Preface

Welcome to the first edition of *Residential Wiring Concepts and Applications*. This textbook was created to provide a comprehensive overview of the tools, materials, and the *National Electrical Code (NEC)* rules and requirements pertaining to residential wiring. Designed for students new to the study of electricity and those with practical experience, *Residential Wiring Concepts and Applications* provides a firm foundation for the study of residential wiring.

The text is divided into two parts. Part 1 covers basic skills and knowledge, while Part 2 covers hands-on installation and house wiring. The chapters are in an order that fosters learning as each chapter builds upon those that came before. Beginning with the essential tools and materials used in residential wiring and continuing with chapters devoted to the *National Electrical Code* rules for electrical installations, *Residential Wiring Concepts and Applications* contains chapters covering print reading, residential framing, and service calculations. Also included are chapters covering essential material such as retrofitting, service and repair, and charging circuits for electric automobiles.

Residential Wiring Concepts and Applications contains numerous photographs and illustrations to help students understand the ideas described. In addition, step-by-step examples of the most common calculations required by the *NEC* are also included. This text also provides the contextual background information needed to explain the "why" behind the *NEC* rules. Written for the 2023 edition of the *National Electrical Code* cycle, this textbook contains the most up-to-date information on electrical installations.

The job outlook for residential wiring technicians is strong and growing. Anyone who wishes to make a career in the field of residential wiring can find employment in this field. Upon mastery of the material contained herein, the student will have the knowledge to design, install, and troubleshoot electrical systems in homes of any size.

About the Author

Quinton B. Phillips is currently the Program Chair of Electrical Systems Technology and an instructor at Athens Technical College. In 2018, he was selected by faculty and students to receive the Athens Technical College Rick Perkins Award, honoring a technical college instructor who makes significant contributions to technical education through innovation and leadership. After graduating from the University of Georgia's Grady College of Journalism in 1988, Mr. Phillips spent time working in the service industry. Looking for a career path and a solid wage, he enrolled in the Electrical Program at Athens Technical College, and it changed the course of his life. Mr. Phillips worked for several years as an apprentice before starting his own company, ZAP! Electric.

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Contributors

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US Department of Energy
Werner Co.

The *National Electrical Code*®

The most informative and authoritative body of information concerning electrical wiring installation in the United States, and perhaps the world, is the *National Electrical Code*® (*NEC*). This code establishes a set of rules, regulations, and criteria for the installation of electrical equipment. Compliance with these methods will result in a safe installation.

The *NEC* is drafted by a team of experts assembled for this purpose by the National Fire Protection Association (NFPA). This team is formally called the *National Electrical Code* committee. They revise and update the *NEC* every three years. It is imperative that anyone installing electrical wiring obtains and studies the *NEC*. Articles and sections of the *NEC* are referred to throughout this text. Although certain portions, tables, and examples are directly quoted from its text, there is enough useful information in the *NEC* that not having it available would be a tremendous hindrance.

The latest edition of the *National Electrical Code* can be purchased from the National Fire Protection Association by visiting their website. Online access to the *National Electrical Code* and over 1,400 NFPA codes and standards is available with an NFPA LiNK® subscription. NFPA LiNK includes all current editions as well as a library of legacy codes and standards going back five editions. Subscribers also have early access to newly released editions before the printed book is available for purchase. To learn more about NFPA LiNK, visit the NFPA website at www.nfpa.org.

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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

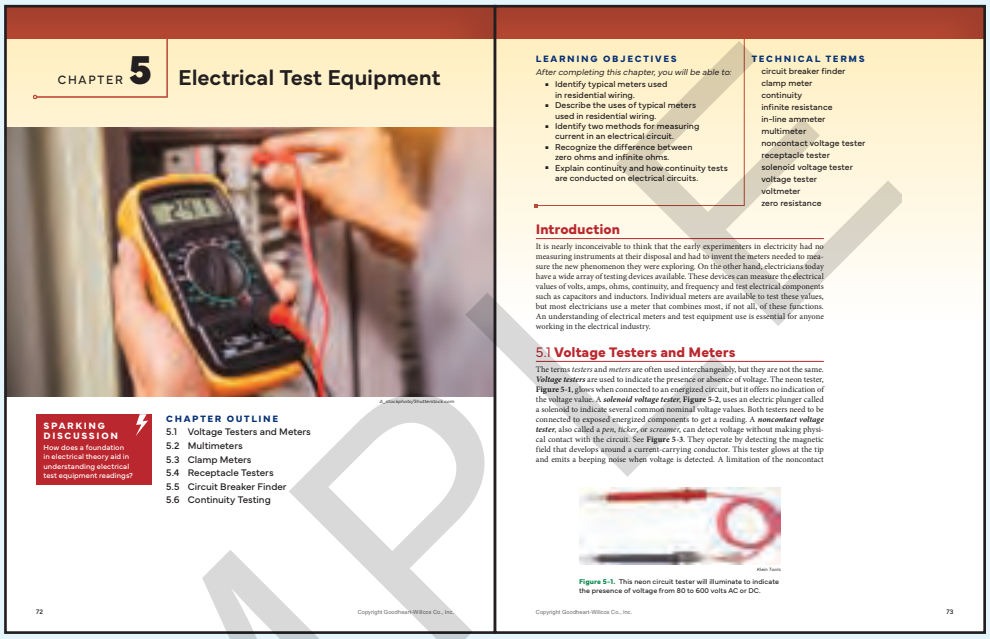
Each chapter opener contains a chapter outline, a list of learning objectives, and a list of technical terms.

The **Chapter Outline** lists 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 list the key words to be learned in the chapter.

The **Introduction** provides an overview and preview of the chapter content.



CHAPTER 5 Electrical Test Equipment

SPARKING DISCUSSION
How does a foundation in electrical theory aid in understanding electrical test equipment readings?

CHAPTER OUTLINE
5.1 Voltage Testers and Meters
5.2 Multimeters
5.3 Clamp Meters
5.4 Receptacle Testers
5.5 Circuit Breaker Finder
5.6 Continuity Testing

LEARNING OBJECTIVES
After completing this chapter, you will be able to:
- Identify typical meters used in residential wiring.
- Describe the uses of typical meters used in residential wiring.
- Identify two methods for measuring current in an electrical circuit.
- Recognize the difference between zero ohms and infinite ohms.
- Explain continuity and how continuity tests are conducted on electrical circuits.

TECHNICAL TERMS
circuit breaker finder
clamp meter
continuity
infinite resistance
in-line ammeter
multimeter
noncontact voltage tester
receptacle tester
solenoid voltage tester
voltage tester
voltmeter
zero resistance

Introduction

It is nearly inconceivable to think that the early experimenters in electricity had no measuring instruments at their disposal and had to invent the meters needed to measure the new phenomenon they were exploring. On the other hand, electricians today have a wide array of testing devices available. These devices can measure the electrical values of volts, amps, ohms, continuity, and frequency and test electrical components such as capacitors and inductors. Individual meters are available to test these values, but most electricians use a meter that combines most, if not all, of these functions. An understanding of electrical meters and test equipment use is essential for anyone working in the electrical industry.

5.1 Voltage Testers and Meters

The terms *testers* and *meters* are often used interchangeably, but they are not the same. *Voltage testers* are used to indicate the presence or absence of voltage. The neon tester, **Figure 5-1**, glows when connected to an energized circuit, but it offers no indication of the voltage value. A ***solenoid voltage tester*, Figure 5-2**, uses an electric plunger called a solenoid to indicate several common nominal voltage values. Both testers need to be connected to exposed energized components to get a reading. A ***noncontact voltage tester***, also called a *pen*, *ticker*, or *screamer*, can detect voltage without making physical contact with the circuit. See **Figure 5-3**. They operate by detecting the magnetic field that develops around a current-carrying conductor. This tester glows at the tip and emits a beeping noise when voltage is detected. A limitation of the noncontact

Figure 5-1. This neon circuit tester will illuminate to indicate the presence of voltage from 80 to 600 volts AC or DC.

Additional Features

Additional features are used throughout the body of each chapter to further learning and knowledge.

Pro Tips provide advice and guidance that is especially applicable for on-the-job situations.

Safety Notes alert you to potentially dangerous materials and practices.

Code Applications provide opportunities to apply understanding of the *National Electric Code* to different scenarios.

Procedures provide clear instructions for hands-on activities.



Part 2 House Wiring

Some bathroom sinks have a lower countertop at 32". In this case, make sure any device box is mounted no lower than 38" to the bottom or 42" to the top. It is best practice to check with the carpenter or kitchen and bath designer to confirm counter heights and if tile or a backsplash will be installed.

When installing tile, use boxes that are still adjustable after the drywall and tile are installed. This type of box is also useful near wood surfaces or other combustible materials.

22.1.1 Nail-on Box Installation

Non-metallic nail-on boxes have ***stand-off ridges*** that position the box forward from the framing stud to which it is nailed, **Figure 22-2**. This stand-off permits the sheetrock or other wall finish to be flush with the front edge of the box. Device boxes should never be installed with the front edge of the box flush with the stud. The stand-off is 1/2", the depth of the typical drywall used in dwelling units. It should be noted drywall is also available in 3/8" and 5/8" thicknesses.

PRO TIP Sizing Boxes

For single-gang boxes, it is good practice to install a larger box than what is required. The cost difference in box sizes is minimal, and the larger box eases installation and speed of trimming boxes. Larger and deeper devices can cause problems. It is convenient to have the extra space a deeper box offers. Two-gang, three-gang, and four-gang boxes generally do not have issues with device installation.

Section 314.20 allows the front edge of the box to be recessed no more than 1/4" from the finished surface if the wall finish is of noncombustible material such as tile, gypsum, or plaster. When tile is installed on drywall, the box would likely be recessed more than 1/4" and would require the addition of a ***box extender***, or an adjustable box allowing the box's front edge to be within the required 1/4", **Figure 22-3**. When installing a box extender, it must be compatible with the box being extended. One manufacturer's box extender may not fit with another brand.

After the drywall taping and mudding is completed, it is not uncommon to have gaps or spacing greater than 1/8" by the edge of the box. An electrician must consider repairing noncombustible surfaces that surround incomplete or broken boxes per *Section 314.21*. A smaller gap will ensure the receptacle or switch faceplate will cover the entire opening,

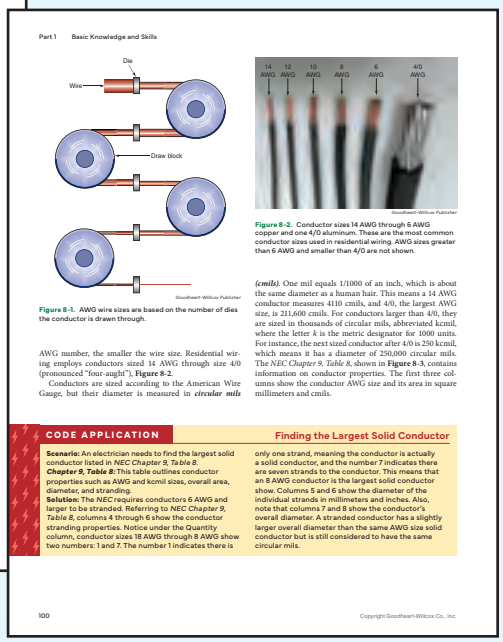
Figure 22-2. A non-metallic nail-on box with a stand-off ridge for framing.

Figure 22-3. Box extender.

and if installed flush with the drywall, the ears of the receptacle will rest snugly against the box. If the wall surface is wood or other combustible material, the box edge shall extend to or project past the finished surface.

SAFETY NOTE Flush-Mounted Boxes

Under no circumstances is the box, box extender, or a mud ring allowed to be recessed from the combustible surface. A flush-mounted box reduces the likelihood of a shorted-out receptacle igniting a fire on the combustible material.



Part 1 Basic Knowledge and Skills

Figure 8-1. AWG wire sizes are based on the number of dies the conductor is drawn through.

Figure 8-2. Conductor sizes 14 AWG through 6 AWG copper and one 4/0 aluminum. These are the most common conductor sizes used in residential wiring. AWG sizes greater than 6 AWG and smaller than 4/0 are not shown.

AWG number, the smaller the wire size. Residential wiring employs conductors sized 14 AWG through size 4/0 (pronounced "four-aught"), **Figure 8-2**.

Conductors are sized according to the American Wire Gauge, but their diameter is measured in ***circular mils*** ***(cmils)***. One mil equals 1/1000 of an inch, which is about the same diameter as a human hair. This means a 14 AWG conductor measures 4110 cmils, and 4/0, the largest AWG size, is 211,600 cmils. For conductors larger than 4/0, they are sized in thousands of circular mils, abbreviated kcmil, where the letter *k* is the metric designator for 1000 units. For instance, the next sized conductor after 4/0 is 250 kcmil, which means it has a diameter of 250,000 circular mils. The *NEC Chapter 9, Table 8*, shown in **Figure 8-3**, contains information on conductor properties. The first three columns show the conductor AWG size and its area in square millimeters and cmils.

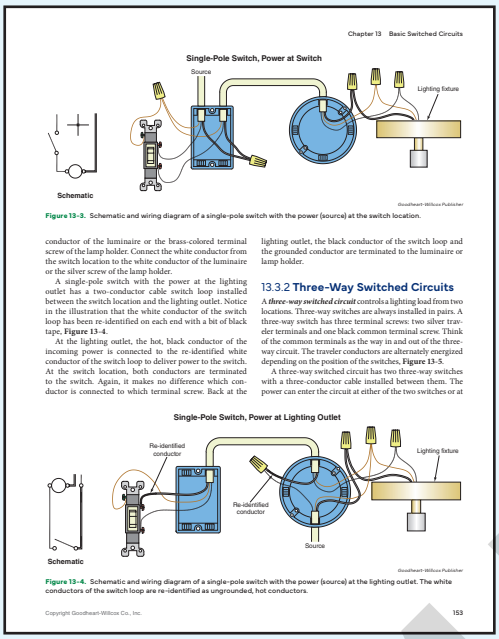
CODE APPLICATION Finding the Largest Solid Conductor

Scenario: An electrician needs to find the largest solid conductor listed in *NEC Chapter 9, Table 8*.
Chapter 9, Table 8: This table outlines conductor properties such as AWG and kcmil sizes, overall area, diameter, and stranding.
Solution: The *NEC* requires conductors 6 AWG and larger to be stranded. Referring to *NEC Chapter 9, Table 8*, columns 4 through 6 show the conductor stranding properties. Notice under the Quantity column, conductor sizes 18 AWG through 8 AWG show two numbers: 1 and 7. The number 1 indicates there is only one strand, meaning the conductor is actually a solid conductor, and the number 7 indicates there are seven strands to the conductor. This means that an 8 AWG conductor is the largest solid conductor show. Columns 5 and 6 show the diameter of the individual strands in millimeters and inches. Also, note that columns 7 and 8 show the conductor's overall diameter. A stranded conductor has a slightly larger overall diameter than the same AWG size solid conductor but is still considered to have the same circular mils.

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Illustrations and Photos

Illustrations have been designed to clearly and simply communicate the specific topic. Photographic images provided show the latest equipment. *NEC Tables* reflect changes made to the 2023 edition.



Chapter 13 Basic Switched Circuits

Single-Pole Switch, Power at Switch

Source

Lighting fixture

Schematic

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Figure 13-3. Schematic and wiring diagram of a single-pole switch with the power (source) at the switch location.

conductor of the luminaire or the brass-colored terminal screw of the lamp holder. Connect the white conductor from the switch location to the white conductor of the luminaire or the silver screw of the lamp holder.

A single-pole switch with the power at the lighting outlet has a two-conductor cable switch loop installed between the switch location and the lighting outlet. Notice in the illustration that the white conductor of the switch loop has been re-identified on each end with a bit of black tape, **Figure 13-4**.

At the lighting outlet, the hot, black conductor of the incoming power is connected to the re-identified white conductor of the switch loop to deliver power to the switch. At the switch location, both conductors are terminated to the switch. Again, it makes no difference which conductor is connected to which terminal screw. Back at the lighting outlet, the black conductor of the switch loop and the grounded conductor are terminated to the luminaire or lamp holder.

13.3.2 Three-Way Switched Circuits

A ***three-way switched circuit*** controls a lighting load from two locations. Three-way switches are always installed in pairs. A three-way switch has three terminal screws: two silver traveler terminals and one black common terminal screw. Think of the common terminals as the way in and out of the three-way circuit. The traveler conductors are alternately energized depending on the position of the switches, **Figure 13-5**.

A three-way switched circuit has two three-way switches with a three-conductor cable installed between them. The power can enter the circuit at either of the two switches or at

Single-Pole Switch, Power at Lighting Outlet

Re-identified conductor

Lighting fixture

Re-identified conductor

Source

Schematic

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Figure 13-4. Schematic and wiring diagram of a single-pole switch with the power (source) at the lighting outlet. The white conductors of the switch loop are re-identified as ungrounded, hot conductors.

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Part 2 House Wiring

Fish tapes come with a formed head that includes a loop of material for the attachment of conductors or cables, **Figure 38-1**.

When fishing in walls or other tight spaces, it is recommended to close off the head by applying some electrical tape. Electrical tape can help prevent the fish tape from hanging up within the wall. Sometimes the manufactured head becomes deformed or breaks off and needs to be replaced. You can bend a new loop on the end of the tape using a lineman's pliers.

When fishing an insulated wall from the basement to the attic, leaving an open loop on the end of the fish tape can be advantageous. For example, a hole is drilled at the top and bottom of the wall. Pushing the fish tape directly from the top hole through the bottom hole is an almost impossible task. Instead, pushing a fish tape with an open end into the wall from the top and bottom allows the two fish tapes to

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Figure 38-1. The steel fish tapes shown here have a preformed hook, while the fiberglass fish tapes have a nonconductive eyelet.

PROCEDURE **Bending a New Loop on a Metal Fish Tape**

It sometimes becomes necessary to replace the manufactured head on a steel fish tape. Use the following steps to create a head that is more likely to keep its shape and less likely to become brittle and break, **Figure 38-2**.

1. Using linesman's pliers, cut the fish tape to create a clean end.
2. Turn the pliers so they are in the same plane as the tape. Grasp the last inch or so of the tape and create a 15- to 30-degree bend.
3. Heat the last 3" of tape with a torch. The process of gently heating and slowly cooling allows you to use less force to create a tighter bend without making the tape brittle.
4. Grab the tape with the pliers just behind the first bend. Bend a loop in the tape until the portion of the tape that was previously bent comes to rest against the straight fish tape.
5. Move the pliers to hold the bent section against the straight section until the tape cools.
6. Wrap the section where the end meets the straight section with electrical tape.

Bending a New Loop on a Metal Fish Tape

Step 1. Cut fish tape to create a clean end.

Step 2. Bend to 15 to 20 degrees.

Step 3. Heat the last 3" of the tape.

Step 4. Bend a loop and hold until cool.

Step 5. Wrap with electrical tape.

Completed loop.

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Figure 38-2. Forming a new hook on a steel fish tape.

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End-of-Chapter Content

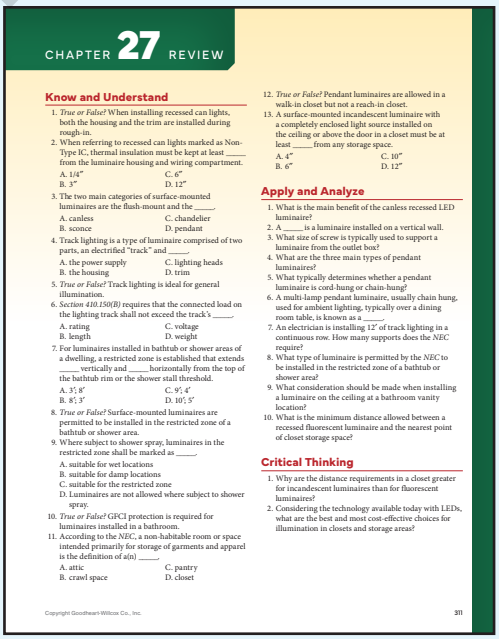
End-of-chapter material provides an opportunity for review and application of concepts.

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.



CHAPTER 27 REVIEW

Know and Understand

1. *True or False?* When installing recessed can lights, both the housing and the trim are installed during rough-in.
2. When referring to recessed can lights marked as Non-Type IC, thermal insulation must be kept at least _____ from the luminaire housing and wiring compartment.
   A. 1/4" C. 6"
   B. 3" D. 12"
3. The two main categories of surface-mounted luminaires are the flush-mount and the _____.
   A. canless C. chandelier
   B. sconce D. pendant
4. Track lighting is a type of luminaire comprised of two parts, an electrified "track" and _____.
   A. the power supply C. lighting heads
   B. the housing D. trim
5. *True or False?* Track lighting is ideal for general illumination.
6. *Section 410.150(B)* requires that the connected load on the lighting track shall not exceed the track's _____.
   A. rating C. voltage
   B. length D. weight
7. For luminaires installed in bathtub or shower areas of a dwelling, a restricted zone is established that extends _____ vertically and _____ horizontally from the top of the bathtub rim or the shower stall threshold.
   A. 3', 8" C. 9', 4'
   B. 8', 3" D. 10', 5'
8. *True or False?* Surface-mounted luminaires are permitted to be installed in the restricted zone of a bathtub or shower area.
9. Where subject to shower spray, luminaires in the restricted zone shall be marked as _____.
   A. suitable for wet locations
   B. suitable for damp locations
   C. suitable for the restricted zone
   D. Luminaires are not allowed where subject to shower spray.
10. *True or False?* GFCI protection is required for luminaires installed in a bathroom.
11. According to the *NEC*, a non-habitable room or space intended primarily for storage of garments and apparel is the definition of a(n) _____.
    A. attic C. pantry
    B. crawl space D. closet
12. *True or False?* Pendant luminaires are allowed in a walk-in closet but not a reach-in closet.
13. A surface-mounted incandescent luminaire with a completely enclosed light source installed on the ceiling or above the door in a closet must be at least _____ from any storage space.
    A. 4" C. 10"
    B. 6" D. 12"

Apply and Analyze

1. What is the main benefit of the canless recessed LED luminaire?
2. A _____ is a luminaire installed on a vertical wall.
3. What size of screw is typically used to support a luminaire from the outlet box?
4. What are the three main types of pendant luminaires?
5. What typically determines whether a pendant luminaire is cord-hung or chain-hung?
6. A multi-lamp pendant luminaire, usually chain hung, used for ambient lighting, typically over a dining room table, is known as a _____.
7. An electrician is installing 12' of track lighting in a continuous row. How many supports does the *NEC* require?
8. What type of luminaire is permitted by the *NEC* to be installed in the restricted zone of a bathtub or shower area?
9. What consideration should be made when installing a luminaire on the ceiling at a bathroom vanity location?
10. What is the minimum distance allowed between a recessed fluorescent luminaire and the nearest point of closet storage space?

Critical Thinking

1. Why are the distance requirements in a closet greater for incandescent luminaires than for fluorescent luminaires?
2. Considering the technology available today with LEDs, what are the best and most cost-effective choices for illumination in closets and storage areas?

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TOOLS FOR STUDENT AND INSTRUCTOR SUCCESS

Student Tools

Student Text



Residential Wiring Concepts and Applications is a comprehensive text that focuses on the information and requirements, techniques, processes, and procedures used by residential electricians.

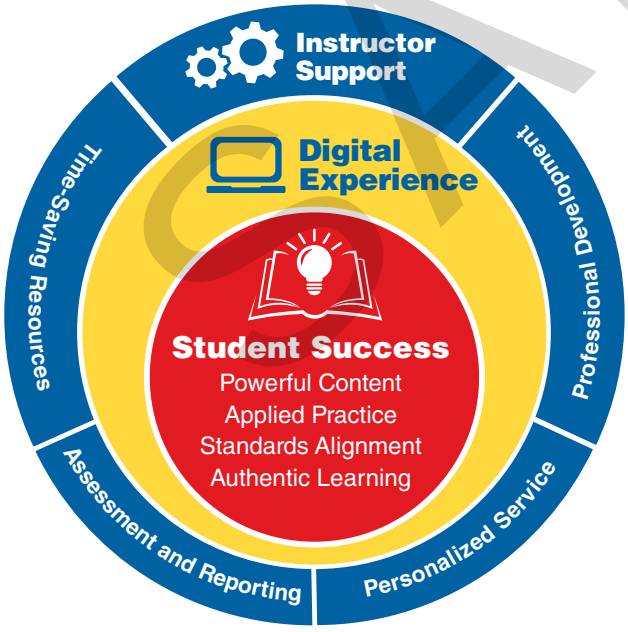
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See www.g-w.com/residential-wiring-concepts-applications-2024 for a list of all available resources.

Professional Development

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