research (1989) shows that students can be guided away from misconceptions through a process of reasoning that helps them build on the accurate facets of their knowledge as they gradually revise the inaccurate facets.

Implications of This Research It is important for instructors to address inaccurate prior knowledge that might otherwise distort or impede learning. In some cases, inaccuracies can be corrected simply by exposing students to accurate information and evidence that conflicts with flawed beliefs and models. However, it is important for instructors to recognize that a single correction or refutation is unlikely to be enough to help students revise deeply held misconceptions. Instead, guiding students through a process of conceptual change is likely to take time, patience, and creativity.

WHAT STRATEGIES DOES THE RESEARCH SUGGEST?

In this section we offer (1) a set of strategies to help instructors determine the extent and quality of students' prior knowledge, relative to the learning requirements of a course. We then provide strategies instructors can employ to (2) activate students' relevant prior knowledge, (3) address gaps in students' prior knowledge, (4) help students avoid applying prior knowledge in the wrong contexts, and (5) help students revise and rethink inaccurate knowledge.

Methods to Gauge the Extent and Nature of Students' Prior Knowledge

Talk to Colleagues As a starting point for finding out what prior knowledge students bring to your course, talk to colleagues

who teach prerequisite courses or ask to see their syllabi and assignments. This can give you a quick sense of what material was covered, and in what depth. It can also alert you to differences in approach, emphasis, terminology, and notation so that you can address potential gaps or discrepancies. Remember, though, that just because the material was taught does not mean that students necessarily learned it. To get a better sense of students' knowledge, as well as their ability to apply it, you might also ask your colleagues about students' proficiencies: for example, what concepts and skills did students seem to master easily? Which ones did they struggle with? Did students seem to hold any systematic and pervasive misconceptions? This kind of information from colleagues can help you design your instructional activities so they effectively connect to, support, extend, and, if needed, correct, students' prior knowledge.

Administer a Diagnostic Assessment To find out what relevant knowledge students possess coming into your course, consider assigning a short, low-stakes assessment, such as a quiz or an essay, at the beginning of the semester. Students' performance on this assignment can give you a sense of their knowledge of prerequisite facts and concepts, or their competence in various skills. For example, if your course requires knowledge of a technical vocabulary and basic calculus skills, you could create a short quiz asking students to define terms and solve calculus problems. You can mark these assignments individually to get a sense of the skill and knowledge of particular students, or simply look them over as a set to get a feel for students' overall level of preparedness. Another way to expose students' prior knowledge is by administering a concept inventory. Concept inventories are ungraded tests, typically in a multiple-choice format, that are designed to include incorrect answers that help reveal common misconceptions. Developing a concept inventory of your own can be time-

intensive, so check the Internet to see whether there are inventories already available in your discipline that would suit your needs. A number of concept inventories have been widely used and have high validity and reliability.

Have Students Assess Their Own Prior Knowledge In some fields and at some levels of expertise, having students assess their own knowledge and skills can be a quick and effective—though not necessarily foolproof—way to diagnose missing or insufficient prior knowledge. One way to have students self-assess is to create a list of concepts and skills that you expect them to have coming into your course, as well as some concepts and skills you expect them to acquire during the semester. Ask students to assess their level of competence for each concept or skill, using a scale that ranges from cursory familiarity ("I have heard of the term") to factual knowledge ("I could define it") to conceptual knowledge ("I could explain it to someone else") to application ("I can use it to solve problems"). Examine the data for the class as a whole in order to identify areas in which your students have either less knowledge than you expect or more. In either case, this information can help you recalibrate your instruction to better meet student needs. See Appendix A for more information about student self-assessments.

Use Brainstorming to Reveal Prior Knowledge One way to expose students' prior knowledge is to conduct a group brainstorming session. Brainstorming can be used to uncover beliefs, associations, and assumptions (for example, with questions such as "What do you think of when you hear the word *evangelical*?"). It can also be used to expose factual or conceptual knowledge ("What were some of the key historical events in the Gilded Age?" or "What comes to mind when you think about environmental ethics?"), procedural knowledge ("If you were going to do a

research project on the Farm Bill, where would you begin?"), or contextual knowledge ("What are some methodologies you could use to research this question?"). Bear in mind that brainstorming does not provide a systematic gauge of students' prior knowledge. Also, be prepared to differentiate accurate and appropriately applied knowledge from knowledge that is inaccurate or inappropriately applied.

Assign a Concept Map Activity To gain insights into what your students know about a given subject, ask them to construct a concept map representing everything that they know about the topic. You can ask students to create a concept map (see Appendix B), representing what they know about an entire disciplinary domain (for example, social psychology), a particular concept (for instance, Newton's third law), or a question (for example, "What are the ethical issues with stem cell research?"). Some students may be familiar with concept maps, but others may not be, so be sure to explain what they are and how to create them (circles for concepts, lines between concepts to show how they relate). There are a number of ways to construct concept maps, so you should give some thought to what you are trying to ascertain. For instance, if you are interested in gauging students' knowledge of concepts as well as their ability to articulate the connections among them, you can ask students to generate both concepts and links. But if you are primarily interested in students' ability to articulate the connections, you can provide the list of concepts and ask students to arrange and connect them, labeling the links. If there are particular kinds of information you are looking for (for example, causal relationships, examples, theoretical orientations) be sure to specify what you want. Review the concept maps your students create to try to determine gaps in their knowledge, inappropriate links, and the intrusion of lay terms and ideas that may indicate the presence of naïve theories or preconceptions.

Look for Patterns of Error in Student Work Students' misconceptions tend to be shared and produce a consistent pattern of errors. You (or your TAs or graders) can often identify these misconceptions simply by looking at students' errors on homework assignments, quizzes, or exams and noting commonalities across the class. You can also keep track of the kinds of problems and errors that students reveal when they come to office hours or as they raise or answer questions during class. Paying attention to these patterns of error can alert you to common problems and help you target instruction to correct misconceptions or fill gaps in understanding. Some instructors use classroom response systems (also called "clickers") to quickly collect students' answers to concept questions posed in class. Clickers provide an instant histogram of students' answers and can alert instructors to areas of misunderstanding that might stem from insufficient prior knowledge.

Methods to Activate Accurate Prior Knowledge

Use Exercises to Generate Students' Prior Knowledge Because students learn most effectively when they connect new knowledge to prior knowledge, it can be helpful to begin a lesson by asking students what they already know about the topic in question. This can be done any number of ways, such as by asking students to brainstorm associations or create a concept map. Once students have activated relevant prior knowledge in their heads, they are likely to be able to integrate new knowledge more successfully. However, since activities like this can generate inaccurate and inappropriate as well as accurate and relevant knowledge, you should be prepared to help students distinguish between them.

Explicitly Link New Material to Knowledge from Previous Courses Students tend to compartmentalize knowledge by

course, semester, professor, or discipline. As a result, they may not recognize the relevance of knowledge from a previous course to a new learning situation. For example, students who have learned about the concept of variability in a statistics course often do not bring that knowledge to bear on the concept of volatility in a finance course both because of the difference in terminology and because they do not see the link between the two contexts. However, if you make the connection between variability and volatility explicit, it allows students to tap into that prior knowledge and build on it productively.

Explicitly Link New Material to Prior Knowledge from Your Own Course Although we often expect students to automatically link what they are learning to knowledge gained earlier in the same course, they may not do so automatically. Thus, it is important for instructors to highlight these connections. Instructors can help students activate relevant prior knowledge by framing particular lectures, discussions, or readings in relation to material learned previously in the semester. For example, in a literary theory course, the professor might begin class by saying, "In Unit 2 we discussed feminist theory. Today we are going to talk about a school of thought that grew out of feminist theory.") Sometimes all it takes to activate students' relevant prior knowledge is a slight prompt, such as: "Think back to the research design Johnson used in the article from last week" or "Where have we seen this phenomenon before?" Students can also be encouraged to look for connections within course materials in other ways. For example, the instructor can ask students to write reflection papers that connect each reading to other readings and to larger themes in the course. Also, discussions provide an ideal opportunity to elicit students' knowledge from earlier in the semester and to link it to new material.

Use Analogies and Examples That Connect to Students' Everyday Knowledge Examples or analogies that draw on students' everyday lives and the wider world make new material more understandable and create more robust knowledge representations in students' minds. For example, an instructor could draw on students' memories from childhood and experiences with younger siblings to help them understand concepts in child development. Similarly, an instructor could use students' experiences with the physical world to introduce concepts such as force and acceleration. Analogies are also useful for connecting new knowledge to prior knowledge. For example, students' experience with cooking can be enlisted to help them understand scientific processes such as chemical synthesis (just as in cooking, when you mix or heat chemicals, you need to know when precision is and is not critical). Students often show more sophisticated reasoning when working in familiar contexts, and we can build on their knowledge from these contexts as we explore new material.

Ask Students to Reason on the Basis of Relevant Prior Knowledge Often students have prior knowledge that could help them reason about new material and learn it more deeply. Thus, it can be useful to ask students questions that require them to use their prior knowledge to make predictions about new information before they actually encounter it. For example, before asking students to read an article from the 1970s, you might ask them what was going on historically at the time that might have informed the author's perspective. Or when presenting students with a design problem, you might ask them how a famous designer, whose work they know, might have approached the problem. This requires students not only to draw on their prior knowledge but also to use it to reason about new knowledge.

Methods to Address Insufficient Prior Knowledge

Identify the Prior Knowledge You Expect Students to Have The first step toward addressing gaps in students' prior knowledge is recognizing where those gaps are. This requires identifying in your own mind the knowledge students will need to have to perform effectively in your course. To identify what the prior knowledge requirements are for your class, you might want to begin by thinking about your assignments, and ask yourself, "What do students need to know to be able to do this?" Often instructors stop short of identifying all the background knowledge students need, so be sure to continue asking the question until you have fully identified the knowledge requirements for the tasks you have assigned. Be sure to differentiate declarative (knowing what and knowing why) from procedural knowledge (knowing how and knowing when), recognizing that just because students know facts or concepts does not mean they will know how to use them, and just because students know how to perform procedures does not mean that they understand what they are doing or why. (See "Strategies to Expose and Reinforce Component Skills" in Chapter Four.)

Remediate Insufficient Prerequisite Knowledge If prior knowledge assessments (as discussed in previous strategies) indicate critical gaps in students' prior knowledge relative to the learning requirements of your course, there are a number of possible responses depending on the scale of the problem and the resources and options available to you and to your students. If only a few students lack important prerequisite knowledge, one option that might be open to you is simply to advise them against taking the course until they have the necessary background. Alternatively, if a small number of students lacks prerequisite knowledge but seem capable of acquiring it on their own, you might consider

providing these students with a list of terms they should know and skills they should have and letting them fill in the gaps on their own time. If a larger number of students lacks sufficient prior knowledge in a key area, you might decide to devote one or two classes to a review of important prerequisite material or (if it is applicable) ask your teaching assistant to run a review session outside class time. If a sizable proportion of your class lacks knowledge that is a critical foundation for the material you planned to cover, you may need to revise your course altogether so that it is properly aligned with your students' knowledge and skills. Of course, if your course is a prerequisite for other courses, such fundamental revisions may have broader implications, which may need to be addressed at a departmental level through a discussion of objectives and course sequencing.

Methods to Help Students Recognize Inappropriate Prior Knowledge

Highlight Conditions of Applicability It is important to help students see when it is and is not appropriate to apply prior knowledge. For example, a statistics instructor might explain that a regression analysis can be used for quantitative variables but not for qualitative variables, or a biology instructor might instruct students to save their expressive writing for other courses and instead write lab reports that focus on conciseness and accuracy. If there are no strict rules about when prior knowledge is applicable, another strategy is to present students with a range of problems and contexts and ask them to identify whether or not a given skill or concept is applicable and to explain their reasoning.

Provide Heuristics to Help Students Avoid Inappropriate Application of Knowledge One strategy to help students avoid applying their prior knowledge inappropriately is to provide them

with some rules of thumb to help them determine whether their knowledge is or is not relevant. For example, when students are encountering different cultural practices and might be tempted to assess them according to their own cultural norms, you might encourage them to ask themselves questions such as "Am I making assumptions based on my own cultural knowledge that may not be appropriate here? If so, what are those assumptions, and where do they come from?" By the same token, if you know of situations in which students frequently get confused by the intrusion of prior knowledge (for example, students' understanding of negative reinforcement in the second story at the beginning of this chapter), you might want to provide them with a rule of thumb to help them avoid that pitfall. For example, an instructor teaching classical learning theory could advise his students, "When you see 'negative' in the context of negative reinforcement, think of subtraction."

Explicitly Identify Discipline-Specific Conventions It is important to clearly identify the conventions and expectations of your discipline so that students do not mistakenly apply the conventions of other domains about which they know more. For example, students may have experience with writing from a science course (lab reports), from a history course (analytical paper), or from an English course (personal narrative), so when they take a public policy course they may not know which set of knowledge and skills is the appropriate one to build on. It is important to explicitly identify the norms you expect them to follow. Without explicit guidance, students may analogize from other experiences or fields that they feel most competent in, regardless of whether the experiences are appropriate in the current context.

Show Where Analogies Break Down Analogies can help students learn complex or abstract concepts. However, they can be

problematic if students do not recognize their limits. Thus, it is important to help students recognize the limitations of a given analogy by explicitly identifying (or asking students to identify) where the analogy breaks down. For example, you might point out that although the digestive system is similar to plumbing in that it involves tube-like organs and various kinds of valves, it is far more complex and sensitive than any ordinary plumbing system.

Methods to Correct Inaccurate Knowledge

Ask Students to Make and Test Predictions To help students revise inaccurate beliefs and flawed mental models ask them to make predictions based on those beliefs and give them the opportunity to test those predictions. For example, physics students with an inaccurate understanding of force could be asked to make predictions about how forces will act on stationary versus moving objects. Being confronted with evidence that contradicts students' beliefs and expectations can help them see where their knowledge or beliefs are incorrect or inadequate, while motivating them to seek knowledge that accounts for what they have seen. Predictions can be tested in experiments, in or outside a laboratory environment, or through the use of computer simulations.

Ask Students to Justify Their Reasoning One strategy to guide students away from inaccurate knowledge is to ask them to reason on the basis of what they believe to be true. When students' reasoning reveals internal contradictions, it can bring them to the point where they seek accurate knowledge. A caveat to this approach is that students may not necessarily see those internal contradictions. Moreover, if their attitudes and beliefs are very deeply held (for example, religious beliefs that defy logical argument), these contradictions may have little effect.

Provide Multiple Opportunities for Students to Use Accurate Knowledge Misconceptions can be hard to correct in part because they have been reinforced through repeated exposure. Thus, replacing inaccurate knowledge with accurate knowledge requires not just introducing accurate knowledge but also providing multiple opportunities for students to use it. Repeated opportunities to apply accurate knowledge can help counteract the persistence of even deeply held misconceptions.

Allow Sufficient Time It is easier for students to fall back on deeply held misconceptions than to employ the reasoning necessary to overcome them. Therefore, when you are asking students to use new knowledge that requires a revision or rethinking of their prior knowledge, it can be helpful to minimize distractions and allow a little extra time. This can help students enlist the cognitive resources necessary to identify flaws in their knowledge or reasoning and instead to consciously employ more thoughtful, critical thinking.

SUMMARY

In this chapter we have examined the critical role of prior knowledge in laying the groundwork for new learning. We have seen that if students' prior knowledge has gaps and insufficiencies it may not adequately support new knowledge. Moreover, if prior knowledge is applied in the wrong context, it may lead students to make faulty assumptions or draw inappropriate parallels. In addition, inaccurate prior knowledge—some of which can be surprisingly difficult to correct—can both distort students' understanding and interfere with incoming information. Consequently,

a critical task for us as instructors is to assess what students know and believe so we can build on knowledge that is accurate and relevant, fill in gaps and insufficiencies where they exist, help students recognize when they are applying prior knowledge inappropriately, and help students revise inaccurate knowledge and form more accurate and robust mental models.