Employ a holistic perspective by accounting for the broader system within which the problem exists. Typically one extends the problem boundary to include actors and forces associated with both natural systems and those associated with social or cultural institutions or norms.
2. Take a long-term view of the problem by seeking to understand the history of its evolution and how things might unfold in the future, given the dynamic forces in play.
3. Know what kind of outside expertise is needed and when/where to get it from those who have a greater depth of knowledge in the disciplinary tools needed to tackle important parts of the problem.
4. Identify and engage relevant and diverse stakeholders.
5. Explicitly address the political/cultural context and dynamics that are relevant to the problem, recognizing that even the definition of the problem can vary from one stakeholder group to the next.
6. Employ sound scientific methodologies to understand and solve problems. This means that students must be: a) literate in the sciences and in technology; b) able to use social and natural scientific methodologies to build knowledge about the problem and its possible solutions; and c) comfortable working with a variety of data, form facts, and conclusions based on sound analyses, while recognizing the uncertainty and limits of their conclusions.
7. Assess technological, economic, cultural, social, and political merits of possible solutions. This assessment implies paying attention to the political, geographical, historical, and cultural dimensions of the problem.
8. Evaluate the system-wide (both supra- and sub-system) impact of possible solutions.
9. Be self-reflective and self-critical of their analysis by carefully articulating their own mental models and assumptions about the problem and to subject those models to scrutiny[5].

To introduce, develop, and reinforce critical reasoning concepts and practices in science and technology through a problem-centric, habits of mind approach, students are provided opportunities to demonstrate their capability through a variety of assignments. During the early part of the course, students work on: 1) developing basic critical thinking skills through cognitive innovation, and 2) developing basic problem solving skills for solution entrepreneurs. The content for developing basic science and technology critical thinking skills is organized around seven topics: 1) Introduction to Critical Thinking, 2) Clarifying Ideas, 3) Mapping Arguments and Decisions, 4) Heuristic Reasoning, 5) Comparative Reasoning, 6) Ideological Reasoning, and 7) Empirical Reasoning. The content for developing basic science and technology problem solving skills is organized around thirteen topics: 1) Introduction to Sustainability, 2) Naturalistic Sustainability/Biomimicry/Biometrics, 3) SRI Innovation Model[6], 4) Recording Data in an Engineering Log, 5) Problem Solving Tools, and 6) Introduction to Systems Thinking, 7) The Power of the Solution Economy, 8) The Wavemakers, 9) Disruptive Technologies, 10) Business Models That Scale, 11) Currencies and Public-Value Exchanges, 12) The Ecosystems, and 13) Creating Your Own Solution Revolution.

**Learning Activities to Teach Critical Thinking**

During the first half of the course, students engage in a variety of critical thinking learning experiences that teach them how to: develop analysis mapping for making decisions; use design heuristics; develop mental models; utilize comparative, ideological, deductive, and inductive reasoning; and understand the relationship between scientific inquiry and problem solving. During the second half of the course, students work in teams to apply these critical thinking skills to a complex global sustainability problem, investigating how a problem becomes a problem and exploring current solutions and projected future solutions and considering the multiple impacts of such solutions.

The course instructor supports students in developing basic critical thinking and problem solving skills using cognitive innovation through a series of in-class scenarios. For example, students work in teams to role play how they would survive on a deserted island or how they would address energy issues in a corporate staff meeting. Students also learn how to use mental models and analysis maps to illustrate the complex relationships between arguments, reasons, rival causes, and premises by deconstructing a journal article addressing a controversial or politically charged topic. Key to this knowledge development is a strong emphasis on using cognitive innovation skills, such as using analogies, metaphors, naturalistic sustainability, biomimicry, morphological boxes, and analysis maps.

To develop and reinforce critical thinking content, students work in groups of three or four to carry out three critical thinking activities. While engaged in these critical thinking activities, students systematically analyze core science and technology articles by identifying and defining the relationships between the arguments, reasons, evidence, and conclusions found in the assigned readings, supporting articles, and articles holding counter viewpoints. Students demonstrate their understanding by mapping their analysis and visually representing their critical thinking process. Students use Facione and Gittens's *Think Critically*[7] to gain further understanding of, and advance their skills with, critical thinking and cognitive innovation. The following section provides excerpts from these general education course assignments.

As the groups analyze articles for their critical thinking activities, they select additional articles based on how the articles' authors either support or counter the main argument for the critical thinking activities. Groups make judgments about the articles by addressing key questions that allow them to critically analyze the content in order to compare how reasons and supporting evidence relate to the main argument which leads to their conclusion. These questions are:

1. What is central theme or thesis of the article and does it agree with or counter the main argument?

2. What are the reasons and supporting evidence provided by the article and what reasons and supporting evidence agree with, or counter, the main argument for the critical thinking activity?
3. What elements are implicit but are unspoken?
4. How does one reason and present objections or counter arguments?
5. How does one select appropriate reasons and evidence?
6. When should one abandon a line of reasoning?
7. What is the intended flow of reasoning from reason to claim?
8. What assumptions were made and were they supported?
9. What was the author's pathway from the argument to the conclusion and was there a better alternative?

To apply the above questions to their critical thinking activities, groups develop an analysis map that shows the main argument and how counter arguments, their reasons, and evidence relate and flow to support the conclusion. The analysis map shows how a reason or claim is accepted or rejected, how clarifications are made, how unspoken elements are related to reasons, how interpretive comments are used that lead to the conclusion. Analysis maps are specifically used to help students graphically represent their thought process of how relationships interact, impede, advance a solution to be accepted or rejected. An example of an analysis map that examines a framework for planetary boundaries is shown in Figure 2. In this example, students use a variety of conventions to show the relationships and interactions of earth's systems that are in a safe threshold, those that have exceeded a safe threshold, and those that are approaching or barely exceeded a safe threshold for a sustainable earth. The analysis map concludes with two solutions that must be pursued simultaneously.

Three examples of critical thinking activities that provide context for students, while they apply the above questions, are provided below:

> **Critical thinking activity I.** *Your group will develop a ten-page paper that argues a scientific or technological issue from a viewpoint that is counter to your personal viewpoint. Differentiate what makes something true versus something false. What are the reasoning errors? What reason, evidence, or premise is being used as the basis for the argument and how is that argument being countered? You must use a minimum of six references from scholarly journals or books. Your group will document your responses by showing relationships between claims, evidence, arguments, statistics, mental models, etc. You must include the appropriate critical thinking terminology used in the course textbook and from my lectures to show your command of that knowledge*[4].

> **Critical thinking activity II.** *Your group will develop a ten-page paper that compares and contrasts the ideological and heuristic reasoning of a science or technology policy. Your group will decide on a dominant point of view (ideological and heuristic) from which to write your response. You must use a minimum of six articles, which can come from scholarly journals or books, electronic or printed. Your group will document your responses by showing relationships between claims, evidence, arguments, statistics, literary techniques,*

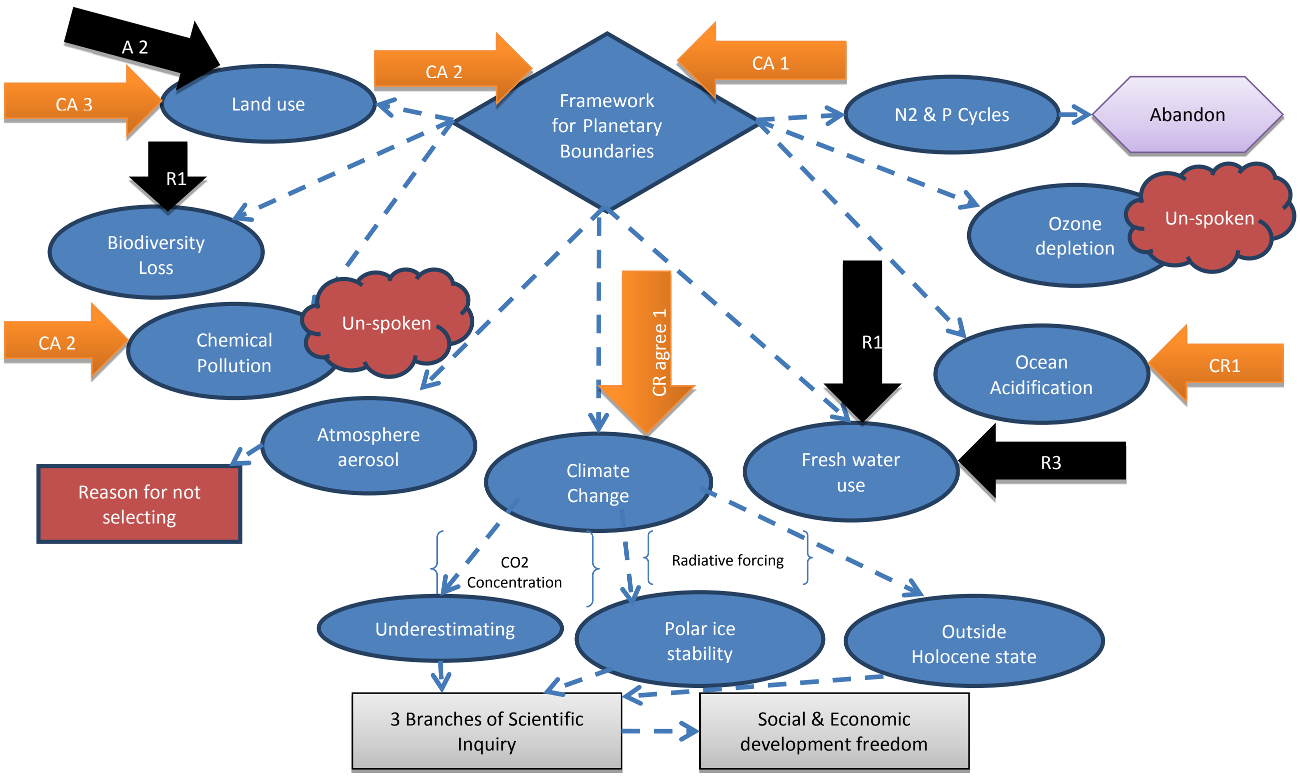
*etc. You must include the appropriate critical thinking terminology used in the course textbook and from my lectures to show your command of that knowledge[4].*

**Critical thinking activity III.** *This assignment focuses on the relationship between inductive and deductive reasoning. Your group will develop a ten-page paper that provides evidence to support a viewpoint of a key scientific or technological phenomena. What statistical and causal generalizations were made as evidence about the scientific phenomenon? How were the studies and analogies that led to the policy controlled? What were the reasoning errors or misleading facts? What reality assumptions were used that guided the policy? Your team will decide on a dominant point of view from which to write your response. You must use a minimum of six articles, which may come from scholarly journals or books, electronic or printed. Your team will document your responses by showing relationships between claims, evidence, arguments, statistics, literary techniques, etc. You must include the appropriate critical thinking terminology used in the course textbook and from my lectures to show your command of that knowledge[4].*

Such critical thinking activities build the base for students studying science and technology problems. The students work in groups, exploring a complex global problem, to learn how critical thinking is utilized in science and technology problem solving. In studying their complex global problem, students learn how science and technology problems evolve over time to their current status and magnitude, what solutions are currently being employed, what are some possible future solutions, and of course, what are their implications in terms of potential future problems. Students' successful application of these skills is evident in their ability to research the culminating activity and from their student evaluation comments explaining how they now think about problems.

**Complex Global Problem.** To develop and reinforce their skills in basic STEM and technology problem solving skills, students work in groups to apply the critical thinking and problem-solving tools to a critical global problem, such as energy supply and demand, food scarcity, water scarcity, or critical infrastructure decline. The focus of such activity is to have students explore how the global problem evolves, the current status of the problem, what is being done to solve the problem, and to propose and assess future solutions. More specifically, students are charged to use a variety of problem solving tools to research and analyze their problem by addressing key questions in each of these three perspectives:

1. Historical perspective: How did your complex global problem become a problem as we know it today? What created the problem? How did the problem evolve? What trends, events, etc. influenced your problem as it evolved?
2. Current status: What is the nature, current status, and magnitude of impact of your complex global problem and what is currently being done to solve this problem?




| Mapping Conventions Legend | | | |
|---|---|---|---|
| | Recognition of Need | | Objection |
| | Flow of Reasoning | | Interpretive Comment |
| | Reason/Evidence | | Abandon |
| | Unspoken Thought | | Reason for not Selecting |

*Figure 2.* Analysis map for a framework for planetary boundaries.

3. Projections for the future: What are future solutions being projected? What is the projected magnitude of impact to society if the problem is not solved? Are proposed solutions a way of slowing down the magnitude of the problem or solving it?

Based on their literature review research and analyses, each team develops short-term, mid-term, and long-term strategies that address their problem -- but notably, at this time, they do not yet create a solution[4].

In addition and throughout the course, besides basic science and technology problem solving content, the instructor teaches students the key principles and concepts of sustainability as defined by experts such as Friedman[8], Friedman[9], Kaku[10], McDonough and Braungart[11], Petroski[12], and Senge, Smith, Kruschwitz, Laur, and Schley[13]. Related topics include population change, energy supply and demand, climate change, biomimcry, biodiversity loss, and critical infrastructure. Furthermore, students use Eggers and MacMillian's *The Solution Revolution: How Business, Government, and Social Enterprises are Teaming Up to Solve Society's Toughest Problems*[1] to gain an understanding of innovation and solution entrepreneurship.

**Applying Critical Thinking Skills in their STEM Program: An Example**

While students are expected to continue to use and develop their critical thinking and problem solving skills through course work and everyday life experiences, they need to use this knowledge in very intentional ways when they begin their STEM program. Students concurrently take a series of analytical methods and issues courses during their freshman and sophomore years to develop a core STEM knowledge base that supports the general education critical thinking and problem solving course. This knowledge base is further developed during their junior and senior year, and it culminates with an Honor's Thesis. All of these learning experiences are designed to develop and enhance cognitive skills for creating future solution innovators that is based on brain research[6, 14, 15,16, 17, 18, 19, 20].

During their first two years, students take four analytical methods courses that provide the tools and techniques to describe and to understand issues in contemporary STEM. A summary of the analytical methods sequence is detailed in Table 1[14].

In addition, students take four issues courses, one each in, bioscience, environment, energy, and engineering and manufacturing. Students also take two connection courses that examine the ethical, social, economic, environmental, philosophic, and historical context of science and technology. These courses explore the complex ways these concerns are integrated with contemporary society. Connections utilize an integrative solution economy problem to apply the analytical methods and issues content through a problem-centric approach. These courses provide the baseline foundation for STEM students gaining an understanding of how to create a solution revolution in an entrepreneurial context. Students also complete their required general educations courses during their first two years.

Third year students work in groups, under the direction of a faculty team, on one of ten solution entrepreneurial problems designed by the faculty. These problems are advanced versions of the problems studied by students during the *Problem Solving Approaches in Science and*

*Technology*[4] course. Students concurrently take course work that develops specific scientific and technological content, tools, and techniques to support their research.

During their fourth year, students also work in groups, again under the direction of a faculty team, on a solution entrepreneurship honors thesis problem. The thesis problems are developed out of the solution entrepreneurial problems students studied during their third year. Sample thesis topics include population change, energy supply and demand, climate change, biomimcry, biodiversity loss, and critical infrastructure. Students may take additional science and technology courses that support their thesis.

An example of an honors thesis topic is *Incentivizing Using Public Transit and Promoting Walking*, where students design a new fresh approach that provides and encourages students, faculty, staff, and administrators to bike, walk, rideshare, or use public transit to commute to and from campus. Transportation initiatives, such as Car2Go©, Zipcar®, Zimride©, Avego©, RelayRides©, Reward Ride©, and Carpooling.com©, have successfully been implemented to address this commuter crisis. These innovations include renting cars or bicycles, ridesharing, providing incentives. Students will also develop apps to monitor and identify commuting alternatives. The thesis must address both a city and university solution.

Table 1.

*Analytical Methods Course Sequence*

| **Analytical Methods I** | **Analytical Methods I** |
|---|---|
| • Introduction to science and scientific method<br>• Introduction to mathematical models<br>• Introduction to functions and their applications to modeling<br>• Using graphical statistics to build empirical models<br>• Critical evaluation of arguments involving data analysis<br>• Introduction to project management | • Introduction to mechanics<br>• Introduction to calculus with applications to modeling 1-dimension motion<br>• Numerical (digital) methods for evaluating derivatives and finding maxima/minima<br>• Further applications of derivatives<br>• Introduction to vectors and tools for modeling 2-D systems<br>• Introduction to Riemann integration |
| **Analytical Methods III** | **Analytical Methods IV** |
| • Integration and introduction to differential equations<br>• Numerical methods to evaluating integrals and solving differential equations<br>• Application to modeling work, energy, and power<br>• Introduction to electricity and magnetism<br>• Introduction to mechanical waves, with applications to audio systems<br>• Introduction to optics, with applications to optical disks and fiber optics | • Introduction to logic and the analysis of language, especially in relation to knowledge-based systems<br>• Introduction to intelligent systems<br>• Development of knowledge-based systems, and advanced project management<br>• Principles of knowledge acquisition<br>• Using expert system shells |

## Conclusion

The ability to think critically and to solve problems in scientific and technological contexts is an essential skill for solution entrepreneurs working to solve society's critical problems in a solution economy. This capability and entrepreneurial spirit requires individuals to understand and apply technological concepts, practices, and tools for solving problems and generating ideas. Learning effective communication skills, especially writing, speaking, and listening, is central to understanding how to think critically using cognitive innovation skills and how to solve problems both individually and collaboratively. Increasing one's self-awareness, interpersonal communication skills, and self-knowledge, i.e., metacognition, is essential in the thinking process. Supporting the development of these cognitive skills early in the undergraduate career and providing consistent reinforcement, increase the likelihood of producing the generation of innovators and entrepreneurs needed to address the critical problems facing our nation.

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