

# Machining Fundamentals

11TH EDITION



**Bob Dixon**

Walters State Community College  
Morristown, Tennessee

**John R. Walker**

Bel Air, Maryland

---

Publisher

**The Goodheart-Willcox Company, Inc.**

Tinley Park, IL  
[www.g-w.com](http://www.g-w.com)

Copyright © 2023  
by  
The Goodheart-Willcox Company, Inc.

Previous editions copyright 2019, 2014, 2004, 2000, 1998, 1993, 1989, 1981, 1977, 1973

All rights reserved. No part of this work may be reproduced, stored, or transmitted in any form or by any electronic or mechanical means, including information storage and retrieval systems, without the prior written permission of The Goodheart-Willcox Company, Inc.

Library of Congress Control Number: 2021935984

ISBN 978-1-64925-979-0

1 2 3 4 5 6 7 8 9 – 23 – 26 25 24 23 22 21

**The Goodheart-Willcox Company, Inc. Brand Disclaimer:** Brand names, company names, and illustrations for products and services included in this text are provided for educational purposes only and do not represent or imply endorsement or recommendation by the author or the publisher.

**The Goodheart-Willcox Company, Inc. Safety Notice:** The reader is expressly advised to carefully read, understand, and apply all safety precautions and warnings described in this book or that might also be indicated in undertaking the activities and exercises described herein to minimize risk of personal injury or injury to others. Common sense and good judgment should also be exercised and applied to help avoid all potential hazards. The reader should always refer to the appropriate manufacturer's technical information, directions, and recommendations; then proceed with care to follow specific equipment operating instructions. The reader should understand these notices and cautions are not exhaustive.

The publisher makes no warranty or representation whatsoever, either expressed or implied, including but not limited to equipment, procedures, and applications described or referred to herein, their quality, performance, merchantability, or fitness for a particular purpose. The publisher assumes no responsibility for any changes, errors, or omissions in this book. The publisher specifically disclaims any liability whatsoever, including any direct, indirect, incidental, consequential, special, or exemplary damages resulting, in whole or in part, from the reader's use or reliance upon the information, instructions, procedures, warnings, cautions, applications, or other matter contained in this book. The publisher assumes no responsibility for the activities of the reader.

**The Goodheart-Willcox Company, Inc. Internet Disclaimer:** The Internet resources and listings in this Goodheart-Willcox Publisher product are provided solely as a convenience to you. These resources and listings were reviewed at the time of publication to provide you with accurate, safe, and appropriate information. Goodheart-Willcox Publisher has no control over the referenced websites and, due to the dynamic nature of the Internet, is not responsible or liable for the content, products, or performance of links to other websites or resources. Goodheart-Willcox Publisher makes no representation, either expressed or implied, regarding the content of these websites, and such references do not constitute an endorsement or recommendation of the information or content presented. It is your responsibility to take all protective measures to guard against inappropriate content, viruses, or other destructive elements.

**Image Credit.** Front cover: Dmitry Kalinovsky/Shutterstock.com

# Introduction

Machinists are highly skilled men and women. They use drawings, hand tools, precision measuring tools, drilling machines, grinders, lathes, milling machines, and other specialized machine tools to shape and finish metal and nonmetal parts. Machinists must have a sound understanding of basic and advanced machining technology, which includes:

- Proficiency in safely operating machine tools of various types (manual, automatic, and computer controlled).
- Knowledge of the working properties of metals and nonmetals.
- The academic skills (such as math, science, English, print reading, and metallurgy) needed to make precision layouts and machine setups.

*Machining Fundamentals* provides an introduction to these important areas of manufacturing technology. The text explains the “how, why, and when” of numerous machining operations, setups, and procedures. Through it, you will learn how machine tools operate and when to use one particular machine instead of another. The advantages and disadvantages of various machining techniques are discussed, along with their suitability for particular applications.

*Machining Fundamentals* details the many common methods of machining and shaping parts to meet given specifications. It also covers more advanced processes, such as laser machining, water-jet cutting, high-energy-rate forming (HERF), cryogenics, chipless machining, electrical discharge machining (EDM), electrochemical machining (ECM), robotics, and rapid prototyping. The importance of computer numerical control (CNC) in the operation of most machine tools and its role in automated manufacturing is explored thoroughly. An updated chapter covers the latest geometric dimensioning and tolerancing (GD&T) standards from ASME Y14.5-2018.

*Machining Fundamentals* has many features that make it easy to read and understand. The heads in each chapter are numbered to quickly locate specific information within a chapter. A chapter outline lists all chapter heads and subheads at the beginning of each chapter. Learning objectives are also presented in the chapter opener, along with a list of selected technical terms important to understanding the material in that chapter.

Throughout the text, technical terms are highlighted in bold italic type as they are introduced and defined. These terms are also listed and defined in the *Glossary* at the end of the text.

The extensive illustrations, photographs, and other visuals throughout *Machining Fundamentals* clarify and reinforce machining operations, procedures, and applications. A color key is used to indicate different materials and types of equipment. Features visually highlight and expand textual content by giving it practical value. *Workplace Skills* and *Career Connection* features introduce students to machining-related careers and the qualities employers are seeking. *Green Machining* features expose students to recent trends in environmentally friendly manufacturing.

Each chapter closes with a chapter review containing a summary and review questions. The summary reiterates and expands on the learning objectives given in the chapter opener. Review questions reinforce key learning objectives and offer students the opportunity to check their understanding. New Apply and Analyze and Critical Thinking questions address NIMS Smart Standards and encourage students to think critically about the value and purpose of their new knowledge and apply what they have learned to practical work situations.

*Machining Fundamentals* is a valuable guide to anyone interested in machining since the procedures and techniques presented have been drawn from all areas of machining technology. Students will gain a strong foundation in machining to support practical skills.

# About the Authors

**Bob Dixon** is a Professor and Head of the Engineering Technology Department at Walters State Community College in Morristown, Tennessee. Dr. Dixon holds bachelor's and master's degrees in Engineering Technology from East Tennessee State University, a master's degree in Industrial Engineering from the University of Tennessee, and a doctorate in Educational Leadership from East Tennessee State University. Prior to entering the education field, Dr. Dixon spent over 20 years in industry working in a variety of machining, manufacturing, and engineering positions. He is an ATMAE Certified Senior Technology Manager and recipient of the 2005 ATMAE Outstanding Faculty of Industrial Technology Award for Region 3.

**John R. Walker** is the author of 13 textbooks and has written numerous magazine articles. Mr. Walker completed his undergraduate studies at Millersville University and has a master's degree in Industrial Education from the University of Maryland. He taught industrial arts and vocational education for more than 32 years, including five years as Supervisor of Industrial Education. He also worked as a machinist for the US Air Force and as a draftsman at the US Army Aberdeen Proving Grounds.

# Reviewers

The author and publisher wish to thank the following industry and teaching professionals for their valuable input into the development of *Machining Fundamentals*.

**Terry Anselmo**

Sun Area Technical Institute  
New Berlin, Pennsylvania

**Marte Arreola**

British Columbia Institute of Technology  
Burnaby, British Columbia

**George F. Beauchemin**

Bay Path Regional Vocational High School  
Charlton, Massachusetts

**Paul R. Bois**

Milford High School and Applied Technology Center  
Milford, New Hampshire

**Mark Bosworth**

Southwestern Illinois College  
Granite City, Illinois

**Craig Brazil**

Sheridan College  
Oakville, Ontario

**Michael Buechler**

Santa Ana College  
Santa Ana, California

**Jason S. Carpenter**

Tennessee College of Applied Technology  
Morristown, Tennessee

**Dr. Chesley Chambers**

Floyd County College & Career Academy  
Rome, Georgia

**Donald Dean**

C-TEC  
Newark, Ohio

**Rose M. DeNunzio**

Eastfield College, Dallas County Community College District  
Mesquite, Texas

**Bruce Dirks**

Owatonna High School  
Owatonna, Minnesota

**David L. Eledge**

Metropolitan Community College  
Omaha, Nebraska

**Gottfried Georgi**

William Horlick High School  
Racine, Wisconsin

**John H. Glenn**

Clinton Technical School  
Clinton, Missouri

**Howard Gray**

Sault College  
Sault Ste. Marie, Ontario

**Richard W. Grossen**

Blackhawk Technical College  
Janesville, Wisconsin

**Garth Hansen**

Dixie Applied Technology College  
Saint George, Utah

**Henry Hatem**

Renton Technical College  
Renton, Washington

**Troy Hayes**

TCAT Crossville  
Crossville, Tennessee

**Michael M. Hilber**

Anoka-Hennepin Secondary Technical Education Program  
Anoka, Minnesota

**Jeremy Hodkiewicz**

Shawano High School  
Shawano, Wisconsin

**Roger Holland**

Minnesota State College Southeast  
Winona, Minnesota

**Bruce Jacobs**

Mt. Baker Middle School  
Auburn, Washington

**Bart Jenkins**

Georgia Northwestern Technical College  
Rome, Georgia

**Stephen B. Jenkins**

Parkside High School and Wor-Wic Community College  
Salisbury, Maryland

**Michael Koppy**

Lake Superior College  
Duluth, Minnesota

**David Laton**

Alabama Department of Postsecondary Education  
Montgomery, Alabama

**Danny Lester**

Somerset Community College  
Somerset, Kentucky

**Tom Livingstone**

The Pennsylvania College of Technology  
Williamsport, Pennsylvania

**William J. McCracken, Jr.**

Colorado Mesa University/Western Colorado Community  
College  
Grand Junction, Colorado

**Dale T. Miller**

Lebanon County Career and Technology Center  
Lebanon, Pennsylvania

**Daniel J. Miller**

SUNY Canton  
Canton, New York

**Daniel Morales**

South Texas College  
McAllen, Texas

**Brian D. Nelson**

Dunwoody College of Technology  
Minneapolis, Minnesota

**James Niehaus**

Southern Indiana Career & Technical Center  
Evansville, Indiana

**Shan Packer**

Central Mountain High School  
Mill Hall, Pennsylvania

**Samuel E. Ray**

The Williamson Free School of Mechanical Trades  
Media, Pennsylvania

**Edward S. Schmidt**

Trenton Central High School  
Trenton, New Jersey

**Preet Singh**

Donna High School  
Donna, Texas

**Bruce A. Smith**

Tulsa Technology Center  
Tulsa, Oklahoma

**Marty Snagg**

Heritage High School  
Conyers, Georgia

**Paul Sorenson**

Minnesota State College Southeast  
Winona, Minnesota

**James Standing**

Algonquin College  
Ottawa, Ontario

**Steve Stayton**

Colbert County Schools  
Tuscumbia, Alabama

**Howard Troup**

Pennsylvania College of Technology  
Williamsport, Pennsylvania

**Daniel W. Wagner, P.E.**

HACC, Central Pennsylvania's Community College  
Harrisburg, Pennsylvania

**Roger Wensink**

Lakeshore Technical College  
Cleveland, Wisconsin

**Olaf Wick**

Wisconsin Indianhead Technical College  
New Richmond, Wisconsin

**Dr. John Wren**

Fanshawe College, St. Thomas Campus  
St. Thomas, Ontario

**Dr. John E. Wyatt**

Mississippi State University  
Starkville, Mississippi

**Nicholas Yates**

Patterson High School  
Baltimore, Maryland

**Jim Zeleny**

Confederation College  
Thunder Bay, Ontario

**Andrew V. Zwanch**

Johnson College  
Scranton, Pennsylvania

# Acknowledgments

The author and publisher would like to thank the following companies, organizations, and individuals for their contribution of resource material, images, or other support in the development of *Machining Fundamentals*.

3D Systems  
3M Company  
Alden Corp.  
American Foundrymen's Society  
American Society of Mechanical Engineers  
AMT—The Association for Manufacturing Technology  
Autocon Technologies, Inc.  
Baldor  
Bethlehem Steel Co.  
BIG Kaiser Precision Tooling Inc.  
Bill Hannan  
Bird-Johnson Company  
Bob Walker  
Bridgeport Machines, Inc.  
Buehler, a division of ITW Company  
C. & E. FEIN GmbH  
Carboloy  
Carl Zeiss, Inc.  
Carpenter Steel Co.  
Chicago-Latrobe  
Chick Machine Tool, Inc.  
Cincinnati Milacron  
CITCO Div., Western Atlas, Inc.  
Clausing Industrial, Inc.  
CNC Software, Inc.  
Coated Abrasive Manufacturers Institute  
Cogsdill Tool Products, Inc.  
Composittek Corporation  
Dake Corporation  
Dapra Corporation  
Delcam International  
DoALL Co.  
duMont Corp.  
DuPont Co.  
Engis Corporation  
EZFeatureMILL—Engineering Geometry Systems  
Fanuc Robotics North America, Inc.  
Federal Products Co.  
FEIN Power Tools, Inc.  
Flow International Corp.  
Ford Motor Co.  
Fowler High Precision  
General Dynamics Corp.  
General Motors Corp.  
Giddings & Lewis, Inc.  
Greenfield Industries  
Grizzly Industrial, Inc.  
Haas Automation, Inc.  
Hardinge, Inc.  
Heli-Coil Corp.  
Helisys, Inc.  
Hertel Cutting Technologies, Inc.  
Heule Precision Tools  
Hirata Corporation of America  
Honeywell, Inc., Industrial Automation and Control  
Hougen Manufacturing, Inc.  
Hydromat, Inc.  
IBAG North America  
IBM  
Iscar Metals, Inc.  
Jenoptik  
Jergens, Inc.  
Jet Equipment & Tools  
John Winter  
Jones & Lamson Machine Co.  
Justrite Manufacturing Company  
Kennametal  
KEO Cutters  
Klein Tools, Inc.  
K.O. Lee Co.  
Komet of America, Inc.  
Landis Div. of Western Atlas  
LeBlond Makino Machine Tool Co.  
Library of Congress, Prints & Photograph Division  
Light Beam Technology, Inc.  
Lockwood Products, Inc.  
Lovejoy Tool Company, Inc.  
L. S. Starrett Co.  
Lufkin Rule Co.  
Lumonics Corp.

Mack Molding Co.  
MAG IAS, LLC  
Magnaflux Corp.  
Mahr Federal Inc.  
Makita USA, Inc.  
Manufacturing Technology, Inc.  
Marposs Corp.  
Master Lock Co.  
Maswerks, Inc.  
Mazak  
Metal Powder Industries Federation  
MHI Machine Tool U.S.A., Inc.  
Microphoto, Inc.  
MIFCO McEnglevan Industrial Furnace Co., Inc.  
Millersville University  
Mitsubishi Materials USA Corporation  
Mitutoyo/MTI Corp.  
Morse Tool Co.  
NASA  
National Broach & Machine Co.  
NEYTECH  
Northrop-Grumman Corp.  
Norton Co.  
NSK America  
OSG Tap & Die, Inc.  
O.S. Walker Co.  
PA&E Bonded Metals Division  
Parker-Kalon  
Parlec, Inc.  
Precision Castparts Corp.  
Quality Vision International, Inc.  
Radyne  
Rem Sales, Inc.  
Renishaw, Inc.  
Republic-Lagun Machine Tool Co.  
Revolution Tool Company  
Rofin-Sinar, Inc.

Rohm and Haas  
Royal Products, Division of Curran Manufacturing Corporation  
Rush Machinery, Inc.  
Sandvik Coromant Co.  
Sharnoia Corp.  
Sharp Industries, Inc.  
SpeedFam  
Standard Tool Co.  
Stratasys, Inc.  
Sulzer  
Sunnens Products Company  
Tibor Machine Products  
Tornos-Bechler S.A.  
Tri-Tool, Inc.  
Union Carbide Corp.  
US Air Force  
US Air Force Thunderbirds  
US Amada, Ltd.  
US Army  
US Navy  
US Navy Mass Communication Specialist 2nd Class Andrea Perez  
Valenite, Inc.  
Vermont Machine Tool and the Bryant Grinder Division  
Waldes Kohinoor Inc.  
Webber Gage Div., L. S. Starrett Co.  
Webster Instrument, Inc.  
Weiler Corporation  
Westech Products Group/Gantrex Machine Tool Loaders  
William Schotta, Millersville University  
Willis Machinery and Tools Corp.  
Wilson Instruments/Instron Corporation  
W.J. Savage Co.  
WMW Machinery Company, Inc.  
www.mini-lathe.com  
Yukiwa Seiko USA, Inc.



# New to This Edition

This new edition of *Machining Fundamentals* brings the content up to date with the latest standards and industry practices. End-of-chapter reviews have been improved and expanded with new Apply and Analyze and Critical Thinking questions to allow students to apply the knowledge from the chapter in practical scenarios and contemplate and expand on the importance and usefulness of the knowledge and standard practices. Details of the new elements in this edition include:

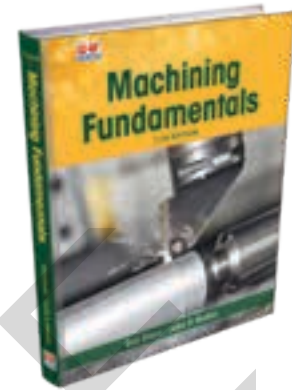
- Alignment with new NIMS Smart Standards (Machining Level 1), rolled out by NIMS in Fall 2021, help prepare students for certification. (See OIR and G-W product page for more information.)
- New photos and updated content reflect industry changes in technology, including basic CNC coding, standard and new machines currently in use, and practical workplace skills and troubleshooting tips, as well as increased diversity and representation in our classrooms and workplaces.
- New end-of-chapter Review Questions offer Know and Understand questions, as well as new Apply and Analyze and Critical Thinking questions to get students to use and reflect on their new knowledge rather than simply regurgitate text from the chapter.
- Updated Geometric Dimensioning and Tolerancing (GD&T) content reflects ASME Y14.5M-2018, so students will be able to properly read and interpret the latest industry drawings and prints.

# TOOLS FOR STUDENT AND INSTRUCTOR SUCCESS

## Student Tools

### Student Text

*Machining Fundamentals* is a comprehensive text that provides an introduction to the various machining operations, setups, and procedures, preparing students for a NIMS Level I Machining certification. This colorful and detailed textbook covers all traditional machining methods, as well as newer and nontraditional methods, including CNC technology, automated manufacturing, additive manufacturing, metal characteristics, and quality control. This edition includes updated coverage of geometric dimensioning and tolerancing; features on careers, workplace skills, and green machining practices; updated illustrations; and new and improved end-of-chapter Review Questions that promote the application of learned knowledge and critical-thinking skills.



### Workbook

The workbook that accompanies *Machining Fundamentals* follows the textbook on a chapter-by-chapter basis and includes instructor-created questions and activities to help students recall, review, and apply concepts introduced in the book.

## Certification

*Machining Fundamentals* reflects NIMS's latest Smart Standards and is correlated to the duties and standards for NIMS Machining Level I to help students achieve certification.

## Instructor Tools

### LMS Integration

Integrate Goodheart-Willcox content within your Learning Management System for a seamless user experience for both you and your students. LMS-ready content in Common Cartridge® format facilitates single sign-on integration and gives you control of student enrollment and data. With a Common Cartridge integration, you can access the LMS features and tools you are accustomed to using and G-W course resources in one convenient location—your LMS.

G-W Common Cartridge provides a complete learning package for you and your students. The included digital resources help your students remain engaged and learn effectively:

- **eBook content.** G-W Common Cartridge includes the textbook content in an online, reflowable format. The eBook is interactive, with highlighting, magnification, note-taking, and text-to-speech features.
- **Workbook.** Students can have access to a digital version of the Workbook.
- **Videos.** Students can access dozens of professional videos that demonstrate important procedures in the text. These videos clarify steps and aid students in visualizing important skills.
- **Activities.** The digital resources include self-graded interactive labeling activities that students can use to improve comprehension and understanding.
- **Drill and Practice.** Learning new vocabulary is critical to student success. These vocabulary activities, which are provided for all key terms in each chapter, provide an active, engaging, and effective way for students to learn the required terminology.

When you incorporate G-W content into your courses via Common Cartridge, you have the flexibility to customize and structure the content to meet the educational needs of your students. You may also choose to add your own content to the course.

For instructors, the Common Cartridge includes the Online Instructor Resources. QTI® question banks are available within the Online Instructor Resources for import into your LMS. These prebuilt assessments help you measure student knowledge and track results in your LMS gradebook. Questions and tests can be customized to meet your assessment needs.



## Online Instructor Resources (OIR)

Online Instructor Resources provide all the support needed to make preparation and classroom instruction easier than ever. Available in one accessible location, the OIR includes Instructor Resources, Instructor's Presentations for PowerPoint®, and Assessment Software with Question Banks. The OIR is available as a subscription and can be accessed at school, at home, or on the go.

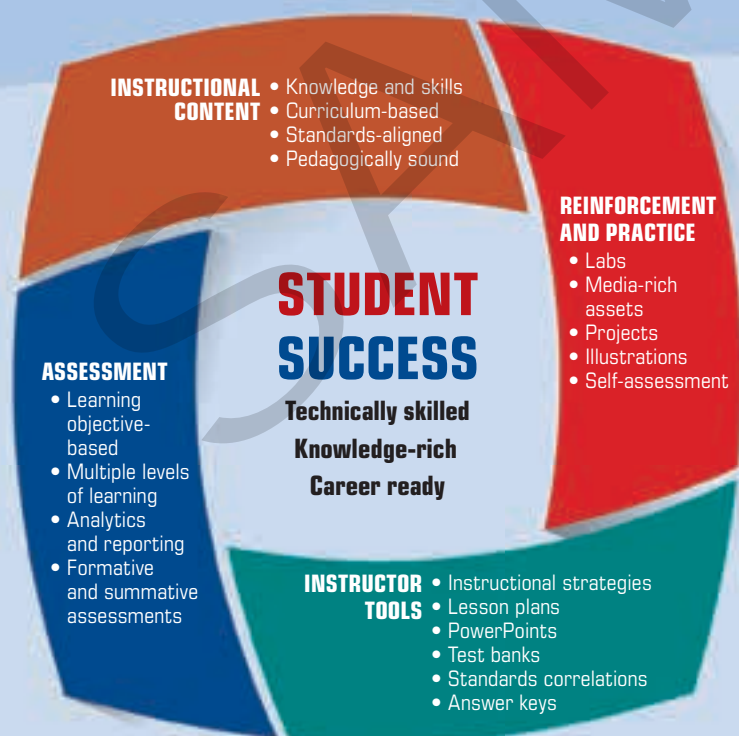
**Instructor Resources** One resource provides instructors with time-saving preparation tools such as answer keys, editable lesson plans, and other teaching aids.

**Instructor's Presentations for PowerPoint®** These fully customizable, richly illustrated slides help you teach and visually reinforce the key concepts from each chapter.

**Assessment Software with Question Banks** Administer and manage assessments to meet your classroom needs. The question banks that accompany this textbook include hundreds of matching, completion, multiple choice, and short answer questions to assess student knowledge of the content in each chapter. Using the assessment software simplifies the process of creating, managing, administering, and grading tests. You can have the software generate a test for you with randomly selected questions. You may also choose specific questions from the question banks and, if you wish, add your own questions to create customized tests to meet your classroom needs.



## G-W Integrated Learning Solution



The G-W Integrated Learning Solution offers easy-to-use resources that help students and instructors achieve success.

- ▶ EXPERT AUTHORS
- ▶ TRUSTED REVIEWERS
- ▶ 100 YEARS OF EXPERIENCE

# Features of the Textbook

The instructional design of this textbook includes student-focused learning tools to help you succeed. This visual guide highlights these features.

## Chapter Opening Materials

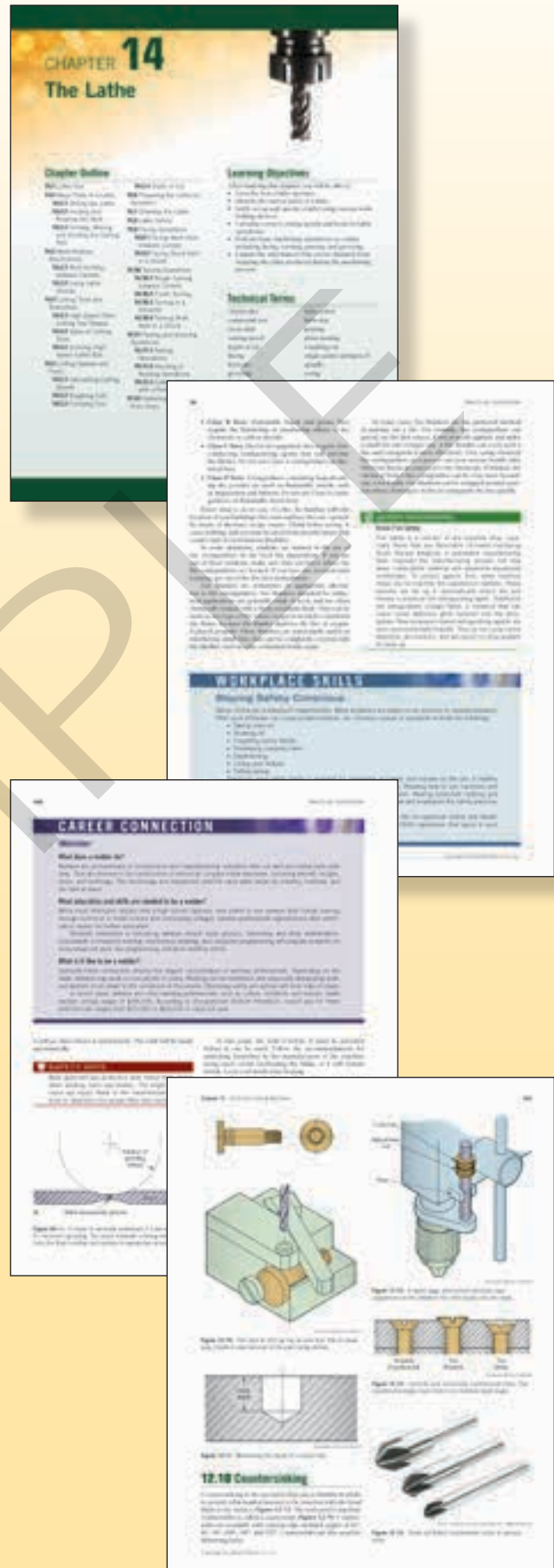
Each chapter opener contains a chapter outline, a list of learning objectives, and a list of technical terms. The **Chapter Outline** summarizes the topics that will be covered in the chapter. **Learning Objectives** clearly identify the knowledge and skills to be gained when the chapter is completed. **Technical Terms** lists the key words to be learned in the chapter.

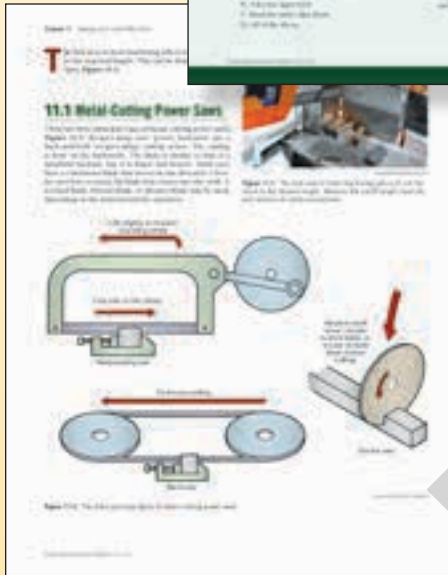
## Additional Features

Additional features are used throughout the body of each chapter to further learning and knowledge. **Safety Notes** alert you to potentially dangerous materials and practices and emphasize important tips. **Workplace Skills** features highlight the professional behaviors and traits that employers want. **Career Connection** features and profiles provide a variety of paths for career success. **Green Machining** features highlight key items related to sustainability, energy efficiency, and environmental issues.

## Illustrations

**Illustrations** have been designed to clearly and simply communicate the specific topic. Illustrations and photographic images have been updated or replaced for this edition to show the latest equipment and practices.
















## End-of-Chapter Content

End-of-chapter material provides an opportunity for review and application of concepts. A concise **Summary** provides an additional review tool and reinforces key learning objectives. This helps you focus on important concepts presented in the text. **Know and Understand** questions enable you to demonstrate knowledge, identification, and comprehension of chapter material. **Apply and Analyze** questions extend learning and develop your abilities to use learned material in new situations and to break down material into its component parts. **Critical Thinking** questions develop higher-order thinking and problem solving, personal, and workplace skills.

## Color Code

A consistent color code is used in the line illustrations throughout *Machining Fundamentals* to help you better visualize the machining operations and procedures. Specific colors are used to indicate different materials and equipment features. The following key shows what each color represents:

|   |  |   |   |
|---|--|---|---|
|  | <b>Metals</b>                                |  | <b>Fasteners</b>  |
|  | <b>Alternate metal</b>                       |  | <b>Abrasives</b>  |
|  | <b>Machines/machine parts</b>                |  | <b>Fluids</b>   |
|  | <b>Tools</b>                                 |  | <b>Miscellaneous</b>                                      |
|  | <b>Cutting edges</b>                         |  | <b>Direction or force arrows, dimensional information</b> |
|  | <b>Work-holding and tool-holding devices</b> |   |   |

# Brief Contents

|           |   |     |           |   |     |
|-----------|---|-----|-----------|---|-----|
| <b>1</b>  | An Introduction to Machining Technology . . . . .       | 1   | <b>18</b> | Milling Machine Operations . . . . .            | 323 |
| <b>2</b>  | Careers in Machining Technology. . .                    | 14  | <b>19</b> | Precision Grinding. . . . .                     | 355 |
| <b>3</b>  | Shop Safety . . . . .                                   | 29  | <b>20</b> | Band Machining and Broaching . .                | 381 |
| <b>4</b>  | Understanding Drawings. . . . .                         | 41  | <b>21</b> | Introduction to CNC Machining. . .              | 400 |
| <b>5</b>  | Measurement . . . . .                                   | 57  | <b>22</b> | CNC Programming Basics. . . . .                 | 414 |
| <b>6</b>  | Layout Work . . . . .                                   | 84  | <b>23</b> | CNC Milling . . . . .                           | 429 |
| <b>7</b>  | Hand Tools . . . . .                                    | 96  | <b>24</b> | CNC Turning . . . . .                           | 442 |
| <b>8</b>  | Fasteners . . . . .                                     | 133 | <b>25</b> | Automated Manufacturing . . . . .               | 453 |
| <b>9</b>  | Jigs and Fixtures . . . . .                             | 149 | <b>26</b> | Quality Control . . . . .                       | 467 |
| <b>10</b> | Cutting Fluids . . . . .                                | 156 | <b>27</b> | Geometric Dimensioning and Tolerancing. . . . . | 483 |
| <b>11</b> | Sawing and Cutoff Machines. . . . .                     | 162 | <b>28</b> | Metal Characteristics . . . . .                 | 497 |
| <b>12</b> | Drills and Drilling Machines . . . . .                  | 173 | <b>29</b> | Heat Treatment of Metals . . . . .              | 513 |
| <b>13</b> | Offhand Grinding. . . . .                               | 206 | <b>30</b> | Metal Finishing . . . . .                       | 532 |
| <b>14</b> | The Lathe . . . . .                                     | 215 | <b>31</b> | Electromachining Processes . . . . .            | 546 |
| <b>15</b> | Other Lathe Operations . . . . .                        | 253 | <b>32</b> | Nontraditional Machining Techniques . . . . .   | 554 |
| <b>16</b> | Cutting Tapers and Screw Threads on the Lathe . . . . . | 272 | <b>33</b> | Other Processes. . . . .                        | 566 |
| <b>17</b> | The Milling Machine . . . . .                           | 294 |           |   |     |

# Contents

## Chapter 1 An Introduction to Machining Technology . . . . . 1

- 1.1 The Evolution of Machine Tools . . . . . 2
- 1.2 Basic Machine Tool Operation . . . . . 5
- 1.3 Nontraditional Machining Processes . . . . . 7
- 1.4 Automating the Machining Process . . . . . 8
- 1.5 The Evolving Role of the Machinist . . . . . 10
- 1.6 Acquiring Machining Skills and Knowledge . . . . . 11

## Chapter 2 Careers in Machining Technology . . 14

- 2.1 Machining Job Categories . . . . . 15
- 2.2 Preparing to Find a Job in Machining  
Technology . . . . . 22
- 2.3 How to Get and Keep a Job . . . . . 23
- 2.4 Keeping Your Skills Current . . . . . 26

## Chapter 3 Shop Safety . . . . . 29

- 3.1 Safety in the Shop . . . . . 30
- 3.2 General Machine Safety . . . . . 33
- 3.3 General Tool Safety . . . . . 34
- 3.4 Fire Safety . . . . . 34
- 3.5 Safety Data Sheets . . . . . 37

## Chapter 4 Understanding Drawings . . . . . 41

- 4.1 Dimensions . . . . . 45
- 4.2 Information Included on Drawings . . . . . 47
- 4.3 Prints . . . . . 51
- 4.4 Types of Drawings Used in the Shop . . . . . 51
- 4.5 Parts List . . . . . 51
- 4.6 Drawing Sizes . . . . . 54

## Chapter 5 Measurement . . . . . 57

- 5.1 The Rule . . . . . 58
- 5.2 The Micrometer Caliper . . . . . 60
- 5.3 Vernier Measuring Tools . . . . . 65
- 5.4 Gages . . . . . 69
- 5.5 Dial Indicators . . . . . 76
- 5.6 Helper Measuring Tools . . . . . 77

## Chapter 6 Layout Work . . . . . 84

- 6.1 Layout Tools . . . . . 85
- 6.2 Layout Steps . . . . . 92

## Chapter 7 Hand Tools . . . . . 96

- 7.1 Clamping Devices . . . . . 97
- 7.2 Pliers . . . . . 98
- 7.3 Wrenches . . . . . 100
- 7.4 Screwdrivers . . . . . 104
- 7.5 Striking Tools . . . . . 106
- 7.6 Chisels . . . . . 107
- 7.7 Hacksaw . . . . . 108
- 7.8 Files . . . . . 113
- 7.9 Reamers . . . . . 117
- 7.10 Hand Threading . . . . . 119
- 7.11 Hand Polishing . . . . . 127
- 7.12 Broaching Operations . . . . . 128

## Chapter 8 Fasteners . . . . . 133

- 8.1 Threaded Fasteners . . . . . 134
- 8.2 Nonthreaded Fastening Devices . . . . . 143
- 8.3 Adhesives . . . . . 145

Chapter **9**  
**Jigs and Fixtures . . . . . 149**

- 9.1** Jigs . . . . . 150
- 9.2** Fixtures . . . . . 151
- 9.3** Jig and Fixture Construction . . . . . 152

Chapter **10**  
**Cutting Fluids . . . . . 156**

- 10.1** Types of Cutting Fluids . . . . . 157
- 10.2** Application of Cutting Fluids . . . . . 159
- 10.3** Choosing a Cutting Fluid . . . . . 159
- 10.4** Cutting Fluid Safety . . . . . 160

Chapter **11**  
**Sawing and Cutoff Machines. . . . 162**

- 11.1** Metal-Cutting Power Saws . . . . . 163
- 11.2** Power Hacksaw . . . . . 164
- 11.3** Power Band Saw . . . . . 165
- 11.4** Troubleshooting Power Hacksaws and Band Saws . . . . . 168
- 11.5** Metal-Cutting Circular Saws . . . . . 169
- 11.6** Power Saw Safety . . . . . 170

Chapter **12**  
**Drills and Drilling Machines . . . . 173**

- 12.1** Drilling Machines . . . . . 174
- 12.2** Drill Press Safety . . . . . 177
- 12.3** Drills . . . . . 177
- 12.4** Drill-Holding Devices . . . . . 182
- 12.5** Work-Holding Devices . . . . . 184
- 12.6** Cutting Speeds and Feeds . . . . . 188
- 12.7** Cutting Fluids . . . . . 189
- 12.8** Sharpening Drills . . . . . 189
- 12.9** Drilling . . . . . 193
- 12.10** Countersinking . . . . . 197
- 12.11** Counterboring . . . . . 198
- 12.12** Spotfacing . . . . . 199
- 12.13** Tapping . . . . . 200

- 12.14** Reaming . . . . . 201
- 12.15** Microdrilling . . . . . 203

Chapter **13**  
**Offhand Grinding . . . . . 206**

- 13.1** Bench and Pedestal Grinders . . . . . 207
- 13.2** Other Types of Grinders . . . . . 208
- 13.3** Grinding Wheels . . . . . 208
- 13.4** Abrasive Belt and Wheel Grinder Safety . . . . 211
- 13.5** Using a Dry Grinder . . . . . 211
- 13.6** Using a Wet Grinder . . . . . 212

Chapter **14**  
**The Lathe . . . . . 215**

- 14.1** Lathe Size . . . . . 216
- 14.2** Major Parts of a Lathe . . . . . 216
- 14.3** Work-Holding Attachments . . . . . 221
- 14.4** Cutting Tools and Toolholders . . . . . 230
- 14.5** Cutting Speeds and Feeds . . . . . 237
- 14.6** Preparing the Lathe for Operation . . . . . 240
- 14.7** Cleaning the Lathe . . . . . 241
- 14.8** Lathe Safety . . . . . 241
- 14.9** Facing Operations . . . . . 242
- 14.10** Turning Operations . . . . . 243
- 14.11** Parting and Grooving Operations . . . . . 247
- 14.12** Gathering Information from Chips . . . . . 249

Chapter **15**  
**Other Lathe Operations . . . . . 253**

- 15.1** Boring on a Lathe . . . . . 254
- 15.2** Drilling on a Lathe . . . . . 255
- 15.3** Reaming on a Lathe . . . . . 256
- 15.4** Knurling on a Lathe . . . . . 257
- 15.5** Filing and Polishing on a Lathe . . . . . 259
- 15.6** Using Steady and Follower Rests . . . . . 260
- 15.7** Using Mandrels . . . . . 262
- 15.8** Grinding on the Lathe . . . . . 263
- 15.9** Other Lathe Attachments . . . . . 265
- 15.10** Industrial Applications of the Lathe . . . . . 266



Chapter **16**  
**Cutting Tapers and Screw Threads  
on the Lathe . . . . . 272**

- 16.1** Turning Tapers . . . . . 273
- 16.2** Measuring Tapers . . . . . 279
- 16.3** Cutting Screw Threads on the Lathe . . . . . 281

Chapter **17**  
**The Milling Machine . . . . . 294**

- 17.1** Types of Milling Machines . . . . . 295
- 17.2** Milling Operations . . . . . 300
- 17.3** Milling Cutter Basics . . . . . 301
- 17.4** Types and Uses of Milling Cutters . . . . . 302
- 17.5** Holding and Driving Cutters . . . . . 310
- 17.6** Milling Cutting Speeds and Feeds . . . . . 313
- 17.7** Cutting Fluids . . . . . 314
- 17.8** Milling Work-Holding Attachments . . . . . 315
- 17.9** Milling Safety Practices . . . . . 319

Chapter **18**  
**Milling Machine Operations . . . . 323**

- 18.1** Vertical Milling Machine . . . . . 324
- 18.2** Vertical Milling Machine Operations . . . . . 324
- 18.3** Horizontal Milling Machine Operations . . . . . 331
- 18.4** Milling Machine Care . . . . . 341
- 18.5** Cutting a Spur Gear . . . . . 342
- 18.6** Cutting a Bevel Gear . . . . . 346
- 18.7** Thread Milling . . . . . 349
- 18.8** Milling Machine Safety . . . . . 350
- 18.9** Industrial Applications . . . . . 351
- 18.10** High-Velocity Machining . . . . . 351

Chapter **19**  
**Precision Grinding . . . . . 355**

- 19.1** Types of Surface Grinders . . . . . 356
- 19.2** Work-Holding Devices . . . . . 357
- 19.3** Grinding Wheels . . . . . 358
- 19.4** Cutting Fluids . . . . . 362
- 19.5** Grinding Applications . . . . . 363
- 19.6** Grinding Problems . . . . . 365

- 19.7** Grinding Safety . . . . . 367
- 19.8** Universal Tool and Cutter Grinder . . . . . 367
- 19.9** Sharpening Cutters . . . . . 367
- 19.10** Cylindrical Grinding . . . . . 372
- 19.11** Internal Grinding . . . . . 374
- 19.12** Centerless Grinding . . . . . 375
- 19.13** Form Grinding . . . . . 376
- 19.14** Other Grinding Techniques . . . . . 376

Chapter **20**  
**Band Machining and Broaching . . 381**

- 20.1** Band Machining Advantages . . . . . 382
- 20.2** Band Blade Selection . . . . . 383
- 20.3** Welding Blades . . . . . 385
- 20.4** Band Machine Preparation . . . . . 387
- 20.5** Band Machining Operations . . . . . 389
- 20.6** Band Machine Power Feed . . . . . 390
- 20.7** Other Band Machining Applications . . . . . 391
- 20.8** Troubleshooting Band Machines . . . . . 393
- 20.9** Band Machining Safety . . . . . 393
- 20.10** Broaches and Broaching Machines . . . . . 393
- 20.11** Advantages of Broaching . . . . . 396

Chapter **21**  
**Introduction to CNC Machining . . 400**

- 21.1** History of CNC . . . . . 401
- 21.2** Advantages and Disadvantages of Using CNC . . 401
- 21.3** CNC Milling Machines . . . . . 402
- 21.4** CNC Turning Machines . . . . . 404
- 21.5** CNC Safety . . . . . 407
- 21.6** CNC Coordinate Systems . . . . . 408
- 21.7** CNC Movement Systems . . . . . 409

Chapter **22**  
**CNC Programming Basics . . . . . 414**

- 22.1** Developing CNC Programs . . . . . 415
- 22.2** Programming Methods . . . . . 416
- 22.3** CAD and CAM Software . . . . . 418
- 22.4** CNC Programming Codes . . . . . 420
- 22.5** CNC Modal Commands . . . . . 422

Chapter **23**  
**CNC Milling . . . . . 429**

- 23.1** Miscellaneous Function Codes . . . . . 430
- 23.2** Work-Holding Devices . . . . . 431
- 23.3** Planning the Program . . . . . 432
- 23.4** Initial Programming and Preparing the Machine . . . . . 434
- 23.5** Programming the Machining Operations . . . . . 436

Chapter **24**  
**CNC Turning . . . . . 442**

- 24.1** Work-Holding Devices for CNC Turning Centers . . . . . 443
- 24.2** Planning for a CNC Turning Program . . . . . 444
- 24.3** Initial Programming . . . . . 446
- 24.4** Programming the Machine Operations . . . . . 446

Chapter **25**  
**Automated Manufacturing . . . . . 453**

- 25.1** Flexible Manufacturing Systems . . . . . 454
- 25.2** Robotics . . . . . 457
- 25.3** Safety in Automated Manufacturing . . . . . 459
- 25.4** Rapid Prototyping Techniques . . . . . 461
- 25.5** The Future of Automated Manufacturing . . . . . 464

Chapter **26**  
**Quality Control . . . . . 467**

- 26.1** The History of Quality Control . . . . . 468
- 26.2** Types of Quality Control . . . . . 469
- 26.3** Nondestructive Testing Techniques . . . . . 469
- 26.4** Other Quality Control Techniques . . . . . 479
- 26.5** Calibration and Traceability . . . . . 479

Chapter **27**  
**Geometric Dimensioning and Tolerancing . . . . . 483**

- 27.1** Definitions . . . . . 484
- 27.2** Application of Geometric Dimensioning and Tolerancing . . . . . 486
- 27.3** Form Tolerances . . . . . 488
- 27.4** Profile Tolerances . . . . . 489
- 27.5** Orientation Tolerances . . . . . 489

- 27.6** Location Tolerances . . . . . 490
- 27.7** Runout Tolerances . . . . . 493
- 27.8** Bonus Tolerancing . . . . . 493

Chapter **28**  
**Metal Characteristics . . . . . 497**

- 28.1** Classifying Metals . . . . . 498
- 28.2** Ferrous Metals . . . . . 498
- 28.3** Nonferrous Metals . . . . . 505
- 28.4** High-Temperature Metals . . . . . 508
- 28.5** Rare Metals . . . . . 509
- 28.6** Other Materials . . . . . 509

Chapter **29**  
**Heat Treatment of Metals . . . . . 513**

- 29.1** Heat-Treatable Metals . . . . . 514
- 29.2** Heat Treatment of Steel . . . . . 514
- 29.3** Heat Treatment of Other Metals . . . . . 517
- 29.4** Equipment for Heat Treatment . . . . . 517
- 29.5** Hardening Carbon Steel . . . . . 519
- 29.6** Tempering Carbon Steel . . . . . 521
- 29.7** Case Hardening Low-Carbon Steel . . . . . 521
- 29.8** Hardness Testing . . . . . 523
- 29.9** Heat Treatment Safety . . . . . 529

Chapter **30**  
**Metal Finishing . . . . . 532**

- 30.1** Quality of Machined Surfaces . . . . . 533
- 30.2** Other Metal Finishing Techniques . . . . . 536

Chapter **31**  
**Electromachining Processes . . . . . 546**

- 31.1** Electrical Discharge Machining (EDM) . . . . . 547
- 31.2** Electrical Discharge Wire Cutting (EDWC) . . . . . 549
- 31.3** Small-Hole EDM Drilling . . . . . 550
- 31.4** Electrochemical Machining (ECM) . . . . . 551

Chapter **32**  
**Nontraditional Machining Techniques . . . . . 554**

- 32.1** Chemical Machining . . . . . 555
- 32.2** Hydrodynamic Machining (HDM) . . . . . 557

|             |   |     |
|-------------|---|-----|
| <b>32.3</b> | Waterjet Abrasive Milling . . . . .     | 558 |
| <b>32.4</b> | Ultrasonic Machining . . . . .          | 559 |
| <b>32.5</b> | Electron Beam Machining (EBM) . . . . . | 561 |
| <b>32.6</b> | Laser Beam Machining . . . . .          | 562 |

Chapter **33**

**Other Processes. . . . . 566**

|             |                              |     |
|-------------|------------------------------|-----|
| <b>33.1</b> | Machining Plastics . . . . . | 567 |
| <b>33.2</b> | Machining Ceramics . . . . . | 572 |
| <b>33.3</b> | Chipless Machining. . . . .  | 573 |

|             |   |     |
|-------------|---|-----|
| <b>33.4</b> | Powder Metallurgy . . . . .               | 576 |
| <b>33.5</b> | High-Energy-Rate Forming (HERF) . . . . . | 578 |
| <b>33.6</b> | Cryogenics. . . . .                       | 581 |

**Appendix A: Math Review . . . . . 586**

**Appendix B: Reference Section . . . . . 609**

**Glossary . . . . . 644**

**Index . . . . . 656**

SAMPLE

# Feature Contents

## WORKPLACE SKILLS

|  |     |   |     |
|--|-----|---|-----|
| Joining Organizations .....                | 9   | Teamwork .....                            | 281 |
| Investigating Education and Training ..... | 20  | Decision Making and Problem Solving ..... | 408 |
| Staying Safety Conscious.....              | 36  | Professional Behavior.....                | 433 |
| Applying for a Job.....                    | 94  | Lifelong Learning.....                    | 450 |
| Preparing for a Job Interview.....         | 153 | Computer Ethics.....                      | 457 |
| Evaluating Job Offers .....                | 158 | Respecting Diversity .....                | 484 |
| Being an Efficient Employee .....          | 211 | Discrimination in the Workplace.....      | 541 |
| Attitude on the Job .....                  | 221 | Entrepreneurship .....                    | 547 |
| Creativity and Brainstorming.....          | 267 |   |     |

## CAREER CONNECTION

|                                     |     |                                 |     |
|-------------------------------------|-----|---------------------------------|-----|
| CAD Technician .....                | 44  | Aerospace Engineer .....        | 366 |
| Civil Engineer.....                 | 75  | Welder.....                     | 386 |
| Assembler/Fabricator .....          | 111 | CNC Programmer/Technician.....  | 421 |
| Ironworker.....                     | 136 | Quality Control Inspector ..... | 473 |
| High School CTE Teacher .....       | 170 | Metallurgist.....               | 501 |
| Industrial Production Manager ..... | 198 | Foundry Worker .....            | 523 |
| Industrial Machinery Mechanic ..... | 305 | Mechanical Engineer.....        | 560 |
| Machinist .....                     | 348 | Biomedical Engineer.....        | 572 |

## GREEN MACHINING

|  |     |   |     |
|--|-----|---|-----|
| Renewable and Nonrenewable Resources .....                 | 4   | Recycling Cutting Tools .....                                 | 290 |
| Green Manufacturing.....                                   | 18  | Cleaning Machined Parts.....                                  | 298 |
| Green Fire Safety .....                                    | 36  | Proactive Maintenance .....                                   | 393 |
| Electronic Drawings and CAD .....                          | 51  | Efficiency in CNC Machining .....                             | 410 |
| Recycling Steel.....                                       | 103 | Government Programs as Green Catalysts.....                   | 418 |
| Environmentally Friendly Adhesives .....                   | 146 | Leadership in Energy and Environmental Design<br>(LEED) ..... | 458 |
| Health and Environmental Impacts of Cutting<br>Fluids..... | 157 | Recycling Aluminum .....                                      | 506 |
| Recycling Tungsten Carbide Drills.....                     | 177 | Metal Finishes.....   | 533 |
| Reducing Chips .....                                       | 261 | Powder Metallurgy .....                                       | 576 |