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Encouraging Knowledge Transfer in Food Science and Nutrition Education: Suggestions from Cognitive Research

Megan A. Sumeracki, Yana Weinstein-Jones,* Cynthia L. Nebel, and Shelly J. Schmidt

Abstract: For several decades, cognitive psychologists have been studying how we learn, and from this work it becomes possible to identify ways to help students learn in the classroom effectively. Importantly, this work does not just inform how to memorize facts, but also how to learn complex material in a way that allows students to apply what they are learning in future situations. The laboratory to classroom model used by many researchers to apply cognitive psychology to real educational situations, such as classroom learning and students' independent studying, is described first. Then the focus turns to important issues within education, such as students' ability to transfer knowledge to new situations and understand complex material. Finally, three learning strategies are discussed (concrete examples, elaborative interrogation, and retrieval practice) that instructors can implement to help students to both acquire knowledge and apply it to new situations, integrating examples from food science and nutrition.

Keywords: concrete examples, elaboration, retrieval, science of learning, transfer

Introduction

For decades, cognitive psychologists have been studying the mind to understand how we learn, and have made strides in applying this knowledge to student learning in the classroom. Of course, understanding how students learn is important for scholars and instructors in many fields, and not just for cognitive psychology. In this article, the way cognitive psychologists engage in research to further inform educational practices is first briefly discussed. Some important issues to consider in classroom settings are included, such as knowledge transfer to novel situations and learning basic facts compared with complex relationships. Then, three evidence-based learning strategies are described—concrete examples, elaborative interrogation, and retrieval practice. Instructors can use these strategies in their classrooms to improve knowledge acquisition, as well as application of that knowledge to real-life situations.

Cognitive Psychology Research

Cognitive psychologists study basic processes involved in human thinking, such as perception, attention, learning, and memory. Knowledge of how these basic processes work can then inform appropriate learning strategies for students, to be used both in the classroom and for independent studying. Most who study cognitive science and apply its findings to the classroom do not simply conduct an experiment or even a set of experiments in the laboratory and immediately make sweeping recommendations for the classroom. Instead, learning strategies—created based upon our knowledge of how basic mental processes work—are tested in a number of different circumstances, sometimes referred to as the laboratory to classroom model (Weinstein & Sumeracki, 2019). Cognitive psychologists typically start with basic experiments carried out in a controlled laboratory environment, using very simple materials[i], such as lists of word or nonsense syllables. Very simple materials are used to maintain control so that researchers can pinpoint causal effects on learning. Researchers in this area then move to applied laboratory experiments where they start to introduce more complex materials, including text passages, video

[i] Materials here refer to the stimuli that are presented to the participants during an experiment. In learning experiments, the materials are the content that the participant is attempting to learn, such as word lists, text passages, video lectures, etc.

JFS3-2019-0003 Submitted 1/14/2019, Accepted 3/11/2019. *Author Sumeracki is with Psychology Dept., Rhode Island College, Craig-Lee Hall, 600 Mount Pleasant Ave, Providence, RI 02908, U.S.A. Author Weinstein-Jones is with Centre for Education Improvement Science Inst. of Education, Univ. College London, Gower Street, London, WC1E 6BT, United Kingdom. Author Nebel is with Dept. of Psychology, Henderson Learning Resources Center, Washburn Univ., 1700 SW College Ave, Topeka, KS 66621, U.S.A. Author Schmidt is with Dept. of Food Science and Human Nutrition, Univ. of Illinois at Urbana-Champaign, 367 Bevier Hall, 905 S. Goodwin, Urbana, IL 61801, U.S.A. Direct inquiries to author Sumeracki (E-mail: msumeracki@ric.edu).*

*At the time of writing this manuscript, Yana Weinstein-Jones was also affiliated with the Univ. of Massachusetts Lowell

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lectures, or diagrams that might be found in a lecture or textbook. At this level, control is maintained, but the researcher is now investigating the learning of more realistic materials. Finally, researchers go into the classroom itself and test the learning strategies in live settings. The researchers still have control groups, but the classroom environment has a number of variables that differ from student to student or within a student across different contexts, and may introduce variability in the data, making effects more difficult to observe. For example, in a real classroom, students may be affected by cognitive resources such as their working memory capacity, their prior knowledge of the material, or how interested they are in the class. As researchers continue to conduct more and more experiments along the laboratory to classroom model, they also examine different learner characteristics, different materials or topics of study, different ways of implementing effective learning strategies, and different types of assessments (see Jenkins, 1979). By going through this laboratory to classroom process, researchers can be much more confident in their ability to recommend what will help students learn in many contexts, and attend to the needs of classroom learning.

Knowledge Transfer

One important concept to consider when applying cognitive psychology to education is the purpose of the learning process in a given scenario. Of course, instructors want students to remember classroom content, but a very important aspect of education is to guide student learning such that students will be able to apply their knowledge in future situations. The application of learned knowledge to a new situation is referred to as *knowledge transfer* (Barnett & Ceci, 2002; Schwartz, Bransford, & Sears, 2005), and arguably transfer is a primary goal of education (Georghiades, 2000; Klausmeier, 1961). Educators do not promote the learning of content solely for students to be able to answer factual test questions in the confines of their classrooms. Rather, students need to learn, retain, and recall information in order to be able to use it at a later time—outside the classroom.

While transferring knowledge is a goal in every discipline, it is of particular importance in applied fields. In areas such as food science and nutrition, students will be required to use classroom materials in their future careers. It is also imperative that students transfer what they learn across courses (for example, from introductory microbiology and chemistry courses to later food science courses). Those working in the food industry will need to use acquired knowledge to make contributions and advances in areas such as food stability, food safety, quality assurance, cost reduction, product development, sustainability, as well as countless other areas. For example, the food scientist will need to connect the acquired knowledge they obtained in their chemistry laboratory class about the isoelectric point of a protein and the optimum pH for the high protein beverage they are formulating. Those working as registered dietitians or dietitian nutritionists will need to use acquired knowledge to help their clients make healthier food choices. For example, the dietitian will need to connect the acquired knowledge they obtained in their psychology course about behavior modification and helping their client to include more fruits and vegetables in their diet and less fast food. The ability to correctly apply knowledge from the classroom may have important implications for these students. If a student is unable to appropriately apply their knowledge in a future career as a food inspector, for example, this could have critical public health consequences. For these fields, it is therefore important to understand the underlying processes and utilize research-based learning strategies that support transfer.

Transfer requires three important processes or stages, all of which can be informed by cognitive psychological principles—Stage 1: Students notice where and when something they have learned could be useful in a future situation; Stage 2: Students retrieve the relevant information; and Stage 3: Students appropriately apply the information in the new situation. (Each of the three stages is described in detail below). For example, when working on extending the shelf-life of a dual-textured food product, such as a raisin and flake cereal, students must recognize that they learned about the concept of water activity in the past and that somehow this concept is relevant to the current situation (Stage 1). Students must then successfully bring to mind what they learned (Stage 2) and apply their knowledge in the new situation (Stage 3). Specifically, students would need to recall what they know about water activity and make the connection between their knowledge and how this impacts extending the product's shelf-life.

Transfer can be conceptualized as existing on a continuum from near to far transfer (Barnett & Ceci, 2002; but see Perkins & Salomon, 1989 and Jesson, 2010 for other conceptualizations). If students are transferring information to something very similar, such as a question that asks about the same content but in a new and different way, this would be *near* transfer. If instead students are applying information to solve a novel problem or explain a real-world scenario that they had not previously learned about, that would be considered *far* transfer. An example of *near transfer* within a course might be students learning about basic food safety practices (for example, clean, separate, cook, and chill) in an introductory food science course followed by an assignment in which students are given a variety of foodborne illness outbreak scenarios and asked to identify which food safety practice(s) was most likely violated and was, thus, the cause of the outbreak. An example of *near transfer* between courses might be students learning about pathogenic microorganisms in a microbiology course and then being asked to develop a Hazard Analysis and Risk-Based Preventive Controls (HARPC) plan for a product they are developing in their capstone food product development course. An example of *far transfer* from a course to the workplace might be a nutritional scientist using information about basic genetics learned in an introductory biology course to their work at a pet food company developing a line of personalized nutrition pet food products (Wall, 2016).

Stage 1: Recognizing transfer situations

If the new situation appears very similar to how the information was originally learned (that is, near transfer), students are much more likely to recognize the transfer situation (Butler, 2010). However, the situations will not always be very similar. Students will likely need to use information in a variety of transfer situations, most of which are not necessarily similar to the classroom setting. In order to promote transfer to the varied situations that might be required, instructors must intentionally expose students to a wide variety of examples of possible transfer scenarios, and the various stages of transfer to prepare them to recognize when transfer will be necessary or useful. This exposure will make a greater variety of situations more familiar to students, which should in turn help them recognize novel situations spontaneously as ones in which previous knowledge might be useful (Einstein et al., 2005). In addition, giving students practice with *how* to transfer their knowledge in new situations can improve their ability to transfer (Ford, Smith, Weissbein, Gully, & Salas, 1998). While it is unlikely that an instructor can expose students to *every* situation they may encounter in the future, the more exposure to varied situations they get, the more likely the students are to notice that their acquired knowledge may be useful. In the nutritional scientist example about basic genetics and developing personalized nutrition pet food products above, if the biology instructor had talked about the connection among genetics, health and well-being, and nutritional needs, a student would be much more likely to recognize the real-life situation of developing the pet food line as one in which they might use the basic genetics knowledge. While all types of transfer situations involve using learned information under new circumstances, the far transfer scenario (for example, from the classroom to a career environment working with animals and food) is very different to the original learning situation, and the need to transfer knowledge may be less obvious to students. In this case, students must be able to recognize that something they learned in the past could be useful in the new situation they are facing.

Stage 2: Retrieving relevant information

For knowledge transfer to be successful, students must also be able to accurately retrieve that knowledge in the new transfer situation. For example, if the students working in the field as nutritional scientists recognize that they could use information from genetics, but cannot actually recall the information, transfer will not occur. Thus, learning strategies that promote better retention of knowledge will enhance retrieval. Cognitive psychologists have identified several effective learning strategies that are supported by considerable research in both the laboratory and the classroom. Concrete examples, elaborative interrogation, and retrieval practice are among the strategies that may prove most beneficial for promoting learning and transfer (Gick & Holyoak, 1983; Pashler et al., 2007), and, thus, will be discussed later in this article.

Stage 3: Appropriately applying information in the new situation

Students must also be able to use their previously learned information in the new situation. That is, students need to not only recognize that they can use prior information and recall that information, but must also determine how to appropriately apply it in the new situation. In order to learn how to appropriately apply information, students need to actually practice doing so (Dixon & Brown, 2012). Certainly, the goal cannot be to give students practice transferring to every situation in which they would ever need to use previously learned knowledge; this would likely be impossible. However, students should be exposed to a great deal of practice transferring knowledge to new scenarios, and in ways that are likely to bear some resemblance to what they will need to do on their own. Additional transfer practice will make it more likely that the student will be able to transfer acquired knowledge successfully on their own when they need to do so. Further, having many opportunities to practice transfer will promote students' ability to see how information can be applied to ill-structured situations that may differ considerably from the well-structured problems they typically see on classroom exams. Many opportunities to practice transfer can also be provided in multiple classes throughout the curriculum, so that practice with overlapping content across courses is repeated across time—another effective learning strategy ("spaced practice"; Kang, 2016; Weinstein, Madan, & Sumeracki, 2018).

Transfer can be practiced in a number of ways. A simple and relatively quick in class method of practicing transfer is posing a question to students that requires them to apply what they have just learned to solve a real-life problem. An example of a question that could be posed to practice transfer after discussing the different types of heat treatment that are used in food processing (for example, blanching, pasteurization, and commercial sterilization) might be "Why does milk that has both been heat treated and stored under refrigerated conditions still go bad over time, even if it has not been opened?" This type of transfer practice may be facilitated by the use of student response systems (for example, iClickers; https://www.iclicker.com) or application software that works with students' personal devices (for example, TopHat; https://tophat.com).

Another example of transfer practice could be asking students to think about developing reduced fat baked goods, such as cakes, for restaurant menus or as new food products. The students must recognize that fat plays multiple specific roles in various types of baked products. In order to produce a palatable and appealing product, the students need to determine how to make key recipe adjustments to compensate for the functional losses resulting from the lower levels of fat in the modified product. Knowledge about the specific roles (for example, coating of the gluten strands to shorten them and thus tenderize the protein matrix and resulting product, incorporation of air when fat is creamed with sugar to act as a leavening agent during the baking process, and distribution of fat-soluble flavors throughout the product) must be retrieved to determine how to compensate for their absence in the low-fat product. Additional knowledge about flour proteins and their chemical behavior under various circumstances could be applied to theorize (and then to test) that a flour with lower gluten content would help to tenderize a reduced fat cake. Similarly, additional knowledge about the protein structure and leavening abilities of whipped egg whites could be applied to suggest a way to achieve leavening in the product, and so forth. All along the way, the students are seeing how the concepts they are learning in their courses apply to real world scenarios.

Examples of more extensive methods of practicing transfer are the use of case studies and experiential learning activities. Figure 1 is an example of a case study used in the nutrition and health section of an introductory food science and human nutrition course. The students learn about a number of nutrition principles, guidelines, and tools, such as the Dietary Reference Intakes (DRIs), the Dietary Guidelines for Americans, MyPlate, and the Nutrition Facts Label, and then they are asked to apply what they have learned by analyzing Danni's diet and responding to the many questions she poses in the case study. The case study is intended to be something the students can personally relate to and therefore be interested and engaged in answering Danni's questions. The case study is also intentionally composed of questions that have correct answers and questions that have more open-ended and somewhat opinion-based answers. Both types of questions require the students to practice transferring the knowledge they have learned to respond to Danni's dilemmas. Of course, students should support their answers to both types of questions with research-based evidence. Additionally, experiential learning activities can be a great way to encourage students to build knowledge that is inherently more transferable because it was gained by doing, not just by listening (Bohn & Schmidt, 2008).

Section 1: Danni's Case Study

Hi my name is Danni. I am a 19 year old, female college sophomore. I play extramural volleyball and try to exercise one or two times a week, but schoolwork and my part time job sometimes get in the way. I am becoming more interested in health and nutrition and want to know if I am consuming a healthy diet. Below is a typical example of my day's intake of food and beverages.

Breakfast	Lunch	Dinner	Snacks
1C 2% milk	Asian Sesame Chicken salad (dressing included)	1/2 pepperoni pizza, regular crust, frozen	100g Greek yogurt, berry flavor
1.5C frosted flakes	4 multi grain crackers	1C Iceberg lettuce and 2 tablespoons ranch dressing, regular	2 oz Pretzels, salted
12 fl oz apple juice	20 oz diet soda	1C 2% milk	
		2 Chocolate Chip cookies	

Since the start of my freshman year, I have gained about 10 pounds. I heard that eating more protein and fewer carbohydrates would help me lose weight, but I am not sure if that is true or not. Also, I read an article that said eating yogurt would help me better digest my food, so that may also help me lose weight. I have been considering taking a vitamin and mineral supplement, but I am not sure if I need one or not. There are other supplements that I have looked at, like individual amino acid supplements, but I am not sure if they are safe or not. It seems like there is a lot of conflicting information out there when it comes to diet and health – one day there is a report in the news that says coffee is bad for you and the next day there is another report that says it is good for you. I have so many questions; I really need to get some answers!

Figure 1–Case study used in the nutrition and health section of an introductory food science and human nutrition course.

Learning Basic Facts Compared with Complex Relationships

Teachers often make a distinction between basic and more complex learning—that is, learning basic facts compared with complex relationships. Take the following example, mentioned in another recent article in this journal (Schell & Porter, 2018). Imagine that a student is learning about the role of fiber in the maintenance of gut health. The end goal of this learning might be for the student to be able to explain why a doctor might prescribe a plant-based diet to a patient suffering from lung inflammation (that is, describing a complex relationship). However, prior to achieving that goal, students may need to demonstrate their learning of the basic facts about fiber and gut health. Learning the basic facts about fiber and gut health (for example, that inulin-type soluble fibers have anti-inflammatory properties; Anderson et al., 2009) is a crucial foundational step. After learning and understanding this *basic fact*, the student also needs to learn the *complex relationships* among fiber, fatty acids, and the respiratory system (Wood, Shivappa, Berthon, Gibson, & Hebert, 2015). However, despite the apparent difference in complexity between retrieving basic facts and describing complex relationships, the learning process will be much the same for both.

Learning involves the strengthening of new connections in the brain. More specifically, new information manifests itself as new patterns between neurons in the brain, which must then be repeated in order for learning to have occurred (Furst 2019; Weinstein & Sumeracki, 2019, p.75)—and this happens regardless of whether the new information involves basic facts or complex relationships. Working with concrete examples linked to abstract concepts, asking and answering "how" and "why" questions (elaborative interrogation), and practicing retrieval (that is, bringing information to mind from memory, typically without the use of any aids, although sometimes cues or scaffolds are used) all have the potential to strengthen patterns of activation. This means that strategies that work for learning basic facts will also be effective for learning complex relationships; the difference is not in the strategies themselves, but in the way that the strategies are implemented. Each type of material that a student might need to learn should be studied in the most appropriate way. For example, it seems obvious that few people would choose to learn how to ride a bike by reading a book instead of practicing riding the bike; similarly, one should not expect students to learn complex relationships between concepts by *only* practicing basic facts. Instead, it is better for students to practice describing the complex relationships in their own words from memory, come up with concrete examples of the relationships in action, and explain how and why these relationships exist.

Evidence-based Strategies to Enhance Learning

Described individually below are three evidence-based learning strategies—concrete examples, elaborative interrogation, and retrieval practice—that instructors can implement to help students both acquire the important knowledge of the course and apply that knowledge to new situations. Integrated within each strategy are examples from food science and nutrition. For more discussion of these strategies and others, please see Weinstein et al. (2018) and Sumeracki, Madan, and Weinstein (2018).[ii]

Concrete examples

In the previous section on learning basic facts compared with complex relationships, examples were used: learning basic facts about the role of fiber in the maintenance of gut health (basic facts), and explaining why a doctor might prescribe a plant-based diet to a patient suffering from lung inflammation (complex relationships). By using these two examples, the abstract idea of "basic facts compared with complex relationships" has been made more concrete. Instructors can utilize concrete examples in this way to facilitate learning. Concrete information is remembered better than abstract information, in part because concrete information is easier to turn into an image (Caplan & Madan, 2016). Try to imagine "basic facts compared with complex relationships"—what does this look like? Now, try to imagine a picture of the gut fermenting fiber (basic fact), and then a more complicated picture showing both the respiratory system and the digestive system interacting (complex relationships). This concrete example renders itself as an image more readily than the abstract idea of "basic facts compared with complex relationships", and encoding information in two forms—as images and as words—can help later retrieval of the information (see Weinstein et al., 2018).

While the authors are not aware of any controlled studies that have examined how often teachers use concrete examples in the classroom, it seems likely that teachers do this quite frequently (see, for example, Boulton, 2016). But does providing concrete examples guarantee understanding of the abstract idea? Qualitative research into teachers' perceptions suggests that there are cultural differences in terms of how teachers would answer this question. In one study of math teaching, U.S. teachers said that abstract ideas could be learned solely through concrete examples, without explicitly teaching the abstract ideas, whereas Chinese teachers tended to emphasize that it is very important to connect concrete examples and abstract ideas in order to ensure understanding of the abstract (Cai & Wang, 2010). In fact, the research suggests that the latter is true: students will not spontaneously connect concrete examples to abstract ideas without explicit instruction and practice (Berry, 1983). This process of connecting concrete examples to abstract ideas—or, "induction of schemas from examples"—was studied in detail by Mary L. Gick in the 1970s and 1980s.

Gick and Holyoak (1983) gave participants a concrete example of a problem that could be solved through "convergence," or various forces coming together at a common point in the middle. In the abstract—or general—form of this problem, some target needs to be destroyed, but destroying it with a single force will result in destroying more than just the target. In the first concrete example of the problem, Gick and Holyoak described how a General wanted to destroy a fortress that was surrounded by mines. A full-scale attack on the fortress from one direction would detonate the mines, but one small force would not be enough to destroy the fortress. So, the solution was to send small groups of soldiers to converge all around the fortress. An analogous concrete example of this problem involves radiation of a tumor: A large dose of radiation would destroy healthy tissue in addition to the tumor and a small dose would not destroy the tumor, but multiple small doses could converge all around the tumor to destroy it. The question is, can students transfer their understanding of the fortress problem to solve the radiation problem? Across four experiments, Gick and Holyoak found that it was very difficult to produce transfer from one concrete example of convergence to another. In other words, students do not necessarily *transfer* their understanding of the principle behind a concrete example to another concrete situation that appears to be different on the surface but relies on the same abstract principle. However, when *two* different concrete examples were provided, participants induced the schema from the examples (that is, developed an understanding of the abstract idea) with much greater success. For example, a participant might have read the story about the fortress, and then another story about an oil fire being extinguished with multiple hoses. They were then approximately twice as likely to correctly figure out the radiation problem, compared to studying only one of the concrete examples. The experiments reported by Gick and Holyoak demonstrate the importance of providing multiple different examples of abstract concepts to promote transfer.

What does this mean for student learning? It is important for students to be able to learn general information (that is, abstract ideas) and be able to apply that information in new specific situations (that is, concrete examples). To guide learning, teachers often give students an example of how to apply the abstract idea to a concrete example, hoping that this will demonstrate how the abstract idea can manifest itself in one situation and that this demonstration will ultimately help students transfer their learned knowledge to a different situation. Yet, the research shows that one example is often not enough (for example, Gick & Holyoak, 1983). The likelihood that students will be able to transfer their learned knowledge to new situations can be increased by simply providing multiple concrete examples. For example, if students were learning about the relationship between diet and the respiratory system, an instructor might first use a study as an example that showed high fat intake leading to bronchial hyperresponsiveness, but then also describe another study in which a fatty, meat-based diet led to a higher incidence of phlegmy coughs (both studies are mentioned in Wood et al., 2015). Doing this would help the students grasp the underlying abstract idea—that a high-fat diet can lead to respiratory issues—and make them more able to transfer this acquired knowledge to analogous situations in the future, such as a patient with certain eating patterns and a condition such as asthma.

Elaborative interrogation

Elaboration is one of the most frequently discussed concepts in the memory literature and is thought to greatly improve memory (Anderson, 1983). Elaboration is a very broad term that essentially means making connections or associations between what is to be learned and other memories, such as prior knowledge or personal memories (Hirschman, 2001). This can mean a lot of different things, but one strategy that seems to be effective at improving learning of more complex content is elaborative interrogation. The process of elaborative interrogation involves having students ask "how" and "why" questions, and then having them find the answers to those questions (Pressley, McDaniel, Turnure, Wood, & Ahmad, 1987). When compared to passive reading of the content, elaborative interrogation tends to improve student learning due to the connections made to prior knowledge and the additional information that students attach to the memory while answering how and why questions. Research has also shown that elaborative

[ii]For free visual depictions of each of the strategies, as well as other free resources, visit www.learningscientists.org/downloadable-materials. These materials can be given to students to help them utilize these strategies during independent learning, or used in the classroom.

interrogation is an effective strategy for students to use both on their own and in pairs (Woloshyn & Stockley, 1995).

For example, students studying in food science will likely need to learn about enzymes. If a student is reading text material about what enzymes are and the importance of enzymes in fermented foods, they could generate a number of elaborative interrogation questions about enzymes. For example: *How do enzymes decrease the activation energy of a reaction? How do biosystem conditions* (such as, *temperature, pH*) *affect enzyme activity*? *What are the ways of applying enzymes in food production*? *What are some problems caused by undesirable enzymes*? *How do we inactivate undesirable enzymes*? Given the breadth of the concept "Enzymes," an instructor may wish to break this topic down into smaller parts to guide students' questioning. For example, instructors could have students focus on enzymes used in food production, enzymes used by the body to breakdown macronutrients, enzymes used in specific food industry sectors, culinary uses of enzymes, and so on to ensure that students learn the most important material. Importantly, after the students generate these questions they should try to answer them. Figuring out the answer to the questions they are posing will help students understand the overall concept of enzymes, as well as the specific role enzymes play in a variety of diverse systems.

One important nuance of elaborative interrogation is that the quality of the elaborations may matter for student learning (Woloshyn & Stockley, 1995). Of course, ideally, students will be able to come up with accurate and detailed answers to their "how" and "why" questions, but depending on students' general understanding of the material and what they already know about the topics being studied—their background knowledge—this may not always happen. Some research has shown that elaborative interrogation tends to help students with a range of background knowledge from limited understanding of the material to relatively more extensive understanding (Ozgungor & Guthrie, 2004; Woloshyn, Pressley, & Schneider, 1992). Unsurprisingly, students with a more extensive understanding of the material tend to perform better overall than do students with a more limited understanding of the material (Woloshyn et al., 1992). However, other research suggests students need to at least have some general knowledge related to the to-be-learned information in order for elaborative interrogation to improve learning (Willoughby, Waller, Wood, & MacKinnon, 1993). Taken together, it seems that elaborative interrogation can be used even when students have a more limited knowledge base, so long as they have some background knowledge, but that care should be taken to help correct any misunderstandings and help students increase the quality of their elaborations over time. Because there has not been much research on elaborative interrogation in live classroom settings (see Sumeracki et al., 2018), instructors may need to adjust their use of the technique in their own classrooms depending on student ability. For example, instructors may need to provide a guide for students in how to come up with effective explanations, particularly in cases where students' familiarity with the material is low (Clinton, 2017; Clinton, Alibali, & Nathan, 2016). More research is needed to examine elaborative interrogation in the classroom, and specifically the quality of elaborations and how to improve them over the course of students' formal education.

Retrieval practice

Retrieval practice involves bringing information to mind from memory, and benefits learning in a number of different ways (Roediger, Putnam, & Smith, 2011). Retrieval practice has the potential to greatly improve student learning, and for that reason it has been suggested by a number of scholars that educators implement retrieval as a teaching strategy (for an example from Food Science, see Schell & Porter, 2018). Some of the benefits of retrieval are indirect, meaning that retrieval practice improves something else, and that thing improves learning. For example, when students bring information to mind on a practice test or a low-stakes quiz, they gain insight into what they know and what they do not know and are better able to allocate their study time in the future. However, retrieval practice also has a direct effect on learning. This means that even in the absence of feedback, the act of bringing information to mind itself reinforces our learning.

There are a number of ways to implement retrieval-based learning strategies in the classroom. One simple way is to provide students with a number of low-stakes or no-stakes quizzes or tests. Answering questions on quizzes and tests requires that students bring the information to mind. In fact, learning and memory researchers formerly referred to the benefits of retrieval practice as *the testing effect*, and retrieval via tests and quizzes is one of the most frequently studied ways of implementing retrieval practice. However, retrieval practice can be implemented without the use of a formal test or quiz. One example could be to guide students to be able to answer their elaborative interrogation questions from memory. Following the enzyme example from the previous section, students could take out a blank sheet of paper and write out the answers to questions such as *How do enzymes decrease the activation energy of a reaction? How do biosystem conditions (*e.g., *temperature, pH) affect enzyme activity?* and so on. Students could also work together to verbally describe and explain the answers to these questions from memory to one another, with a partner to help correct errors or fill in the gaps of what is retrieved. Students can bring information to mind while creating concept maps—an organizational structure containing concepts in "nodes" or "bubbles" with lines linking these concepts together and explaining the relationships among the concepts. When students create concept maps from memory, this can improve learning compared to when they simply read or even create concept maps with the material in front of them (Blunt & Karpicke, 2014). In the field of food science, for example, students could create a concept map around the topic of *water activity*, retrieving information from memory and adding it to the map via meaningful and well-thought-out connections. Instructors can even encourage the students to come up with ways that water activity might be useful in future industry jobs to add to the concept map, encouraging knowledge transfer.

Anecdotally, there are two main concerns that tend to arise when discussing retrieval practice to promote learning. The first concern is that frequent tests or quizzes in the classroom might be problematic because of test anxiety. This is a valid concern; those who research test anxiety indicate that it is commonly experienced by students and has a negative impact on academic performance (Maloney, Sattizahn, & Beilock, 2014). However, some research has indicated that frequent low-stakes or no-stakes quizzes may actually help to reduce test anxiety (Agarwal, D'Antonio, Roediger, McDermott, & McDaniel, 2014; Szpunar, Khan, & Schacter, 2013). Further, logically, the more frequently an instructor implements small tests and quizzes, the fewer points each individual test or quiz will be worth in the course, potentially reducing anxiety by reducing the stakes of each test or quiz.

The second main concern that tends to come up when discussing retrieval practice to promote learning is the distinction between rote memorization and conceptual understanding. The notion that basic facts and complex relationships rely on the same learning process has already been discussed in this paper, but it is important to note that retrieval practice is not only useful for learning facts, but is also just as useful for learning complex relationships. For example, in a set of experiments conducted by the first author (Megan Sumeracki, formerly Smith) and colleagues (Smith, Blunt, Whiffen, & Karpicke, 2016), compared to students who repeatedly read the material, students who practiced retrieval were better able to answer application questions that required the students to transfer what they learned to new situations that they had not read about. In one experiment, the students learned about the respiratory system. One week later, the students completed a learning assessment in which they answered questions about new situations that were not in the original text. For example, the students were asked to explain what would happen in the respiratory system if a person was in a very dusty environment; to explain what would happen to a person with Polio, a disease that can paralyze the muscles in the body; and to explain why cigarette smoke, which damages the cilia, would make it harder for someone to breathe. Practicing retrieval improved students' ability to accurately apply what they had learned and answer these questions, even though the students had never seen these specific questions before in the experiment.

Conclusion

Cognitive psychologists have been investigating how students learn for several decades, and many researchers are particularly interested in how the science of human learning can be applied to student learning in classroom environments. While it is important for students to acquire factual knowledge, a main goal of education is for the students to be able to understand complex content and transfer what they have learned to new situations. Instructors in food science and nutrition fields know that students must be able to transfer what they have learned from one subject to another, and must be able to apply the knowledge as professionals to be effective in their careers. Knowledge transfer can be difficult to achieve, but research demonstrates that particular evidence-based learning strategies can help. Instructors can implement the use of multiple concrete examples, elaborative interrogation, and retrieval practice to help promote meaningful learning and transfer in their courses.

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M. Sumeracki, Y. Weinstein-Jones, C. Nebel, and S. Schmidt collaboratively drafted the manuscript.

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