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Deliberate Practice and Mastery Learning Contributions to Medical Education and Improved Healthcare

William C. McGaghie[1], Diane B. Wayne[1,2], Jeffrey H. Barsuk[1,2], and S. Barry Issenberg[3]

[1]Department of Medical Education and Northwestern Simulation, Northwestern University Feinberg School of Medicine, USA
[2]Department of Medicine, Northwestern University Feinberg School of Medicine, USA
[3]Gordon Center for Research in Medical Education, University of Miami Miller School of Medicine, USA

Correspondence: William C. McGaghie, wcmc@northwestern.edu

Abstract

K. Anders Ericsson was a scholarly giant who not only left an authoritative legacy in contemporary psychology but also forever impacted medical education and patient care. His groundbreaking work on deliberate practice has inspired scientists and medical educators to study and improve professional expertise in service of science and public welfare. This article celebrates Ericsson's scholarship in three categories. First, by acknowledging its key contributions to theory and medical education engineering and science. Second, by documenting Ericsson's research impact on medical education from empirical findings, its influence on mastery learning research and development by our group and other scholars, and by shaping new directions for medical learning and teaching. Third, the article addresses the road ahead in medical education that includes scholarly arguments and practical barriers revealed by Ericsson's research and writing. We conclude with a short reflection about Anders Ericsson's work, life, and gifts of mentorship.

Keywords

Deliberate practice, mastery learning, medical education, healthcare

Introduction

Medical education aims to help physicians learn the knowledge, clinical skills, acumen, and professionalism needed for patient care. Learning standards for physicians must be uniformly high because the public expects to receive the best possible healthcare, medical services that fulfill the Institute of Medicine's (2001) six aims for quality patient care: safety, effectiveness, patient centered, timely, efficient, and equitable. High healthcare expectations are in place for physicians in all medical specialties at all career stages. This motivates undergraduate, graduate, and continuing medical educators to continuously re-engineer their curricula in response to scientific and technological advancements, cultural shifts, economic incentives, and social imperatives. Medical education is challenging, thought-provoking work because curriculum leaders must plan, implement, calibrate, evaluate, and revise curricula as needed to accomplish high achievement standards that meet society's expectations using state-of-the-art education thinking and instruction methods. Individual and community health depends on the clinical expertise of a medical workforce that is educated with rigor, foresight, and attention to the commonweal.

This article is one of a set of eight contributions that together comprise a *Festschrift* in honor of K. Anders Ericsson for this issue of the *Journal of Expertise.* The article shows that Ericsson's scholarly reach extends far beyond its home in academic psychology. Medical education research sparked by Anders' scholarship on deliberate practice (DP) has produced compelling new data about physician skill acquisition and maintenance. These investigations are having a profound effect on traditional medical education, moving dated apprenticeship training approaches toward more rigorous, evidence-based models. The impact of Ericsson's research and writing is seen every day in the education of physicians and other health professionals. Ericsson's work on DP, now a basic principle of medical education and mastery training, will continue to impact countless patients and their health outcomes.

There are two foundation ideas about medical education that warrant early expression in this article. The first is *education engineering*, the work needed to design, develop, implement, and calibrate rigorous curricula and learning programs in medical education. Medical curriculum plans that introduce DP principles into standard training are an innovation in education engineering. The second is *education science*, precise, robust studies intended to address such questions as, "Can key features of expert clinical practice be isolated and used as a basis for education and training?" [and] "Do the curricula and education programs that use DP work? If the curricula work, how and why?" Ericsson's groundbreaking research on DP toward the goal of acquiring expertise needs to be understood in the medical education context as a curriculum engineering success and an education science challenge.

This article is written as a selective, narrative review (McGaghie, 2015) which is the format Anders Ericsson preferred for much of his synthetic scholarship. The present article has three sections that address Anders Ericsson's lasting influence on medical education and healthcare: (a) key contributions to theory and medical education engineering and science; (b) research impact on medical education from empirical findings, research and development by our own group and other scholars, and by shaping new directions for medical learning and teaching; and (c) the road ahead in medical education including scholarly arguments and practical barriers. We conclude with personal reflections about the work and life of Anders Ericsson including his scholarly legacy, character, and mentorship.

Key Contributions

We choose to cast Anders Ericsson's key contributions to medical education and healthcare into two connected categories: (a) theory—paradigm shift ideas, and (b) engineering and scientific methods. Rich, precise theoretical principles drawn from Ericsson's work have led to improved practice in medical education engineering and science.

Theory—Paradigm Shift Ideas

An historical premise in academic psychology is that individual human differences grounded in heredity (Galton, 1869) and measured by intelligence and standardized aptitude and education achievement tests (DeBoeck et al., 2020; Sternberg, 2020) are chiefly responsible for variation in skill and knowledge acquisition and the formation of expertise. Innate capacities are also hypothesized to make collateral contributions to social, professional, and economic life success (Herrnstein & Murray, 1994; Devlin et al., 1997). This argument for the hereditary origins of expertise, formerly called genius, is a foundation historical doctrine of Western academic psychology whose cornerstone is measurement and statistical technologies that rely on a normal distribution of results (DeBoeck et al., 2020; Sternberg, 2020).

Anders Ericsson became prominent among medical educators from publication of a 1993 *Psychological Review* article with a thesis contrary to historical doctrine about the innate origins of expertise (Ericsson et al., 1993). The article reviewed evidence and presented new data that gave rise to a key dissenting argument, "Individual differences, even among elite performers, are clearly related to assessed amounts of deliberate practice. Many characteristics once believed to reflect innate talent are actually the result of intense practice extended for a minimum of 10 years" (p. 303). Ericsson later extended the argument by stating, "When someone has gained special skills or knowledge representing mastery of a particular subject through experience and instruction, we call this person an expert" (Ericsson, 2014, p. R508).

Deliberate practice involves sustained hard work, feedback, and perseverance under exacting conditions. Ericsson et al. (1993) state, ". . . deliberate practice is a highly structured activity, the explicit goal of which is to improve performance. Specific tasks are invented to overcome weaknesses, and performance is carefully monitored to provide cues [feedback] for ways to improve . . . deliberate practice requires effort. Individuals are motivated to practice because practice improves performance . . . with no immediate monetary awards" (p. 368). Ericsson and Pool (2016) later extended the DP definition by adding several conditions: DP is confined to a well-defined domain, requires involvement by a coach or teacher to create and manage practice activities, takes learners beyond their comfort zone, requires full attention and concentration, and breeds effective mental representations that are refined and improved with practice.

Ericsson's work has so impacted modern psychology that his groundbreaking DP research is now accepted vocabulary. For example, Nobel Laureate Daniel Kahneman in his book, *Thinking, Fast and Slow* (2011) clearly endorses DP principles. Kahneman (2011) writes, "The acquisition of skills requires a regular environment, an adequate opportunity to practice, and rapid and unequivocal feedback about the correctness of thoughts and actions. When these conditions are fulfilled, skill eventually develops, and the intuitive judgments and choices that quickly come to mind will mostly be accurate" (p. 416).

The Ericsson et al. (1993) DP article contributes to a paradigm shift in academic psychology (Kuhn, 2012) and reinforces behavioral ideas from several early contrarian scholars including John B. Watson (1924) and David McClelland (1973) who present arguments opposed to psychological orthodoxy about the acquisition of expertise. These arguments grounded in behavioral psychology are amplified in selected contemporary work such as Angela Duckworth's book, *Grit: The power of passion and perseverance* (2016), concerning a personality variable associated with conscientiousness that contributes to expertise. Arguments about the behavioral and DP origins of expertise and expert performance, compared to the innate view of their etiology, also coincide with more recent notions of practical intelligence advanced by Robert Sternberg and his protégés (Cianciolo & Sternberg, 2018; Sternberg et al., 2000).

This short chronicle on a historical rivalry of ideas in academic psychology illustrates contrasting expressions about the heritability of individual human capacities. However, the strict and interminable nature vs. nurture debate about the origins of expertise is now considered overly simplified because of research evidence that has informed and enriched the discussion. For example, a recent counterpoint to the primacy of DP argues that the construct is a necessary but not a sufficient condition for the acquisition of expertise (Hambrick et al., 2020). This is due, in part, to the imprecise definition and measurement of DP and its insufficiency to explain the growth of expertise without accounting for other variables including individual maturation and development, character and personality, a wide variety of life experiences, and measured cognitive ability (Ackerman, 2020; Hambrick et al., 2020).

There is no doubt that cognitive capacity boosts expertise. However, just like DP, cognitive capacity is a necessary but not a sufficient condition to become an expert. Academic aptitude, access to education resources, opportunities to practice and receive feedback, personal ambition, and other variables including emotional intelligence (MacCann et al., 2020) all contribute to expert performance.

The argument that expert performance has several sources is especially salient in the medical profession and its feeder system of medical education. Individuals who seek and gain access to medical education have high cognitive abilities assessed through a sequence of rigorous individual and institutional selection decisions to receive a place in medical school. Traditionally, scores on the Medical College Admission Test (MCAT) and excellent college grades are the most important criteria for medical school admission. However, evidence and experience suggest that beyond an aptitude threshold the value added of cognitive increments is unknown (Antonovsky, 1987; McGaghie, 1990). After psychometric winnowing and selective admission policies, the practical result is a high and restricted range of talent among medical students. The upshot is that there is negligible post-selection variation in academic aptitude among medical students, which yields little or no medical student attrition for academic reasons (AAMC Data Snapshot, 2018). As a result, medical schools are ideal environments that enable DP to be the engine that drives these students toward learning and expert performance.

In short, medical students, postgraduate residents, subspecialty fellows, and practicing physicians benefit from DP experiences in many ways because they are smart, well-prepared, goal-directed, conscientious, motivated, hardworking, and value social and public health priorities. Such conditions dilute the influence of innate capacities because as Hambrick et al. (2020) point out, "if an environmental intervention [powerful education] were introduced that allowed nearly everyone to reach about the same level of skill in some task [the influence of] heritability would be expected to decrease" (p. 14). Anders Ericsson (2018) agreed by asserting, "Scores on tests of cognitive ability [e.g., MCAT] and intelligence are primarily correlated with performance of beginners, and the correlations diminish as higher performance is attained through the mediation of acquired mechanisms" (p. 763).

Medical Education Engineering and Science

In addition to his groundbreaking work on DP, Anders Ericsson pioneered the expert performance perspective (EPP) to study expertise. Medical educators employ the EPP which uses rigorous, controlled laboratory research methods to identify and isolate key behavioral variables in medicine and healthcare (Ericsson 2007, 2015). Ullèn et al. (2016) state, "The expert performance framework emphasizes the importance of studying *expert performance* using objective measures of performance on standardized, representative tasks rather than more indirect indices of expertise, such as estimates by raters, credentials, or educational level" (p. 428). Laboratory isolation and reproduction of the behavioral variables are used as a point-of-departure to identify essential training goals and build medical curricula.

The EPP approach has been employed under several guises to study the clinical behavior of physicians and other healthcare providers to inform curriculum and education design decisions. For example, studies of neurosurgeons' eye movements have disclosed that variations in visual efficiency (focus level, search pattern) are associated with level of microsurgical skill, eye control, stability, and focusing (Eivazi et al., 2017; Dalvern & Cagiltay, 2020). Research in anesthesiology has demonstrated a linear relationship between time needed to complete a simulated patient intubation and the number of hand movements recorded during the procedure (Trung et al., 2014). Research on psychotherapy processes and expert performance has established a strong link between therapists' targeted time spent on improving therapeutic skills and client outcomes (Chow et al., 2015; Miller et al., 2018). This work has been distilled by Miller et al. (2017) into a set of three steps informed by DP that, "when followed, result in improved [psychotherapy] performance: (1) determining a baseline level of effectiveness; (2) obtaining systematic, ongoing feedback on actual performance; and (3) successive refinement through repetition targeted at objectives just beyond an individual's current level of achievement" (p. 733).

Data derived from EPP studies and other evidence-based sources are subsequently used to engineer powerful education interventions

(Barsuk & Salzman, 2020). The education interventions are delivered via several technologies, especially DP that is enhanced by simulation, smart systems, and environmental engineering to promote medical skill and knowledge acquisition, refinement, and retention (Barsuk & Salzman, 2020; Laufer et al., 2015; Laufer et al., 2017; McGaghie et al., 2020).

The Northwestern University medical simulation education team has distilled Ericsson and colleagues' (1993, 2016) principles of DP into a practical bundle of ten integrated components (McGaghie, Adler, & Salzman, 2020). The bundle starts with ready and ambitious learners, introduces education challenges including DP, measures results, and seeks constant improvement. Bundle components are as follows:

1. Highly motivated learners with good concentration;
2. Engagement with a well-defined learning objective or task at an;
3. Appropriate level of difficulty with;
4. Focused, *deliberate practice* that leads to;
5. Rigorous, precise, and reliable measurements that yield;
6. Actionable feedback from education sources (e.g., simulators, teachers) and where;
7. Trainees also monitor their learning experiences and correct strategies, errors, and levels of understanding, engage in more DP, and continue with;
8. Assessment to reach a rigorous *mastery* standard and then;
9. Advance to another task or unit;
10. Goal: constant improvement

This DP bundle has been used with several variations to shape medical education interventions at Northwestern University and other institutions for more than 15 years (McGaghie et al., 2020a).

Reliable measurement, in the manner of EPP, is an essential bundle feature. These metrics, which do not rely on normal curve assumptions (Downing, 2004; van der Vleuten & Schuwirth, 2005), are needed for formative assessment and to reach valid judgments and decisions about learners including feedback for performance improvement, advancement of individuals within curricula, graduation and clinical competence certification, and program evaluation that may include outcomes research (Downing, 2003; O'Brien et al., 2020). The power of DP in medical education is revealed from its measured impact on learning and its contribution to trainee mastery of essential clinical skills.

Impact on Medical Education

Our medical education research group first acknowledged DP as an important variable for the acquisition of medical expertise in an article titled "Simulation technology for health care professional skills training and assessment" (Issenberg et al., 1999). Citing the Ericsson et al. (1993) article, we wrote, "The most important identifiable factor separating the elite performer from others is the amount of 'deliberate practice.' This includes practice undertaken over a long period of time to attain excellence as well as the amount of ongoing effort required to maintain it" (p. 862). Subsequently, Ericsson's medical education profile received a boost worldwide from publication of an invited review in the Association of American Medical College's flagship journal, *Academic Medicine* where he discussed ". . . the acquisition and maintenance of expert performance in medicine and examine[d] the role of deliberate practice in this domain" (Ericsson, 2004, p. S70).

The lasting impact of DP research and technology in medical education is seen from at least three measures of influence: (a) empirical findings, (b) mastery learning, and (c) new directions for learning and teaching.

Empirical Findings

There is no doubt that DP is an effective mechanism to boost knowledge and skill acquisition among medical learners. Scores of research studies, many cited and summarized in Ericsson's scholarship (Ericsson, 2004, 2008, 2015; Ericsson & Pool, 2016) testify to the statistical and educational significance of DP as a powerful education mechanism in medical training. To illustrate, an early systematic review documented that repetitive [deliberate] practice is a central feature of high-fidelity medical simulations that lead to effective learning (Issenberg et al., 2005). A derivative report from the systematic review revealed a dose-response relationship between the intensity of practice and standardized medical learning outcomes (McGaghie et al., 2006).

Deliberate practice has demonstrated its power and utility as a training variable for acquisition of expertise among medical teams, especially regarding adult (Wayne et al., 2008; Didwania et al., 2011) and pediatric (Cordero et al., 2013; Lemke et al., 2019) resuscitation teams. A recent summary about team DP in medicine and related domains has been published by Harris and colleagues (2017).

The comparative power of DP in medical education has been demonstrated in a systematic, meta-analytic, head-to-head contrast of traditional clinical education based on patient care experience versus simulation-based medical education (SBME) with DP (McGaghie, Issenberg, Cohen, et al., 2011). Quantitative aggregation and analysis of 14 studies involving 633 learners shows that without exception and with very high statistical confidence SBME with DP yields superior education results compared to clinical experience alone (Figure 1). Every study contained in the meta-analysis exceeds the null value without statistical overlap. The effect size for the overall difference between SBME with DP and traditional clinical education is expressed as a Cohen's *d* coefficient = 2.00 (McGaghie & Kristopaitis, 2015). This is a very large difference, a magnitude without precedent in comparative medical education research.

	Statistics for each study				
Research design and study	**Correlation**	**Lower limit**	**Upper limit**	***P*-Value**	**Correlation and 95% CI**
Randomized trials					
1. Wayne et al, 2005[21]	0.81	0.70	0.88	.000	
2. Ahlberg et al, 2007[22]	0.80	0.56	0.91	.000	
3. Andreatta et al, 2006[23]	0.67	0.40	0.84	.000	
4. Korndorffer et al, 2005[24]	0.62	0.29	0.82	.001	
5. Korndorffer et al, 2005[25]	0.52	0.17	0.75	.006	
6. Van Sickle et al, 2008[26]	0.51	0.17	0.74	.005	
Cohort studies					
7. Issenberg et al, 2002[27]	0.78	0.73	0.82	.000	
8. Barsuk et al, 2009[28]	0.61	0.29	0.81	.001	
9. Butter et al 2010[29]	0.59	0.47	0.69	.000	
Case-control studies					
10. Wayne et al, 2008[30]	0.51	0.29	0.68	.000	
Pre-post baseline studies					
11. Wayne et al, 2008[31]	0.80	0.72	0.86	.000	
12. Barsuk et al, 2009[32]	0.79	0.70	0.86	.000	
13. Barsuk et al, 2009[33]	0.77	0.71	0.82	.000	
14. Stefanidis et al, 2006[34]	0.71	0.55	0.83	.000	
Overall effect size	0.71	0.65	0.76	.000	

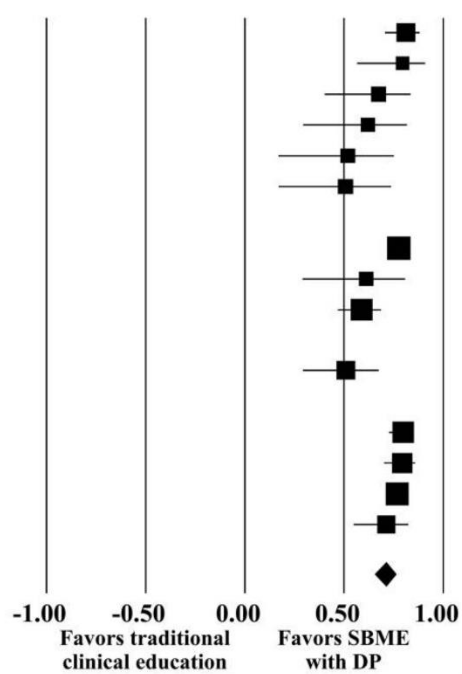

Figure 1. Random-effects meta-analysis of traditional clinical education compared to simulation-based medical education (SBME) with deliberate practice (DP). Effect size correlations with 95% confidence intervals (95% CI) represent the 14 studies included in the meta-analysis. The diamond represents the pooled overall effect size. Source: McGaghie, Issenberg, Cohen, et al. (2011). Reprinted with permission from Wolters Kluwer Health.

Mastery Learning

Mastery learning is a hybrid approach to education engineering grounded in behavioral, constructivist, and social cognitive theoretical traditions (McGaghie & Harris, 2018). Mastery learning uses DP as a foundation to build an even stronger education intervention that highlights baseline and formative assessment, rigorous learning standards as a requirement for education advancement, and opportunities for continued deliberate practice until a high minimum passing standard (MPS) is reached. A premise of mastery learning is that learning time can vary while outcomes are uniform. Mastery learning sets a lofty expectation of "excellence for all," where high achievement is attained among all members of a learner group with little or no outcome variation (McGaghie, 2020; McGaghie et al., 2015). Mastery learning operates best in a psychologically safe environment where assessments identify learning deficits and flaws which are then improved by trainees working together with skillful teachers and coaches. Mastery learning embodies an environmental intervention designed to allow all learners to reach the same level of skill on important tasks, which trumps the presumptive influence of innate attributes as pointed out by Hambrick et al. (2020). Figure 2 (next page) identifies the elements of mastery learning with DP including a flowchart of its events and a medical education example.

Medical students, residents, fellows in postgraduate medical training, and supervising faculty are good candidates for mastery learning of clinical skills embedded in deliberate practice due to their strong cognitive readiness, academic preparation, and motivation to succeed. These conditions coalesce to increase the likelihood that medical learners will achieve high standards even when working with complex and difficult material.

Five selected examples of mastery learning research reports from our medical education research group illustrate the power and utility of the mastery model for skill acquisition and retention. All the mastery learning studies rely on DP as an essential part of the mastery learning education intervention. The mastery learning projects address acquisition of a variety of medical clinical skills including (a) life-saving advanced cardiac life support (ACLS), (b) invasive lumbar puncture (LP), (c) clinical reasoning involved in managing pediatric and adult patients with status epilepticus, and (d) communication skills needed to "break bad news" to patients and their families. We also describe a mastery learning program to (e) educate heart failure patients about ventricular assist device (VAD) self-care, demonstrating that mastery learning contributes to life-sustaining skills among motivated patients and caregivers despite varied education backgrounds.

Advanced cardiac life support. A seminal medical education research report introduced mastery learning with DP to help internal medicine residents acquire advanced cardiac life support (ACLS) skills to a high and uniform standard (Wayne, Butter, Siddall, et al., 2006). The education intervention involved an integrated pretest; intense deliberate practice with feedback in a medical simulation laboratory; formative assessments with more practice, feedback, and correction as needed; and mastery evaluation to a high MPS. All the 41 internal medicine residents evaluated in this research report met or exceeded the learning objectives with slight variation in the time needed to reach the mastery MPS. The residents reported high satisfaction with the training as a collateral outcome.

Two separate research reports (Didwania et al., 2011; Reed et al., 2016) show that ACLS skills acquired to a mastery standard are robust to decay for up to 18 months after simulation training when measured at actual cardiac arrest events (Didwania et al., 2011). Long-term ACLS skill retention from mastery learning curricula is in sharp contrast with rapid skill decay when ACLS education is conducted using traditional teaching approaches (Yang et al., 2012).

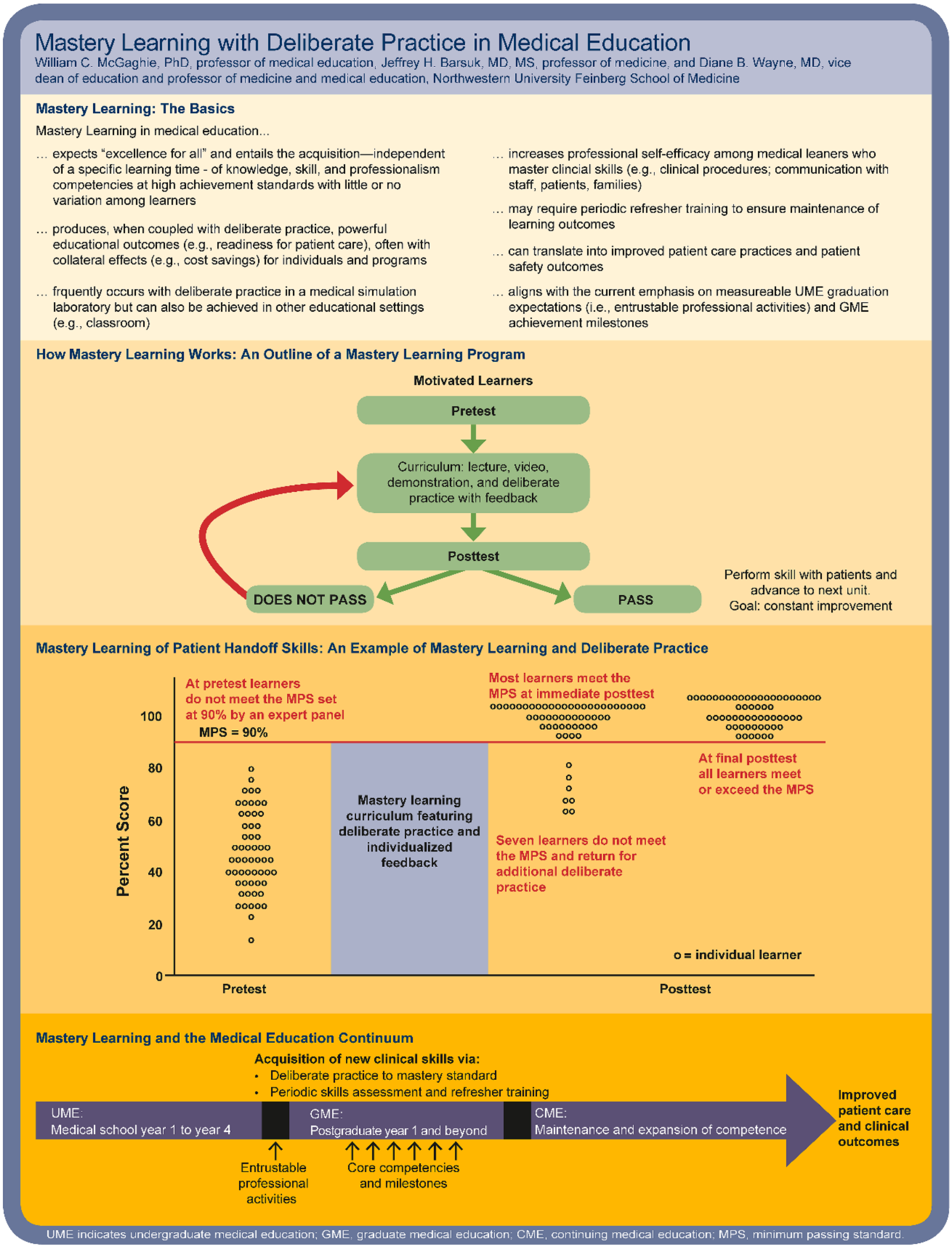

Figure 2. Mastery learning with deliberate practice in medical education. Source: McGaghie et al. (2015). Reprinted with permission from Wolters Kluwer Health.

Lumbar puncture. Lumbar puncture (LP) is an invasive medical procedure whose purpose is to obtain cerebrospinal fluid (CSF) to diagnose central nervous system disorders including infection and cancer. Barsuk et al. (2012) conducted a mastery learning skill acquisition study involving 58 internal medicine (IM) residents and 36 neurology residents. The IM residents were all in the first postgraduate year (PGY-1) of training at the McGaw Medical

Center of Northwestern University in Chicago after earning MD degrees from a variety of U.S. medical schools. The neurology residents were PGY-2, 3, and 4 research volunteers from three other academic medical centers in metropolitan Chicago. The neurology residents, a comparison group, had prior clinical experience with the LP procedure through traditional, learn-by-doing bedside practice with real patients.

The IM residents had little or no actual LP experience. The IM residents started LP learning with a pretest on a mannequin using a 21-item LP skills checklist. The IM residents then experienced a systematic LP mastery learning skill acquisition curriculum involving feedback about pretest performance, DP of LP skills, formative assessments, frequent actionable feedback and coaching, and more practice in a simulation laboratory. The IM residents subsequently took a posttest and were assessed for performance at or above a rigorous MPS on the skills checklist set earlier by an expert panel. Posttest scores from the PGY-1 IM residents were compared to scores of the Neurology residents who took the checklist evaluation but did not receive mastery training.

The data presented in Figure 3 show that one of the 58 IM residents met the MPS at pretest and 55 of the 58 (95%) met the MPS at posttest after the 3-hour simulation-based curriculum. The three IM residents who did not reach the MPS at initial posttest later reached the goal with less than one hour of more DP. This is a 107% improvement from pretest to posttest measured as checklist performance by the IM residents.

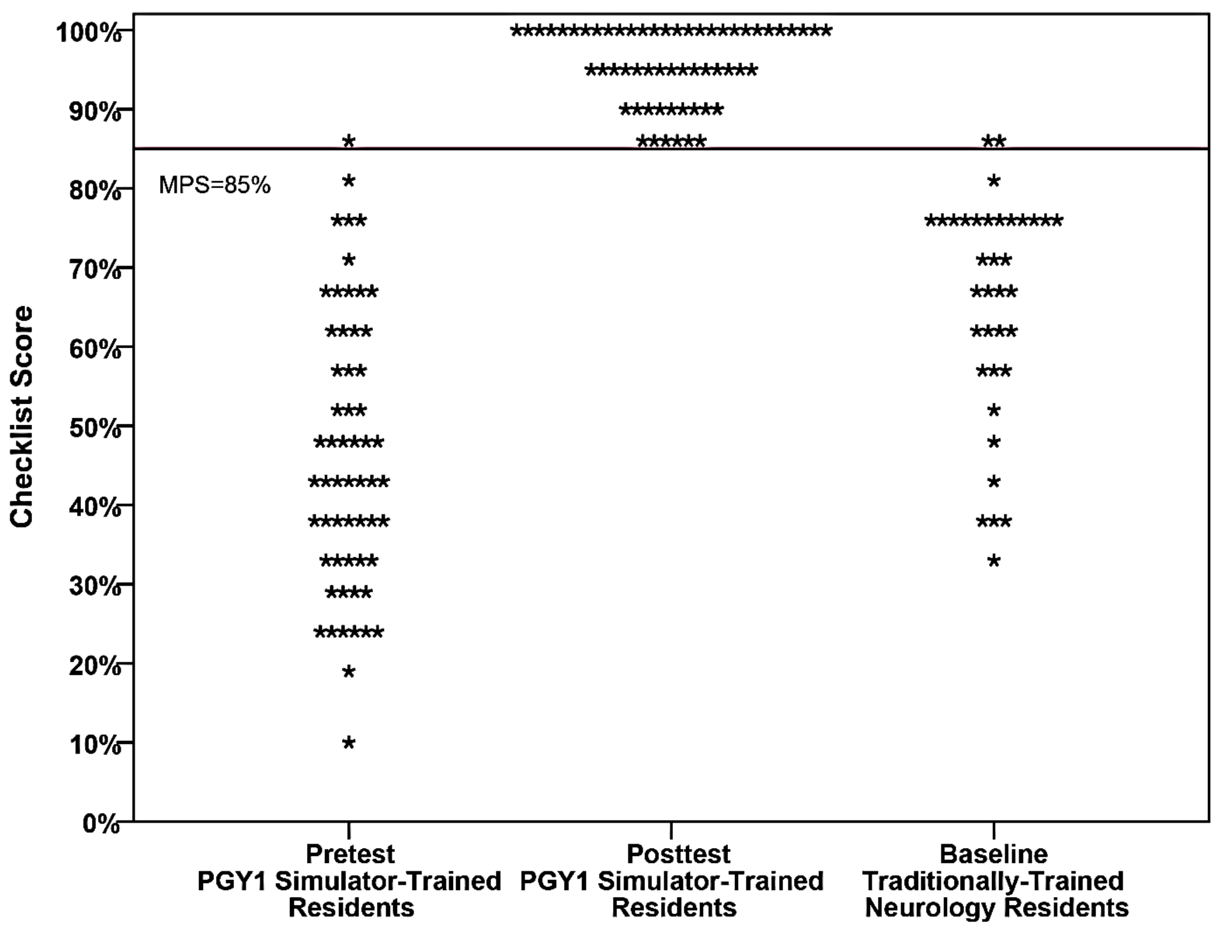

Figure 3. Clinical skills examination (checklist) pre- and final posttest performance of 58 first-year simulator-trained internal medicine residents and baseline performance of 36 traditionally trained neurology residents. Three internal medicine residents failed to meet the minimum passing score (MPS) at initial post-testing. PGY = postgraduate year. Source: Barsuk, Cohen, Caprio, et al. (2012) Reprinted with permission from Wolters Kluwer Health.

Figure 3 also shows that by contrast, only 2 of the 36 (6%) traditionally trained PGY-2, 3, and 4 neurology residents met the MPS despite years of experience and performing multiple LPs on real patients. This study also revealed two surprising findings about the traditionally trained neurology residents not seen in Figure 3. First, nearly 50% of the neurology residents could not report the correct anatomical location for the procedure; they did not know where to stick the needle. Second, over 40% of the neurology residents could not list routine tests (glucose, cell count, protein, gram stain, culture) to be ordered for the CSF after the fluid sample was drawn; they did not know about basic laboratory medicine. These results clearly show the superiority of mastery learning with deliberate practice compared to traditional clinical education toward the goal of clinical skill acquisition. This is EPP evidence (Ericsson 2007, 2015) that underscores the need to use new models of clinical education featuring DP to better train physicians to perform invasive procedures expertly (Nathan & Kincaid, 2012).

Status epilepticus. Status epilepticus (SE) is a neurologic seizure disorder experienced by children and adults where patient management is highly time sensitive. Management of SE patients poses a complex clinical challenge including many potential patient safety problems due to seizure duration, dosage, and timing of antiseizure drugs, and patient response to treatment under changing circumstances.

Malakooti and a team of pediatricians (2015) at the Lurie Children's Hospital in Chicago engineered a mastery learning curriculum for SE management based on an algorithm representing clinical care standards. The curriculum was embodied in a scripted simulation scenario involving "a 2-year-old child [who] develops tonic-clonic seizures requiring recall and practical application of the SE algorithm." The scenario required pediatric resident learners to take a pretest, receive feedback, engage in DP of SE management, and reach a posttest MPS in a fully equipped, high-fidelity, standardized environment including nursing staff. The SE algorithm was also used to create a 22-item checklist to evaluate resident skill acquisition and to provide feedback. A rigorous MPS was established for the checklist data by an expert panel of pediatric neurologists. The simulation scenario, checklist evaluation, debriefing, and feedback were repeated for each resident until the MPS was reached. The mastery learning results show that, "All participants achieved mastery of the algorithm after debriefing and deliberate practice; the majority of participants required 2 simulation and debriefing sessions."

Mikhaeil-Demo et al. (2020) replicated the pediatric SE mastery learning curriculum by engineering and evaluating a new mastery learning program for adult SE patient identification and management. Target learners were 16 PGY-2 neurology residents at the Northwestern Memorial Hospital (NMH) in Chicago. The residents took a baseline SE skills assessment (pretest) measured by a 26-item checklist. The learners then received standardized didactic instruction about adult SE identification and management, pretest feedback, DP with assessment and feedback using a simulation mannequin, and a posttest skills assessment in a medical simulation laboratory. All learners were required to meet or exceed a checklist MPS. After meeting the MPS at posttest, the residents were reassessed during an unannounced in situ simulation session on the medical wards.

Resident checklist performance increased from a median of 44.23% with wide variation at pretest to 94.23% at posttest with little learning outcome variation. There was no significant difference in scores between the simulation laboratory posttest and the in-situ test up to 8 months later. Thus, the adult SE mastery learning curriculum is an environmental intervention that greatly improved resident learner performance under controlled laboratory conditions. The SE identification and management skills were also retained over 8 months during an unannounced simulated encounter in the hospital setting.

Breaking bad news. Breaking bad news (BBN) to patients and their families is a difficult conversation for physicians and other healthcare providers. Education and skill building exercises about BBN are rare events in medical school and postgraduate residency training. Despite the lack of preparation, new and seasoned physicians in many specialties are expected to learn "on the job" and lead BBN discussions with skill and care. There is now widespread agreement in medical education circles that new and effective interventions are needed to boost physician skill and knowledge about BBN (Johnson & Panagioti, 2018).

Vermylen et al. (2020) addressed this medical education problem by creating and evaluating a simulation-based mastery learning (SBML) curriculum on BBN. The BBN program is embedded in a fourth-year clinical rotation that medical students must pass before graduation. To fulfill BBN mastery learning requirements the medical students complete a pretest with a standardized patient (SP) guided by a checklist assessment. Students then undergo a 4-hour BBN skills workshop with advance reading, didactic instruction, DP, and focused feedback with SPs. The medical students must meet or exceed a predetermined MPS at posttest. Students who do not reach the posttest MPS continue with DP, feedback, and assessment until the MPS is reached from retesting.

Figure 4 presents the pretest, initial posttest, and mastery posttest results of the BBN mastery learning education intervention. Seventy-nine fourth year medical students completed the curriculum successfully. The pretest data show that student performance was weak and highly variable despite reports from 55/79 students (70%) that they had previously delivered bad news to actual patients. Initial posttest results show that only six medical students did not reach the MPS at the first attempt; however, these students subsequently achieved mastery with about 45 minutes more time for DP, feedback, coaching, and assessment. Post-course survey data also show the students found the pretest feedback especially helpful. The medical students also reported a significant improvement in self-confidence in conducting BBN conversations. This study extends DP and mastery learning beyond procedural or technical skills into the key domain of communication skills, an essential component of medical expertise.

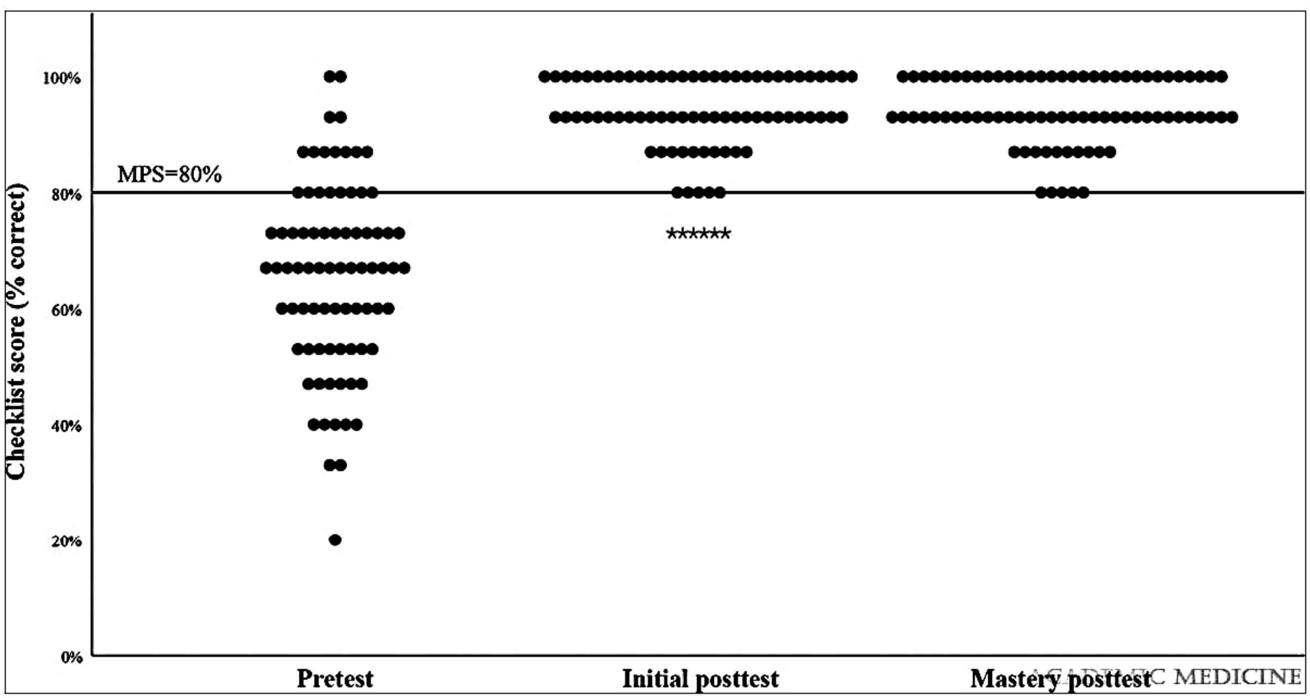

Figure 4. Breaking bad news checklist performance for 79 fourth-year medical students at pretest, initial posttest, and mastery posttest, from a study of an SBML curriculum embedded in the medicine subinternship, Northwestern University Feinberg School of Medicine, 2017-2018. Circles indicate each student's score. Asterisks indicate the students who did not meet the MPS at the initial posttest. Those students did additional deliberate practice and tested again until all reached the MPS as indicated in the mastery posttest column. Abbreviations: SBML, simulation-based mastery learning; MPS, minimum passing standard. Source: Vermylen et al. (2020). Reprinted with permission from Wolters Kluwer Health.

Patient self-care. A VAD is a mechanical heart pump that helps to circulate blood in patients with advanced heart failure. Patients with VAD implantation must participate in daily self-care tasks including maintenance of the VAD controller, power source, and surgical dressings to ensure efficient operation and infection prevention. Poor VAD maintenance can lead to patient injury, sepsis, and death.

Proper VAD maintenance is a critical, life-sustaining, self-care skill that is performed by patients and their caregivers. VAD patients and their [usually family] caregivers have varied education histories and are highly motivated to learn about self-care and equipment maintenance. However, traditional patient and caregiver knowledge and skill training for VAD self-care is neither systematic nor standardized. Barsuk et al. (2019) engineered and implemented a rigorous, SBML curriculum to better educate patients with a VAD and their caregivers about self-care practices. The SBML curriculum contained the elements shown in Figure 2. A randomized trial was conducted to evaluate the SBML self-care curriculum compared to a traditional VAD patient education program.

The trial results show that the SBML self-care curriculum was a highly effective patient education intervention that greatly improved VAD controller and power source maintenance and surgical dressing care. The authors conclude, "SBML provided superior VAD self-care skills learning outcomes compared with usual training. This study has important implications for patients due to the morbidity and mortality associated with VAD self-care" (Barsuk et al., 2019 p. 1).

Other examples of mastery learning reports about acquisition of medical clinical skills such as insertion and maintenance of central venous catheters, forceps delivery during childbirth, screening for malignant melanoma, and many other procedures are available elsewhere (Barsuk et al., 2020). Mastery learning of surgical skills (Teitelbaum et al., 2020) and for management of clinical emergencies (Issa et al., 2020) including use of personal protective equipment for COVID-19 safety (Pokrajac et al., 2020), radiograph interpretation (Lee et al., 2019) and care for acute fractures (Toal et al., 2021) have also been described. The success of these and many other mastery-learning medical curriculum interventions depend on strong doses of DP to produce intended results.

New Directions for Learning and Teaching

We have described medical education curricula and research programs that point to at least four new directions for medical learning and teaching. All the new directions owe their beginnings to the power of DP as a mechanism that boosts medical learning in education settings and facilitates transfer to clinical care. The four new directions are: (a) hybrid deliberate practice, (b) rigorous education engineering and science, (c) policy reform, and (d) translational science.

Hybrid deliberate practice. The original definition of DP articulated by Ericsson et al. (1993) has, with small adjustments (e.g., Ericsson & Pool, 2016), remained intact for nearly three decades. Several adaptations to the original DP model have been introduced in medical education to suit specific training needs. For example, Hunt et al. (2014) have developed and tested rapid cycle deliberate practice (RCDP), ". . . a learner-centered, simulation instructional strategy that identifies performance gaps and targets feedback to improve individual or team deficiencies. Learners have multiple opportunities to practice observational, deductive, decision-making, psychomotor, and crisis resource management skills" (p. 356). Important features of RCDP begin with a no-fault policy where mistakes are assessed and corrected via feedback in a psychologically safe learning environment (Metcalf, 2017). Perretta et al. (2020) list nine core components of RCDP identified as instructional techniques:

1. Deliberate practice
2. Mastery learning
3. Contextualization
4. Specific, observable learning objectives (including measurable metrics)
5. Formative assessment

6. Debriefing (initial, debriefing styles)
7. Feedback-replay loop and micro debriefing
8. Solution-sharing (prescriptions)
9. Scaffolding.

This tailored model of DP aligns with mastery learning principles and has been used to improve individual and team education in such life-saving maneuvers as intubation, neonatal resuscitation, and treatment of septic shock (Hunt, Duval-Arnould, Nelson-McMillan, et al., 2014; Perretta, Duval-Arnould, Poling, et al., 2020).

Harris et al. (2017) describe another variety of DP useful for improving medical team performance of complex clinical skills. This DP hybrid starts by breaking down complex skills into operational subsets. The skill subsets are then presented for DP in combinations that systematically vary by clinical pathology, team composition, context of care, and other variables that represent real-world situations. Detailed planning and presentation of these practice scenarios is needed to ensure that DP sessions address target learning objectives comprehensively.

Other hybrid varieties of DP, especially in situ models where training is linked with real patient processes of care, are used to contextualize clinical medical education. Examples of such DP models address maternal and neonatal health, pediatric emergency teamwork, management of birth complications, and promoting cost effective clinical care expressed as return on financial investment (Griswold et al., 2012). These models embed DP in medical simulation to contribute to safer, more efficient systems of care.

Rigorous education engineering and science. Implementation of novel medical education engineering and science technologies depends on strong doses of DP to function effectively. To illustrate, medical simulation technologies vary widely in fidelity and cost, yet the most effective methods rely on DP for education impact (Motola et al., 2013). Novel and established measurement methods including haptics (Laufer et al., 2015, 2017); artificial intelligence (AI) (Wartman & Combs, 2018); verbal protocol analysis (Yoon et al., 2020); social network analysis (SNA) (Shoham et al., 2015, 2016); and multidimensional scaling (MDS) (Giguère, 2006; Muramatsu et al., 2013) will encourage new ways to study and boost the impact of DP on the acquisition of medical expertise including the formation of mental representations. Rigorous and clinically relevant approaches to education standard setting (Barsuk et al., 2018) and advanced psychometric analyses (McGaghie et al., 2021) promote better understanding of the precision and power of DP-based education interventions, standard setting, and valid personnel decisions.

Policy reform. Widespread introduction and maturation of education interventions featuring DP and especially mastery learning will have far reaching policy consequences for medical education (Green et al., 2020). In particular, endorsement of the "excellence for all" mastery learning principle with the recognition that learning time can vary for individuals and teams will annoy the medical education status quo. Medical schools, postgraduate residency programs, and medical specialty boards and agencies will be challenged by unexpected scheduling, learner assessment, and program management wrinkles. Despite such problems, influential medical organizations such as the American Heart Association (AHA) now approve and strongly support DP-based mastery learning as a pillar for education policy improvement and learning outcome evaluation (Meaney et al., 2013; Cheng et al., 2018).

Translational science. Medical education is just beginning to rigorously evaluate and challenge the traditional belief that learning produced from classroom, laboratory, and hospital experience translates directly to individual and team patient care practices and patient outcomes. The status quo is changing slowly due to rising attention to medical education accountability about the fitness of graduates and practicing physicians to provide effective and safe patient care (Schroedl et al., 2020).

A novel taxonomy that parallels a clinical translational research framework tracks and evaluates medical education learning outcomes as downstream events from education settings to patient care outcomes (McGaghie, 2010; Barsuk & Szmuilowicz, 2015). The taxonomy tracks learning outcomes from powerful medical education interventions across four (T1 to T4) cascaded stages. The stages are *increased or improved* (T1) knowledge, skills, attitudes, and professionalism in a simulation laboratory; (T2) patient care practices in the clinic and at bedside; (T3) patient outcomes in the clinic and at bedside; and (T4) collateral effects such as skill retention, economic return on investment, and systemic education improvements.

This classification scheme is similar to the approach used to test new drugs for efficacy under controlled laboratory conditions and later for clinical effectiveness in community trials (Fletcher, 2020). However, it differs from other taxonomies used historically to map progression of medical education learning outcomes (Dzara & Gooding, 2021). The T1 to T4 taxonomy has been used as one framework to organize and present a growing body of evidence that powerful medical education interventions grounded in DP and mastery learning can have translational, downstream effects on patient care practices and patient outcomes (Brydges et al., 2015; Griswold-Theodorson et al., 2015; McGaghie, Draycott, et al., 2011; McGaghie et al., 2014; McGaghie et al., 2012; McGaghie, Wayne, et al., 2020). Such powerful translational learning outcomes are not shared by traditional medical education programs that rely on clinical experience as the primary instruction method.

The Road Ahead

This article in honor of Anders Ericsson is wide-ranging, beginning with the theoretical, engineering, and scientific contributions of his work on human abilities and DP to medical education and healthcare. The article continues by selectively reviewing the impact of these contributions expressed as empirical findings, mastery learning, and new directions for learning and teaching. We continue by addressing the road ahead, especially about the origins of medical expertise, deliberate practice, and its by-products presented as scholarly arguments and practical barriers.

Scholarly Arguments

We choose to highlight five scholarly arguments about medical education grounded in Ericsson's work on the origins of expertise and DP as an education mechanism: (a) assessment in medical education, (b) engineering and science progress, (c) DP impact, (d) measurement, and (e) research programs.

Assessment in medical education. We pointed out earlier that current medical student selection policies and machinery yields a trainee pool of individuals who are smart, motivated, high achieving, and have personal qualities that boost their chances for success in school and professional life. Academic attrition from medical school is a very rare event. Thus, we endorse learner assessment policies within medical education that focus on mastery of competency-based curriculum goals due to DP, feedback, and constant improvement rather than a measurement emphasis on norm-referenced tests of knowledge acquisition like the NBME Step 1 and 2 exams that are correlated poorly with clinical skill learning (McGaghie, Cohen, et al., 2011; Barsuk, Cohen, Caprio, et al., 2012). These policies emphasize assessment for learning compared to assessment of learning (van der Vleuten & Schuwirth, 2005). Competency-based assessments are embodied in criterion-referenced metrics including performance tests, workplace-based evaluations, professional portfolios, postgraduate milestones, and simulations designed to approximate real world professional thinking and practice (Holmboe, Sherbino, et al., 2010; Holmboe et al., 2020; O'Brien et al., 2020; Yudkowsky et al., 2020)

Engineering and science progress. There is no doubt or disagreement about the value of engineering and science progress, especially as such advancements improve the power and utility of DP as an independent variable in training environments. This calls for continued study and refinement of DP features. For example, Coughlan and colleagues (2014) dissected the performance of superior Gaelic football [soccer] players to probe, "How experts practice: a novel test of deliberate practice theory." These investigators found that football experts "practiced the skill they were weaker at and improved its performance across pre-, post- and retention tests." "In contrast, . . . participants in the [comparison] group predominately practiced the skill they were stronger at . . ." Findings like these strengthen the conviction that DP is best used to improve competence deficits, not to maintain the status quo. Future studies might investigate the integration of DP with artificial intelligence (AI) and machine learning to increase the potency of medical education interventions.

Deliberate practice impact. Comparative effectiveness research in medical education leaves no doubt that interventions grounded in DP produce better results than traditional clinical education (Figure 1). The next step is to determine the best approaches to design and implement curricula and training programs that not only produce short-run impact but also long-run results. In medical education and healthcare this means first evaluating training effects in controlled education settings such as a simulation laboratory. Subsequent studies would follow the effects to downstream results like in situ patient care practices and patient outcomes including reduced errors, fewer complications, faster recovery, reduced hospital stay, and lower healthcare costs. This translational science integrates rigorous medical education research with health services research as a quality improvement strategy to better serve the health of the public (Kalet et al., 2010; Schumacher et al., 2018).

Measurement. Measurement of outcome and mediating variables is a continuous source of scholarly argument in medical education and healthcare research. This is especially the case for medical education programs that address complex patient conditions, like management of Type 2 diabetes, where the clinical conditions can change quickly, there is more than one right answer to clinical problems, and where experts may disagree about the best course of action. Measurement of medical education achievement and clinical care outcomes involved in such complicated situations conflicts with the Ericsson and Pool (2016) training requirement of a "highly developed field" where outcome evaluation is objective, "or at least semiobjective" to permit accurate decisions about learners. Measurement specialists are also challenged about how to reliably capture such elusive education and clinical targets as adaptive capacities (e.g., varied intraoperative decision-making), tacit knowledge, and practical intelligence (Kneebone, 2020) that challenge current assessment technologies (Kalet et al., 2010).

Research progress. Research advancements on DP and its derivatives like mastery learning will have greatest impact when embedded in programs of scholarship that are thematic, sustained, and cumulative. Research programs need to embrace incremental improvements that see science as an everyday activity rather than an extra-ordinary enterprise (Luca & Bazerman, 2020). Such a sustained and cumulative research program is especially needed in medical education to sort out the relative contribution of DP to the acquisition of expertise while controlling for background characteristics of medical learners. We also endorse the corollary idea that, "One-off, stand-alone mastery learning education and research studies will have little impact unless they are connected to other thematic investigations that demonstrate translational, downstream patient outcomes" (McGaghie, Wayne, Barsuk, et al., 2020, p. 380).

Practical Barriers

Practical barriers stymie the wider application of DP and mastery learning in medical education in both overt and subtle ways. Overt barriers include dated program accreditation standards that dictate curriculum coverage and instruction hours. While overt barriers are broken by policy changes driven by professional consensus, subtle barriers are harder to breach. They include a professional culture that relies on time honored education practices and devotion to norm-referenced student evaluations and scores on standardized examinations despite contrary evidence. Practical barriers frustrate innovation in medical education and delay improvement in downstream healthcare quality. Here, we identify two practical barriers in medical education: inertia and new faculty roles.

Inertia. The power of inertia in medical education is seen every day as medical schools, postgraduate residency programs, and subspecialty fellowships continue to be weighted excessively toward the apprenticeship model of clinical education. Fathered by Osler in the 1890s at Johns Hopkins University, the apprenticeship model assumes that clinical exposure to patients is sufficient to insure the acquisition of medical expertise (McGaghie et al., 2020b). This passive approach has been the cornerstone of medical education for more than a century. Its continued use despite engineering, research, and instructional science progress is a clear expression of status quo bias (Samuelson & Zackhauser, 1988). The upshot is that we continue to educate 21st century physicians using obsolete 19th century thinking and technology. Such inertia is an ageless reminder of stubborn resistance to innovation in medical education and healthcare (Berwick, 2003).

New faculty roles. Introduction and adoption of medical education technologies that rely on DP and mastery learning to facilitate learner performance and acquisition of expertise will place new demands on teaching faculty. Passive clinical teaching seen every day on rounds and case conferences must be supplemented by active learner and teacher engagement in simulation laboratories and in situ settings. Active engagement means that learners practice deliberately to acquire clinical medicine skills and coincident mental representations to mastery standards. Learner DP means that faculty must actively plan, manage, and evaluate education sessions. Providing frequent, focused, actionable feedback is especially important on the learner pathway to medical expertise.

Carl Wieman, a Nobel laureate in physics, has endorsed active learning as a quality index for higher education in the neighbor disciplines of science, technology, engineering, and mathematics (STEM). Citing Anders Ericsson, Wieman (2014) writes, "Nearly all techniques labeled as active learning include those features known to be acquired for the development of expertise; in this case, thinking like an expert in the discipline. The active learning methods are designed [by faculty] to have the student working on tasks that simulate an aspect of expert reasoning and/or problem solving while receiving timely and specific feedback from fellow students and the instructor that guides them on how to improve" (p. 8319).

Medical faculty and their teaching surrogates will need preparation to fulfill this new active role. Developing faculty to acquire and employ this novel skill set is a key medical education priority that warrants attention (Eppich & Salzman, 2020). Several problems complicate this faculty development challenge including the recognition that many attending physicians with teaching responsibilities have uneven clinical skills (Barsuk et al., 2016; Birkmeyer et al., 2013) and that clinical experience is not a proxy for quality of health care (Choudry et al., 2005).

Reflections About Anders Ericsson

This article has addressed the scholarly legacy that Anders Ericsson left for medical education and its impact on improved healthcare. We conclude with a brief reflection about Anders' work, life, and gifts of mentorship.

Journalist David Brooks writes in his book, *The Road to Character* (2015), that a life well lived has two defining themes: résumé virtues and eulogy virtues. Résumé virtues have value in academic circles—professional accomplishments, a high *h*-index, public approbation. Eulogy virtues are aspects of character that others praise when a person is no longer around to hear—conscientiousness, grace, humility. We knew Anders Ericsson as an engaging and cosmopolitan colleague from such résumé virtues as rigorous and meaningful scholarship, a disputative and lively spirit, and bonhomie. We suspect that his local colleagues, students, friends, and family members would add eulogy virtues including fidelity, selflessness, humor, and generosity.

Anders Ericsson was a major force of his day in academic psychology and its place in popular culture. In medicine and healthcare his work on DP became a model that legitimized simulation for education and assessment when such new technology was viewed by the establishment as a novelty. Ericsson's work provided a conceptual framework that became a research foundation leading to evidence that learning outcomes are not derived from technology, but how technology is used. The medical education community also benefited from Anders' generous participation in specialty conferences to inform the international conversation about health professions training (Bond et al., 2008; Collins et al., 2019; Lucey, 2018). This scholarship and his personal example will have a lasting impact on medical education worldwide.

In a 1675 letter to his scientific rival Robert Hooke, Isaac Newton made a famous statement, "If I have seen further, it is by standing on the shoulders of giants." This metaphor is now used to symbolize scientific progress. Newton's statement is a reminder that we work in the light of inventions and discoveries made by fellow scientists who we walk with or after, but always together. Knowledge about DP and its sequelae builds on itself, incrementally improving on existing ideas until the cumulative becomes revolutionary and then a new normal. We are grateful to Anders Ericsson for his many scientific contributions and for his life well lived. Anders Ericsson's mentorship brought big shoulders to all of us. He is a giant to be emulated and remembered.

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ORCID iDs

William C. McGaghie
https://orcid.org/0000-0003-1672-0398

Diane B. Wayne
https://orcid.org/0000-0001-6468-0744

Jeffrey H. Barsuk
https://orcid.org/0000-0001-6584-9943

S. Barry Issenberg
https://orcid.org/0000-0002-2524-4736

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