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COMMENTARY

Emerging and Future Directions in Test-Enhanced Learning Research

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Abstract

Over the past eighteen years, research into test-enhanced learning has expanded significantly and remains vibrant to this day. The fact that many major research questions in the literature have already been addressed, however, raises the question: "What's next?" That question motivates this special issue. We asked leading researchers in the field to contribute articles highlighting cutting-edge and new directions in test-enhanced learning research. The resulting review papers, empirical articles, and commentaries address many fascinating topics, including: (a) new approaches that are generating insights into test-enhanced learning in relation to other learning techniques (e.g., combining testing with *elaborative* or *generative learning* activities); (b) investigations of lesser-known test-based learning strategies that have the potential to enhance educational outcomes (e.g., *pretesting* and *prequestioning*, *spaced retrieval practice*, *test-potentiated new learning* or *forward testing*; and *successive relearning*); (c) new research on effective uses of practice testing during self-regulated learning and in other contexts; and (d) how to promote awareness and acceptance of test-enhanced learning among students and practitioners. These articles showcase some of the most promising new directions in test-enhanced learning research, so we anticipate that this special issue will inspire further investigations of practice testing and its educational applications.

Keywords Test-Enhanced Learning · Testing Effect · Retrieval Practice · Metacognition · Education

In 1989, the founding editor of *Educational Psychology Review*, John Glover, published an empirical demonstration of the *testing effect*—that is, the benefit of practicing recall of previously studied information (i.e., *retrieval practice*) on long-term memory for that information—in a now-classic article titled "The "Testing

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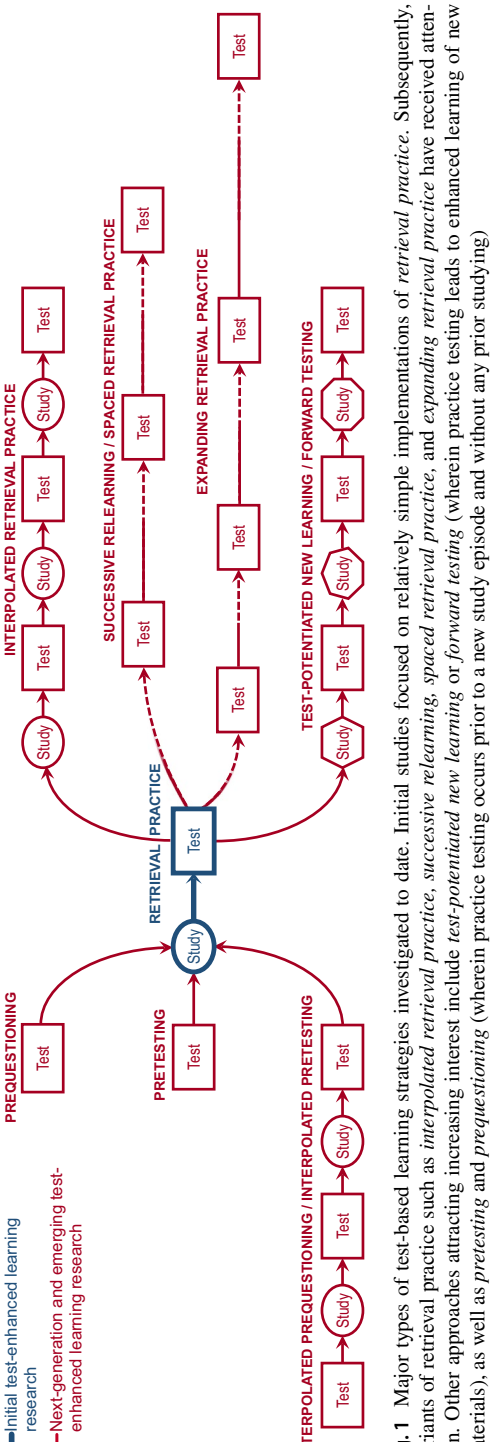

Fig. 1 Major types of test-based learning strategies investigated to date. Initial studies focused on relatively simple implementations of *retrieval practice*. Subsequently, variants of retrieval practice such as *interpolated retrieval practice*, *successive relearning*, *spaced retrieval practice*, and *expanding retrieval practice* have received attention. Other approaches attracting increasing interest include *test-potentiated new learning* or *forward testing* (wherein practice testing leads to enhanced learning of new materials), as well as *pretesting* and *prequestioning* (wherein practice testing occurs prior to a new study episode and without any prior studying)

Phenomenon: Not Gone but Nearly Forgotten" (Glover, 1989). In that article, Glover remarked that "surprising little educationally relevant research has been done on the topic in quite some time" (p. 392). Indeed, the handful of studies then available dated back many decades (e.g., Abbott, 1909; Spitzer, 1939; see also Kühn, 1914; Witasek, 1907), although more recent works had addressed the topic on largely theoretical grounds (e.g., Bjork, 1975; Izawa, 1970). Fast forward to the present day, however, and more than 1,200 peer-reviewed articles addressing the testing effect, retrieval practice, and/or *test-enhanced learning*—that is, the use of practice testing to improve learning, which encompasses retrieval practice and other test-based learning strategies (see Fig. 1 for a comparison of retrieval practice and related strategies)—have been published. In fact, over one hundred such articles have been published annually since 2018 (see Fig. 2), with many of those articles addressing educational implications and applications.

A Brief History of Contemporary Test-Enhanced Learning Research

The revival and rapid expansion of research on test-enhanced learning in the early twenty-first century is one of cognitive psychology and educational psychology's great success stories. By most accounts, that revival began about 18 years ago with a pair of articles—an empirical evaluation of the testing effect across short and longer retention intervals and a literature review—by Roediger and Karpicke (2006a, 2006b). These articles sparked a flurry of research on the testing effect and related phenomena. The earliest studies from this new era of testing-effect research focused on the degree to which practice testing impacts subsequent test performance. These

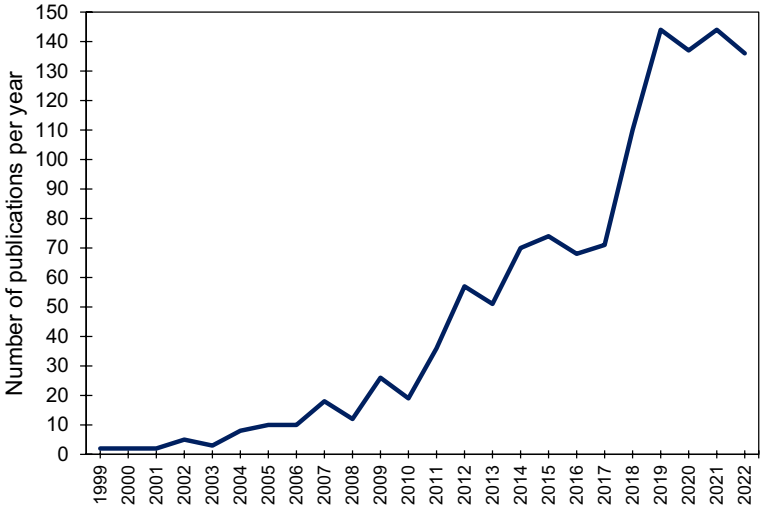

Fig. 2 Publication rates for peer-reviewed articles addressing the "testing effect", "retrieval practice", and/or "test-enhanced learning" from 1999 to 2022. In total, 1,215 such articles were published during that time frame. Results drawn from topic searches of Clarivate's Web of Science database conducted in early September 2023

Table 1 Growth and Evolution of the Contemporary Test-Enhanced Learning Literature

		Next generation and emerging research (~2010-present)	
Characteristic	Initial retrieval practice research (~2006–2010)	Retrieval practice-based strategies	Other test-based learning strategies
Type of practice testing	Retrieval practice Expanding retrieval practice Spaced retrieval practice	Retrieval practice Expanding retrieval practice Interpolated retrieval practice Spaced retrieval practice Successive relearning	Prequestioning Pretesting Interpolated prequestioning/pretesting Test-potentiated new learning/forward testing
Stimulus materials	Simple verbal materials Expository texts	Simple verbal materials Book chapters Expository texts Images/visual categories Mathematical functions Medical procedures Problem-solving materials	Simple verbal materials Book chapters Expository texts Images/visual categories Medical procedures Problem-solving materials
Learning outcomes	Memory	Memory Category learning Metacognitive monitoring Mind wandering Problem-solving skills Relearning/savings Test anxiety Transfer of learning	Memory Category learning Metacognitive monitoring Mind wandering Problem-solving skills Transfer of learning
Retention intervals	Immediate Minutes to hours > 24 h to a week	Immediate Seconds to minutes Minutes to hours > 24 h to weeks Weeks to months	Immediate Minutes to hours > 24 h to weeks

Table 1 (continued)

		Next generation and emerging research (~2010-present)	
Characteristic	Initial retrieval practice research (~2006–2010)	Retrieval practice-based strategies	Other test-based learning strategies
Reference conditions	No testing Restudy Rereading	No testing Restudy Rereading Copying Concept mapping Worked examples	No testing Reading Retrieval practice Restudy Study
Further issues and areas of focus	Effects of testing versus item reexposure	Dosage levels Individual differences Neural mechanisms Combined with elaborative, generative, or other learning strategies	Role of error generation and/or correction (pretesting) Combined with retrieval practice (pretesting) Neural mechanisms

For example references, the reader may wish to consult Dunlosky et al. (2013), Pan and Rickard (2018), Rowland (2014), and other reviews of the testing effect/retrieval practice literature

initial studies, which were beautifully systematic and well-executed, often featured simple verbal materials such as paired associate words (e.g., Carpenter & DeLosh, 2006), with retention intervals of up to one week (e.g., Roediger & Karpicke, 2006a), and comparisons of practice testing against reference conditions such as rereading, restudying, or no testing at all.

Within five years, the literature had extended in many directions beyond demonstrating the testing effect itself, giving rise to a next generation of test-enhanced learning research that is flourishing today. Such research differs from prior work in several ways (see Table 1 for a comparison of the characteristics of initial versus later studies of test-enhanced learning). For instance, the learning materials that are being used have expanded beyond simple verbal materials to a wide range of stimuli (for discussions see Pan & Rickard, 2018; Rowland, 2014; for a listing, see Rawson & Dunlosky, 2011) varying from mathematical functions (e.g., Kang et al., 2011) to medical procedures (e.g., Larsen et al., 2013). Such learning materials have been investigated in different subject domains ranging from history to the physical sciences (e.g., McDaniel et al., 2011; McDermott et al., 2014). In addition, researchers have explored the effectiveness of different variants of retrieval practice-based strategies and other forms of practice testing (e.g., Rawson & Dunlosky, 2011; Richland et al., 2009; for examples, see Fig. 2). Retrieval practice as a learning strategy is further being compared against other potentially more competitive learning strategies such as concept mapping or the study of worked examples (e.g., Karpicke & Blunt, 2011; van Gog & Kester, 2012). Learning outcomes other than memory retention such as transfer of learning, category induction, and problem-solving skills are being measured as well (e.g., Butler, 2010; Jacoby et al., 2010; Leahy et al., 2015).

Test-enhanced learning research has also expanded beyond addressing the impact of practice testing on subsequent test performance to investigating effects on other educationally-relevant factors such as self-regulated learning, metacognitive monitoring, and test anxiety, among others (e.g., Agarwal et al., 2014; Tullis et al., 2013). The idea here is that if practice testing also has a positive impact on these factors (e.g., if testing reduces anxiety), then doing so should also have (an indirect) impact on performance (e.g., reducing anxiety can increase test performance). Further, in line with an educational emphasis, some researchers have transitioned from examining practice testing in laboratory settings to conducting studies in classrooms and other authentic educational contexts (e.g., Foss & Pirozzolo, 2017; McDaniel et al., 2011; Rawson et al., 2013). Such studies have evaluated whether the benefits of practice testing survive in circumstances wherein student learning is potentially impacted by the many other activities that may occur in such contexts (e.g., self-regulated learning behaviors; peer discussion, classroom exercises, etc.).

Overall, the preponderance of evidence to date suggests that test-enhanced learning in the form of retrieval practice is highly beneficial for learning, subsequent test performance, and for the other factors mentioned above. Consistent with that observation, several expert reviews have concluded that retrieval practice is one of the most effective learning strategies (e.g., Carpenter et al., 2022; Dunlosky et al., 2013; Pashler et al., 2007; see also Carpenter, 2023, McDaniel, 2023, Murphy et al., 2023, Pan & Carpenter, 2023; and Yang et al., 2023 in this special issue), with the capacity to enhance learning for different age groups, for a wide range of learning materials,

and in diverse learning contexts. Largely owing to a lack of evidence, however, a strong consensus has yet to emerge with respect to other forms of practice testing (Pashler et al., 2007; see also Dunlosky et al., 2013).

Emerging Directions in Test-Enhanced Learning Research

Given the size and scope of the test-enhanced learning literature, one might expect that many research questions in that literature have already been answered. Indeed, with respect to retrieval practice, a great deal of progress has occurred on empirical, theoretical, and practical fronts. For summaries of key findings focusing on retrieval practice, interested readers can consult a host of review articles and summaries (e.g., Carpenter, 2012; Karpicke, 2012; Karpicke & Grimaldi, 2012; McDermott, 2021; Roediger & Butler, 2011; van den Broek et al., 2016; van Gog & Sweller, 2015), meta-analyses (e.g., Adesope et al., 2017; Pan & Rickard, 2018; Rowland, 2014; Yang et al., 2021), article databases (e.g., Rawson & Dunlosky, 2011; Rickard & Pan, 2018), and book chapters (e.g., Delaney et al., 2010; Karpicke et al., 2014; Kornell & Vaughn, 2016; Roediger et al., 2010, 2011). An examination of those works and conversations with researchers in the field, however, reveals that although much of this work is laudably cumulative, important research questions and topics that have yet to be fully addressed or explained and new questions have arisen. Some of these questions and topics involve retrieval practice, whereas others involve alternative approaches to practice testing.

Titled "Test-Enhanced Learning and Testing in Education: Contemporary Perspectives and Insights," this special issue highlights many of those research questions and topics. It features over a dozen contributions by leading researchers of test-enhanced learning from around the world. These contributions include five review papers, five empirical articles, and three commentaries. As described next, at least four major research themes and four variants of practice testing are addressed (see Table 2 for further details).

Combining, Complementing, and Comparing Practice Testing with Other Learning Strategies

Two review articles in this special issue, McDaniel (2023) and Roelle et al. (2023), discuss an innovative approach to test-enhanced learning research: investigations of retrieval practice in combination with, or in complement to, other kinds of learning strategies. McDaniel (2023) focuses on the combination of retrieval practice with *elaborative encoding* strategies (wherein information is made more memorable by imbuing it with additional meaning, e.g., semantic elaboration, self-explanation, and the keyword mnemonic) and finds that the evidence to date supports using such strategies for learning prior to, but not during, retrieval practice. It is concluded that doing so can yield better learning than retrieval practice alone. Roelle et al. (2023) highlights commonalities in research on *generative learning* (wherein information is made more meaningful by mental reorganization and/or integration with preexisting

Table 2 Types of Test-Enhanced Learning and Research Topics Addressed in the Special Issue

		Special issue articles		
Classification Method	Classification	Review articles	Empirical articles	Commentaries/Reflections
Type of practice testing	Retrieval practice	Carpenter (2023) McDaniel (2023) Roelle et al. (2023) Yang et al. (2023)	Badali et al. (2023)	Agarwal (2023) Murphy et al. (2023) Sumeracki et al. (2024)
	Spaced retrieval practice		Higham et al. (2023)	
	Prequestioning and pretesting	Pan and Carpenter (2023)	Soderstrom and Bjork (2023)	Murphy et al. (2023)
	Test-potentiated new learning/forward testing		Davis and Chan (2023) Kang et al. (2023)	
Research topics	Combining, complementing, or comparing test-enhanced learning with other learning strategies	McDaniel (2023) Roelle et al. (2023)	Higham et al. (2023) Kang et al. (2023)	
	Metacognitive factors and self-regulated learning	Carpenter (2023)	Badali et al. (2023) Davis and Chan (2023) Higham et al. (2023) Soderstrom and Bjork (2023)	
	Application to educational contexts	Carpenter (2023) McDaniel (2023) Roelle et al. (2023) Pan and Carpenter (2023) Yang et al. (2023)	Badali et al. (2023) Davis and Chan (2023) Higham et al. (2023) Kang et al. (2023) Soderstrom and Bjork (2023)	Agarwal (2023) Murphy et al. (2023) Sumeracki et al. (2024)
	Communicating and promoting test-enhanced learning	Carpenter (2023)		Agarwal (2023) Sumeracki et al. (2024)

knowledge; e.g., drawing activities, prompted self-explanation) and retrieval practice. Whereas the literatures on both types of learning strategies have historically unfolded along separate and even antagonistic lines, Roelle et al. concludes that an investigative approach that treats both types of learning strategies as complementary and achieving different aims can yield valuable insights. They also identify investigative criteria that promise to clarify relationships between the two types of learning strategies.

In a related vein, two empirical articles in this special issue, Kang et al. (2023) and Higham et al. (2023), explore novel combinations or comparisons of test-enhanced learning with other learning strategies. As detailed in the following section of this article, both studies reveal circumstances wherein the combination of practice testing and other learning strategies may or may not be beneficial for learning, relative to testing alone or strategies that do not involve testing at all.

New and Emerging Approaches to Practice Testing

Whereas the contemporary test-enhanced learning literature began with a focus on relatively simple implementations of retrieval practice, an entire family of diverse approaches to practice testing—from *successive relearning* to *pretesting*—is now under investigation. To help illustrate such approaches, Fig. 1 presents an overview of different ways to implement test-enhanced learning. At the center of the figure is retrieval practice, the most heavily-investigated approach. Alternative approaches that involve additional practice tests after studying, as well as approaches that involve practice tests interspersed with study of new materials, are detailed on the right side of the figure. Approaches that involve practice testing prior to studying are detailed on the left side of the figure.

In addition, Table 1 details some of the major characteristics of ongoing research on different approaches to practice testing, whereas Table 2 highlights emerging approaches to practice testing that are addressed in this special issue. As noted in the second table, different approaches to practice testing are discussed across multiple articles in the special issue. Neither table is exhaustive of all the emerging trends but instead is meant to showcase the main trends in the special issue and to encourage further research.

Pan and Carpenter's (2023) contribution to the special issue consists of the first comprehensive review of the literature on *prequestioning* and *pretesting effects* (i.e., practice testing prior to the study of to-be-learned information, as opposed to afterwards). Their review suggests that prequestioning and pretesting can, in a variety of circumstances, improve learning outcomes substantially. The need for further research on prequestioning in authentic educational environments is also indicated, and one of the first examples of such research, a classroom study by Soderstrom and Bjork (2023), is included in the special issue. In that study, which was conducted across 10 weeks of an undergraduate research methods course, having students take pretests at the start of lecture sessions improved memory and transfer performance on high-stakes exams at the end of

the course. These results constitute a compelling demonstration of the benefits of pretesting for student learning (for a related commentary, see Carey, 2014).

Two empirical articles in the special issue, Kang et al. (2023) and Davis and Chan (2023), address *forward testing* (i.e., *test-potentiated new learning*). With forward testing, learners engage in retrieval practice prior to learning new sets of materials. Typically, the learning of those materials (as compared to when no retrieval practice occurs prior to learning the new materials) is also enhanced, a phenomenon called the *forward testing effect*. Kang et al. (2023) demonstrates that the combination of forward testing with feature highlighting may not yield greater learning benefits than forward testing alone for learning natural categories. Using forward testing with prose materials, Davis and Chan investigate potential theoretical mechanisms by manipulating test format and obtaining metacognitive judgments, and in so doing provide further insights into the basis for the forward testing effect.

Higham et al. (2023) addresses *spaced retrieval practice,* which itself is a combination of retrieval practice and *distributed practice* (i.e., retrieval practice that is spaced across sessions, an approach to practice testing that combines the potency of the two most effective learning strategies known to learning science). They compare the efficacy of spaced retrieval practice against spaced restudy and find the former is more effective than the latter except when memory ratings are incorporated into practice trials. Those results also have potential implications for a related test-based learning strategy, *successive relearning*. Similar to spaced retrieval practice, successive relearning entails performing retrieval practice across multiple sessions, but requires practicing retrieval to a set criterion within each session (Rawson & Dunlosky, 2022).

Educational Applications and Promoting Effective Uses of Practice Testing

This special issue also includes a series of articles that focus specifically on educational applications of test-enhanced learning as opposed to basic memory or other types of research. One of these articles, a meta-analysis by Yang et al. (2023), addresses effects of practice testing on test anxiety. The results of this meta-analysis, which incorporates findings from 24 empirical studies, reveal that practice testing reduces test anxiety to a medium extent (in effect size terms, a reduction of Hedges' $g = -0.52$). That finding is a welcome antidote to lingering concerns that such testing might in fact do the opposite, a concern that now appears to be unfounded.

An empirical study by Badali et al. (2023) and a commentary by Murphy et al. (2023) provide useful insights into how practice testing can be applied more effectively. Badali et al. investigates how learners use multiple-choice practice tests during self-regulated learning and researcher-controlled conditions, and in so doing provides preliminary answers to the question, Do students' regulate their use of testing in an effective manner? Murphy et al. (2023) offers a host of recommendations for the use of practice testing more generally, including with respect to dosage levels, test formats, the timing of testing, and much more. Both articles present conclusions that students and/or instructors can readily translate into practice.

Despite an abundance of evidence to the contrary, a popular conception of tests as solely for assessment remains a barrier to the widespread use of practice testing (i.e.,

Table 3 Future Directions for Test-Enhanced Learning Research

Theme	Research questions raised in special issue articles
Combining or complementing practice testing with other learning strategies	■ To what extent does combining practice testing with other active learning strategies benefit learning? • How do such combinations (e.g., elaborative learning activities or generative learning activities) influence student learning, achievement, engagement, and motivation? • Are there synergistic effects of such combinations? Deleterious effects of such combinations? Boundary conditions on such combinations? • What are the ideal combinations of strategies?
Comparing practice testing strategies, including with other learning strategies	■ How does practice testing compare to alternative learning strategies? • Other active learning strategies (e.g., elaborative learning activities)? • Potentially competitive forms of restudying (e.g., spaced restudying)? ■ What are the relative benefits of different forms of practice testing (e.g., pretesting vs. retrieval practice)?
New and emerging approaches to practice testing	■ What are the effects of new or relatively unexplored approaches to practice testing (e.g., pretesting, prequestioning, successive relearning, test-potentiated new learning/forward testing, etc.) in authentic educational settings? • What are the cognitive mechanisms involved in the learning benefits of such approaches? • What are the implementation factors, moderators, and boundary conditions on their effects for learning?
Educational applications of practice testing	■ How effective is practice testing in authentic educational settings and for important educational outcomes? • When used to learn different academic disciplines, including science, technology, engineering, and mathematics (STEM) and non-STEM disciplines? • In longitudinal studies, including studies involving multiple sessions? • For academic achievement, retention rates, and ameliorating equity gaps? ■ To what extent do individual differences exist in the effects of practice testing on academic achievement, test anxiety, and other learning outcomes? ■ How is practice testing used in self-regulated learning? • What kinds of decisions do students make when engaging in practice testing during self-regulated learning? • How do students use resources (where available) to engage in practice testing? • What do qualitative data—e.g., surveys or interviews—reveal about the decisions students make while engaging in practice testing?
Promoting effective uses of practice testing	■ What kinds of interventions are successful at promoting acceptance and the use of practice testing? • How can one overcome barriers to public acceptance and student/instructor use of practice testing? • How effective are such interventions across extended time intervals?

instructors and students commonly view practice tests as only useful to measure as opposed to enhance learning). A review by Carpenter (2023) and commentaries by Agarwal (2023) and Sumeracki et al. (2024) provide evidence-based guidance, expert perspectives, and/or insightful anecdotes that can help overcome this barrier. Carpenter's review details five types of interventions—from giving learners the chance to experience retrieval practice to providing feedback on its benefits—that can spur students to adopt retrieval practice during self-regulated learning. Agarwal's commentary describes the author's personal experiences in science communication and her efforts to spread awareness of retrieval practice to sometimes-skeptical instructors, policymakers, and other individuals. It also provides actionable recommendations for how scientists can better communicate and persuade others to embrace the use of practice testing, including ways to dispel misperceptions about the nature and consequences of testing. Sumeracki et al.'s commentary discusses potential "roadblocks" that may impede the adoption of practice testing in authentic educational environments, potential ways to overcome those roadblocks, and the need for additional related research. Overall, the contributions from Agarwal (2023), Carpenter (2023), Sumeracki et al. (2024), and Murphy et al. (2023), along with the perspectives shared in many other articles in this special issue, offer a wealth of insights into how test-enhanced learning can be translated to real-world settings for positive impacts.

Future Directions for the Field

Every article in this special issue mentions or alludes to potential directions for future research. An overview of major research questions that are posed in those articles is presented in Table 3. As detailed in that table, future work on test-enhanced learning can be categorized into the different themes addressed in this special issue. Going forward, research in this field may very well revolve around those questions.

Over the past decade-and-half, researchers have uncovered a great deal about test-enhanced learning. As the articles in this special issue indicate, however, that work is far from over. There remain many unanswered research questions, under-explored approaches to practice testing, and other dimensions of test-enhanced learning that have yet to be thoroughly investigated. Hence, although this special issue reflects the culmination of years of very detailed, impressive, and insightful work, it also constitutes a call for further research. Such research is poised to reveal many more fascinating insights about practice testing and may help evolve the role of testing in education in the years to come.

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