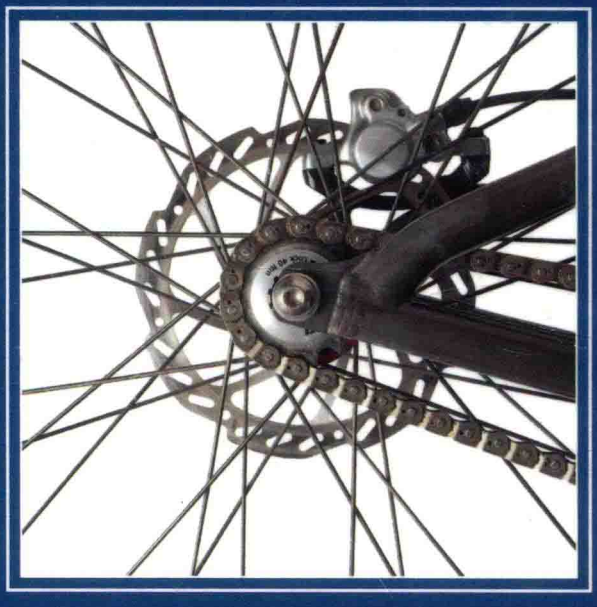
Engineering Mechanics and Design Applications



Transdisciplinary Engineering Fundamentals

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Transdisciplinary
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To my mentors, Professor C. V. Ramamoorthy and Dr. Raymond T. Yeh, dearest friends, who inspired me to write this book.

Preface

In the last decade the number of complex problems facing engineers has highly increased and the technical knowledge and understanding in science and engineering required to address and mitigate these problems has been evolving rapidly. The world is becoming increasingly interconnected as new opportunities and highly complex problems connect the world in ways we are only beginning to understand. When we do not solve these problems correctly and in a timely manner, they rapidly become crises. Problems such as energy shortages, pollution, transportation, the environment, natural disasters, safety, health, hunger, and the global water crisis threaten the very existence of the world as we know it. Recently, fluctuating fuel prices and environmental concerns have set car manufacturers in search of new zero-polluting, fuel-efficient engines. None of these complex problems can be understood from the sole perspective of a traditional discipline. The last two decades of designing large-scale engineering systems have demonstrated that neither mono-disciplinary nor inter- or multidisciplinary approaches provide an environment that promotes the collaboration and synthesis necessary to go beyond existing disciplinary boundaries and produce truly creative and innovative solutions to large-scale, complex problems. These problems not only include the design of engineering systems with numerous components and subsystems, which interact in multiple and intricate ways, but also involve the design, redesign, and interaction of social, political, managerial, commercial, biological, medical, and other systems. Furthermore, these systems are likely to be dynamic and adaptive in nature. Obtaining the solutions to such unstructured problems requires many activities that cut across traditional disciplinary boundaries, that is, transdisciplinary research and education.

The results of transdisciplinary research and education include the following: emphasis on teamwork, bringing together investigators from diverse disciplines, and developing and sharing concepts, methodologies, processes, and tools. All of these help to create fresh, stimulating ideas that expand the range of possibilities. The transdisciplinary approach creates a desire in people to seek collaboration outside the bounds of their professional experience to make new discoveries, explore different perspectives, express and exchange ideas, and gain new insights.

This book was developed completely based on the fundamentals of engineering mechanics for undergraduate students. The mathematical level is similarly limited to that found in engineering mathematics that covers calculus and differential equations.Throughout the book, discussions of theory are followed by practical examples.

Engineering Mechanics with Design Applications: Transdisciplinary Engineering Fundamentals has been written to fulfill the need for a textbook or reference book that is appropriate for use in engineering design practice. It is intended to foster a thorough understanding of the basic condensed knowledge necessary for engineering design.

A general introduction to the concept of Prevention through Design for preventing occupational injuries, illnesses, and fatalities is provided in Chapter 1. Students

should emerge from this transdisciplinary educational experience with a broad understanding of occupational safety and health needs in the design process that will prevent or minimize work-related hazards.

A condensed introduction to engineering statics is provided in Chapter 2, followed by engineering dynamics in Chapter 3. Chapter 4 deals with solid mechanics, which covers many design applications, and Chapter 5 covers failure theories and dynamic loadings. Finally, Chapter 6 integrates knowledge gained from the previous chapters for real-life design analysis and applications. In this chapter, two tragic accidents that occurred in 2010 are discussed. These two disasters killed many workers and caused property damages worth millions of dollers as well as widespread environmental damage. Therefore, the Prevention through Design (PtD) concept and some related concerns are also discussed.

This book is also geared for graduate classes covering engineering fundamentals for nonengineering students and for review by engineering students who have been out of school for several years. It will also be a valuable source for engineering students preparing for the Fundamentals of Engineering Exam and for non-mechanical engineers collaboratively working on large-scale projects. Finally, this book can be used as a textbook for non-mechanical engineering disciplines such as industrial engineering, electrical engineering, and chemical engineering.

Acknowledgment

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1 Prevention through Design
A Transdisciplinary Process

1.1 INTRODUCTION

The main objective of this chapter is to introduce the concept of Prevention through Design (PtD) to prevent occupational injuries, illnesses, and fatalities. Students should emerge from this transdisciplinary educational experience with a broad perspective on occupational safety and health needs in the design process that will prevent or minimize work-related hazards.

1.2 TRANSDISCIPLINARITY AND PtD

1.2.1 Discipline

Since the 1950s the integration of research methods and techniques across disciplines has been of great interest in the social and natural sciences [1]. A particular area of study is called a "discipline," provided it has cohesive tools, specific methods, and a well-developed disciplinary terminology. As disciplines inevitably develop into self-contained shells, interaction with other disciplines is minimized. However, practitioners of a discipline develop effective intra-disciplinary communication based on their disciplinary vocabulary. Many distinguished researchers and educators have contributed to the development of transdisciplinary education and research activities [2–18].

Multidisciplinary activities involve researchers from various disciplines working independently, each from their own discipline-specific perspective, to solve a common problem. Although multidisciplinary teams cross discipline boundaries, they remain limited to the framework of disciplinary research.

In interdisciplinary activities, researchers from diverse disciplines collaborate by exchanging methods, tools, concepts, and processes to find integrated solutions to common problems. Both multidisciplinary and interdisciplinary activities cross discipline boundaries, but their goal remains within the framework of disciplinary research.

1.2.2 Defining Transdisciplinarity

In German-speaking countries, the term *transdisciplinarity* is used for integrative forms of research [19]. Transdisciplinary education and research programs take collaboration across discipline boundaries a step further than do multidisciplinary

and interdisciplinary programs. The transdisciplinary concept is a process by which researchers from diverse disciplines work together to develop and use a shared conceptual framework to solve common problems. A distinctive characteristic of transdisciplinary research is the loosening of theoretical models and the development of a new conceptual synthesis of common terms, measures, and methods that produce new theories and models [20]. The three terms—multidisciplinary, interdisciplinary, and transdisciplinary—are often defined differently by researchers and educators.

Nicolescu [21] stated that transdisciplinarity concerns that which is simultaneously between the disciplines, across the different disciplines, and beyond all disciplines.

Klein [8] defined the above-mentioned three terms as follows: "Multidisciplinary approaches juxtapose disciplinary/professional perspectives, adding breadth and available knowledge, information, and methods. They speak as separate voices, in encyclopedic alignment. ...

Interdisciplinary approaches integrate separate disciplinary data, methods, tools, concepts, and theories in order to create a holistic view or common understanding of complex issues, questions, or problem. ... Theories of interdisciplinary premised on unity of knowledge differ from a complex, dynamic web or system of relations.

Transdisciplinary approaches are comprehensive frameworks that transcend the narrow scope of disciplinary world views through an overarching synthesis, such as general systems, policy sciences, feminism, ecology, and sociobiology. ... All three terms evolved from the first OECD international conference on the problems of teaching and research in universities held in France in 1970."

Hadorn et al. [22] stated, "Transdisciplinary research is research that includes cooperation within the scientific community and a debate between research and the society at large. Transdisciplinary research therefore transgresses boundaries between scientific disciplines and between science and other societal fields and includes deliberation about facts, practices and values."

Peterson and Martin [23] stated that interdisciplinary research has not produced a combination or synthesis that would go beyond disciplinary boundaries to produce innovative solutions to policy questions. However, they proposed that transdisciplinary approaches call for a synthesis of research at the stages of conceptualization, design, analysis, and interpretation by using integrated team approaches.

Stokols et al. [24] defined transdisciplinary science as collaboration among scholars representing two or more disciplines in which the collaborative products reflect an integration of conceptual and/or methodological perspectives drawn from two or more fields.

Petts et al. [25] stated, "One of the broadly agreed characteristics of transdisciplinary research is that it is performed with the explicit intent to solve problems that are complex and multidimensional, particularly problems (such as those related to sustainability) that involve an interface of human and natural systems."

During the past decade, other approaches of transdisciplinarity have been developed and described by several researchers and educators. Common phrases in the definitions above include collaboration, shared knowledge, unity of knowledge, distributed knowledge, common knowledge, integration of knowledge, new knowledge generation, integrated disciplines, beyond discipline, complex problems, and societal fields. Although a precise definition of transdisciplinarity is debatable, by reviewing

the above approaches, definitions, and common phrases, the following definitions can be put forward [18]:

> *Transdisciplinarity* is the development of new knowledge, concepts, tools, and technologies shared by researchers from different disciplines (social science, natural science, humanities, and engineering). It is a collaborative process of organized knowledge generation and integration by crossing disciplinary boundaries to design and implement solutions to unstructured problems.
>
> *Transdisciplinary knowledge* is a shared, common, collective knowledge derived from diverse disciplinary knowledge cultures (engineering, natural science, social science, and humanities).
>
> *The transdisciplinary research process* is the collaboration among scholars from diverse disciplines to develop and use integrated conceptual frameworks, tools, techniques, and methodologies to solve common unstructured research problems. Transdisciplinary research creates new paradigms and provides pathways to new frontiers.
>
> The fundamental characteristics of transdisciplinary research are

- Use of shared concepts, frameworks, tools, methodologies, and technologies to solve common unstructured research problems
- Elimination of disciplinary boundaries for strong collaboration
- Redefinition of the boundaries of natural science, social science, humanities, and engineering by building bridges between them
- Development of shared conceptual frameworks, new knowledge, tools, methodologies, and technologies

1.2.3 Multidisciplinary, Interdisciplinary, and Transdisciplinary Case Studies

Wind power promises a clean and inexpensive source of electricity. It promises to reduce our dependence on imported fossil fuels and to reduce the output of greenhouse gases. Many countries are, therefore, promoting the construction of vast "wind farms" and encouraging private companies by providing generous subsidies. The goal of the U.S. Department of Energy (DOE) in 2010 was to produce 5% of the country's electricity by wind turbine farms. The history of wind power shows a general evolution from the use of simple, lightweight devices to heavy, material-intensive drag devices and finally to the increased use of lightweight, material-efficient aerodynamic lift devices in the modern era.

During the winter of 1887–1888, Charles F. Brush built the first automated wind turbine for generating electricity. It was the world's largest wind turbine with a rotor diameter of 17 m (50 ft) and 144 rotor blades made of cedar wood. The turbine ran for 20 years; the batteries, Which were charged in the cellar of Brush's mansion, lasted even longer [26].

Wind has been an important source of energy in the United States for some time. Over 8 million mechanical windmills have been installed in the country since the 1860s. It is interesting to note that some of these units have been in operation for more than a hundred years [27].