DISCOVERY ENGINEERING IN BIOLOGY

Case Studies for Grades 6–12

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Introduction

A number of amazing innovations have resulted from someone making a careful observation, a mistake, or even just trying an experiment to see what will happen. In 1854, for example, Dr. John Snow wanted to know what was causing an outbreak of cholera in his home city of London. Dr. Snow had noticed that areas with filtered drinking water had fewer deaths and guessed that contaminated water had something to do with the cholera outbreak. To test his theory, he created a map showing the reported cases of the illness in the neighborhood of Soho, as well as the locations of Soho's water pumps. This allowed him to pinpoint a contaminated pump. He went on to share his findings and become "the father of epidemiology" (MPH Online Learning Modules 2015).

Dr. Snow addressed a societal need of the 1850s, namely the necessity for a means to stop cholera outbreaks. Since his work more than 150 years ago, the field of epidemiology has grown exponentially and still uses the principles of careful observation and ideation to tackle modern concerns. The case of Dr. Snow demonstrates that careful observations and discovery-based research can be sourced from or inspired by the natural world and one's own imagination, leading to new ideas and applications sourced from biology itself. The key to harnessing this potential is a careful and imaginative eye, along with a mindful process of engineering to address and solve everyday problems. This book focuses on the intersection of science and engineering through an examination of real-world discoveries that, as in the case of Dr. Snow, led to innovations and solutions to contemporary real-world problems. We call the process of developing an innovation based on an observation of phenomena or a deeper exploration of accidental findings "discovery engineering."

What Is Discovery Engineering?

Each chapter in *Discovery Engineering in Biology* begins with the examination of an observation, discovery, or phenomenon. Students review historical observations or discoveries to connect these revelations to their original context. Then, they place themselves in the role of discoverer by thinking about how innovations and insights can be used to create and design new products or applications to solve problems. Authentic details from original studies and data sets make the book's case studies realistic and interesting.

With each case study, students explore physical materials, design studies, analyze data, or create models of phenomena before considering further applications for a given discovery. Students are tasked to think creatively about science from serendipity, using research and their own personal insight to create and design new products or applications to solve problems. Throughout the process, students become increasingly knowledgeable about how scientific discoveries often unfold and how engineers apply a design process for creative applications.

The cases in this book engage the learner at multiple levels and scaffold the learning process through observations, an examination of data, and the evaluation and synthesizing of information, followed by an application of the engineering design process (EDP) to address an everyday problem.

The reason for including the EDP is to help students understand and apply fundamental science processes while also exploring new ideas for applications. At the same time, the primary documents or historical accounts in the case studies engage students in the authentic contexts of science. By combining these elements, this book addresses the call by the National Academies of Sciences, Engineering, and Medicine in "engaging all students in learning science and engineering through investigation and design … [with] instructional approaches that (1) situate phenomena in culturally and locally relevant contexts, (2) provide a platform for developing meaningful understanding of three-dimensional science and engineering knowledge, and (3) provide an opportunity for the use of evidence to make sense of the natural and engineered world beyond the classroom" (NASEM 2018, p. S-2).

How Is Discovery Engineering Different From Other Engineering Designs?

Engineers identify real-world problems and scan the available knowledge resources to identify those that can be deployed to generate solutions; that include areas within the science, technology, engineering, and mathematics (STEM) disciplines as well as social sciences and humanities. As part of their work, engineers use some version of the EDP as steps to find a solution to a problem, specifically utilizing aspects of designing, building, and testing. In the authentic work of engineers, this process is complex and includes concepts such as constraints, requirements, tradeoffs, optimization, prototyping, and more. However, as engineers conduct their work of addressing problems, it so happens that new applications, products, and ideas are also discovered, calling into question new ways to apply these observations and knowledge to life-science contexts.

Discovery Engineering in Biology starts with a unique or accidental discovery or observation, followed by the consideration of a new application or problem to be solved. As documented by the case studies within this book, this is a realistic process that leverages engineering in the often-unrelated context of biological science. The case studies show that not all discoveries or inventions are a product of controlled experiments or engineering prototypes. Some innovations simply begin with an observation, followed by creative thinking and consideration of how that process or phenomenon might be used for a new application or to solve a problem.

To scaffold the EDP, we have established a six-step formula: asking questions; brainstorming and imagining; creating a plan; designing; testing and evaluating; and improving and revising. It is important to note that this book is not intended to replicate the work of engineers. Instead, its purpose is to provide students with an introduction to engineering design principles anchored to concepts within biological science. This book shows students that their everyday observations of the natural world can provide unique insight into the challenges facing modern society. Furthermore, *Discovery Engineering in Biology* seeks to empower students to leverage their natural curiosity in order to innovate and design new applications or create new products for tomorrow.

The Case Study Approach

At the heart of each case study is a true story, one that describes how someone made a casual observation or did a simple experiment that led to new insight or a discovery. Case studies are designed to get students actively engaged in the process of problem solving and applying ideas to design new products and processes. The narrative of the case supplies authentic details that help place the student in the role of the inventor and provides scaffolds for critical thinking and deep reflection. A case is more than a paragraph to read or a story to analyze; rather, it is a way of framing problems, synthesizing information, and thinking creatively about new applications and solutions.

According to the National Center for Case Study Teaching in Science, the use of cases as an instructional strategy has had a long history of success in schools of business, law, and medicine. For example, cases are effectively integrated into health care–related education programs to increase student understanding of the profession, especially for situation-dependent knowledge needed in clinical settings (Dowd and Davidhizar 1999). Cases are also an appropriate instructional strategy for the secondary science classroom as they can be used to develop students' critical thinking skills, teach science process skills, help students think about the nature of science, and more (Gallucci 2006). Research specifically credits using real-world scenarios in fostering relatable and purpose-driven contexts that can yield improvement in student attitudes and academic achievement, specifically in the areas of mathematics and science (Akınoğlu and Tandoğan 2007). Cases are an instructional method that can engender the development of science reasoning skills during nonlaboratory classroom time. Cases guide students to think expertly about problems. They also provide teachers with the opportunity to coach students to use metacognitive strategies in order to monitor and take control of their own learning. This process reduces rote learning and promotes active engagement. What's more, case studies often enhance student interest by making the topic more relevant to real-life activities.

The case studies provided in this book are designed to supplement instruction by motivating students to apply what they have learned to new contexts and applications. Cases are especially effective for discussing complex scenarios in which there is no single solution to a problem; they are best integrated into the curriculum when learners can benefit from applying their ideas to a real-world situation.

Teaching with case studies provides students with a vicarious experience and casts them in roles that require taking a different perspective, thinking differently about science, and taking ownership over a decision. Each case activity highlights a career in or related to STEM so students can envision themselves engaging in real STEM work. This form of instruction is valuable as it teaches students to think critically about a problem and develop possible solutions, which approximates the problem-solving environment of many professions in science, technology, engineering, and mathematics.

This book is of value to middle and high school science and engineering teachers as each case includes multiple components that teachers can tailor to specific classroom environments. Case studies may be used during the "engage" component of a learning cycle to elicit student interest and provide formative evaluation information about students' preconceptions. A case can also become part of the "extend and apply" component of a lesson. When used at the end of the lesson, the cases may help teachers judge whether their students understand the science of the case sufficiently enough to apply their knowledge to new contexts.

Case studies contextualize student learning and prompt students to use their knowledge to problem-solve in a "real" situation, consider a topic from a new and different perspective, and reflect deeply about their learning. With these texts, students are encouraged to increase their understanding of STEM and improve their critical reasoning skills.

Science, Engineering, and the *Next Generation Science Standards*

The *Next Generation Science Standards* (*NGSS*) challenge science teachers to facilitate learning experiences for students that emulate the practices of scientists and engineers (NGSS Lead States 2013). *A Framework for K–12 Science Education* (NRC 2012; the *Framework*), which established the *NGSS,* recommends that K–12 science education include these dimensions: science and engineering practices (SEPs); crosscutting concepts; and disciplinary core ideas (NRC 2012, p. 2). Engineering stresses that technologies are driven by human effort and influenced by societal needs and values. One of the goals identified in the *NGSS* is for students to understand that "(s)cientists and engineers are guided by habits of mind, such as intellectual honesty, tolerance of ambiguity, skepticism, and openness to new ideas" (NGSS Lead States 2013, p. 69). Hence, one of the central goals of the *NGSS* is to better situate inquiry in the kinds of work (social, cognitive, and physical) that are authentic to both science and engineering. The *NGSS* recommend that K–12 science instruction should:

1. Have broad importance across multiple sciences or engineering disciplines or be a key organizing principle of a single discipline.
2. Provide a key tool for solving problems and understanding or investigating more complex ideas.
3. Relate to the interests and life experiences of students or be connected to societal or personal concerns that require scientific or technological knowledge.
4. Be teachable and learnable over multiple grades at increasing levels of depth and sophistication. That is, the idea can be made accessible to younger students but is broad enough to sustain continued investigation over years (NGSS Lead States 2013, p. xvi).

According to the *Framework*, engineering and technology are featured alongside the life sciences (physical and Earth and space science) for two important reasons: to aid students in understanding the human-built world and to emphasize the value of integrating science, engineering, and technology within K–12 science curriculum and instruction (NRC 2012, p. 8). SEPs bind science, engineering, and technology together, and they include the following: asking questions and defining problems; developing and using models; planning and carrying out investigations; analyzing and interpreting data; using mathematics and computational thinking; constructing explanations and designing solutions; engaging in argument from evidence; and obtaining, evaluating, and communicating information. Through the incorporation of these SEPs, students should not only demonstrate knowledge of science concepts but also apply these understandings using scientific inquiry and the practices of engineering design (NGSS Lead States 2013, Appendix F).

The *NGSS* specifically state that students should "learn how to engage in engineering design practices to solve problems" (NGSS Lead States 2013, p. 104). Furthermore, it states that both middle and high school students are expected to know how to define problems, develop solutions, and test and optimize their designs, such that students can be "expected to engage with major global issues at the interface of science, technology, society and the environment, and to bring to bear the kinds of analytical and strategic thinking that prior training and increased maturity make possible" (NGSS Lead States 2013, p. 128).

Although the *NGSS* do not clearly delineate how teachers are to integrate engineering into science, it makes recommendations about specific engineering practices for students across grade levels.

TABLE 1

NGSS Recommendations for Teaching Engineering Practices

GRADE LEVEL	ENGINEERING PRACTICES		
	Define	Develop Solutions	Optimize
Early Elementary **K–2**	Identify situations/ problems that can be solved through engineering	Convey solutions through visual or physical representations	Compare solutions, test, and evaluate
Upper Elementary **3–5**	Specify criteria and constraints for a solution to a problem	Research multiple possible solutions	Improve a solution based on results of tests, including failure points
Middle Grades **6–8**	Attend to precision, criteria, and constraints that may limit solutions	Combine parts of different solutions to create new solutions	Iteratively test and systematically refine a solution
High School **9–12**	Attend to a range of criteria and constraints for problems of social and global significance	Break a problem into smaller problems that can be solved separately	Prioritize criteria, take into account tradeoffs, and assess social and environmental impacts as complex solutions are tested and refined

Source: Adapted from NGSS Lead States 2013, pp. 105–106.

The recommendations for teaching engineering practices (Table 1) indicate that students should progress from proposing and testing single solutions to a more complex process of prioritizing and systematically assessing complex solutions to problems.

As students explore science and engineering practices, the *NGSS* raise questions about the classical interpretation of the scientific method. Figure 1 shows the traditional model of the scientific method that has historically been taught in science education. The scientific method is typically represented as beginning with a question. This is followed by an examination of what is known (research), the construction of a hypothesis, the design of an experiment, data collection and analysis, and the drawing of a conclusion and communication of the result.

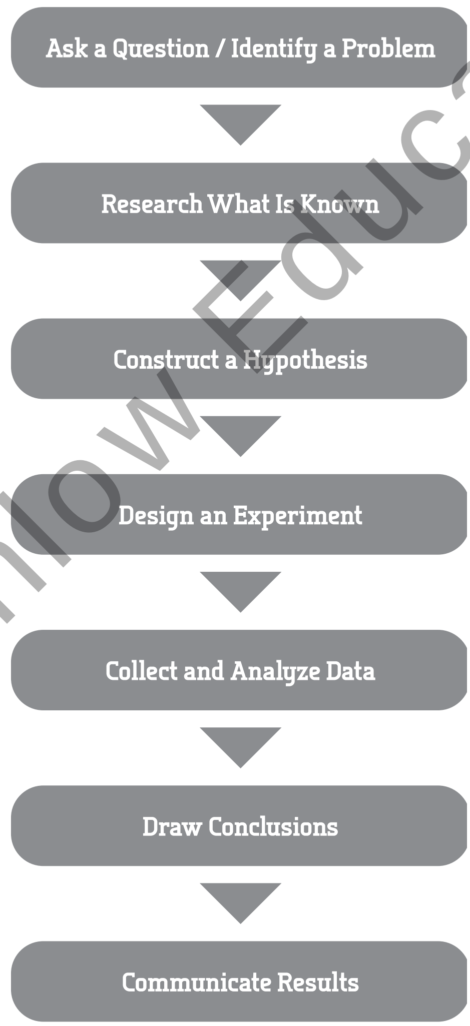
In actual practice, the methods of science are much more iterative and flexible than are often represented in models of the scientific method. That means that, just as with engineering design, these methods can be nonlinear and not confined to a step-by-step process. This has resulted in a change of language, reframing the "scientific method" into "methods of science" to incorporate the iterative nature of scientific endeavor. For example, some fields and areas of science (such as geology or astrophysics) do not lend themselves to controlled experiments; rather, advancements in these fields and areas are made through observations and data analysis without the classically controlled experiment. The inclusion of engineering in this book allows students to compare these processes and consider how both science and engineering follow or bypass the methodologies typically presented within their fields.

The engineering design process may start with ***identifying a problem*** in need of a solution by asking questions to define the problem, ***imagining*** a solution (brainstorming ideas), ***planning*** a solution (designing diagrams and obtaining materials), ***creating*** a product, process, or prototype (following the plan), ***evaluating*** the product (testing or analyzing it), and then ***improving*** the design based on evaluation results. It is a cyclic process in which each iteration leads to a more effective product. Like the scientific method, the EDP is often more fluid than many models represent.

Today, science educators recommend that teachers no longer teach the scientific method as a linear process. Instead, they advocate for the use of the integrated SEP model recommended by the *NGSS*, focusing on teaching students problem-solving skills where science and engineering are blended (NGSS Lead States 2013). The goal is to have students focus on framing questions, developing hypotheses that can be investigated, and then engaging students in systematically analyzing and using data that can form evidence for scientific claims. Lachapelle and Cunningham (2014) suggested that due to the interdisciplinary nature of the EDP, it innately involves scientific reasoning with mathematical problem solving grounded in real-world scenarios.

FIGURE 1

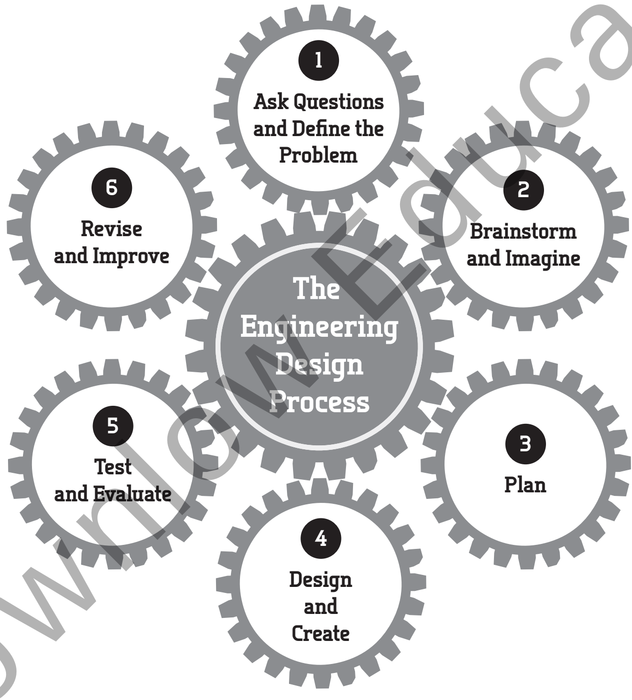
Traditional Model of the Scientific Method



Using the *NGSS* to Inform Engineering Design

FIGURE 2

The Six-Step Engineering Design Process in This Book



The case study approach described in this book is designed to help teachers meet these *NGSS* goals by focusing on real-world problems of interest to the student, employing different levels of depth and sophistication in the problem solving, and integrating thinking across science and engineering. Each case encourages students to use a simplified six-step engineering design model (Figure 2) based on the SEPs and the three central engineering design stages (i.e., define problems, develop solutions, and test/optimize designs) from the *NGSS* (NGSS Lead States 2013, Appendix I). By broadening the process from three to six steps, with guidance at each carefully sequenced step, secondary students will be able to engage in a one form of scaffolded engineering design.

Broadening students' understandings of the nature of science is key to teaching students SEPs and to helping them compare the work of scientists to that of engineers. A fundamental component of the nature of science is developing an understanding of science as a human endeavor that is embedded in previous findings and yet is open to new interpretations as new evidence is uncovered.

Overview of the *Discovery Engineering* Case Study Books

This series includes two books. In addition to *Discovery Engineering in Biology*, there is also *Discovery Engineering in Physical Science* (NSTA 2019). Each case in these books is flexibly designed for use at either the middle or high school level. Investigations are designed to teach one or more science concepts, provide students with background information that teaches the nature of science, and push students to think about new and creative engineering applications. For example, the case "Thalidomide: Hidden Tragedy and Second Chances" (pp. 49–67) could be used when teaching students about human disease. This case illustrates the evaluation of drug treatment for human cancers and the careful steps needed for drug development in human trials.