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The Science of Mindfulness-Based Interventions and Learning: A Review for Educators

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This paper reviews the scientific evidence for the effects of mindfulness training on learning, and provides practical advice for implementation in educational contexts.

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Abstract

Is there sufficient evidence that mindfulness training is ready to be implemented in schools? Going beyond the relatively comprehensive literature on mindfulness and mental health, here we investigate whether mindfulness can help students learn. We begin by drawing on laboratory studies in experimental psychology and cognitive science, and then reflect on research conducted in schools and other applied contexts. We also briefly discuss key insights from the neuroscience of mindfulness, and compare mindfulness to other well-known learning interventions. Our review suggests that mindfulness interventions have the potential to make students more focused, to help them regulate their emotions, to be more flexible and creative, and to change their brains in a way that encourages greater conscious control of their thoughts, feelings, and actions. These findings indicate that mindfulness may improve cognitive abilities that are key to learning outcomes, and may have a complementary relationship with other interventions such as retrieval practice. Field experiments also show promise, and are indicative of high feasibility, low risk, and suggest generalisability across diverse groups, ages, genders, and cultures. However, most studies currently lack standardisation, active control groups, and more experiments are needed that explicitly focus on academic performance in schools. We conclude by providing practical advice and best practices for the implementation of mindfulness training in schools, and highlight the promising future of digital mindfulness-based interventions as a scalable and affordable way to implement mindfulness in educational contexts. This review will be of value to those who are interested in the application of mindfulness to learning contexts, but also researchers and others who wish to know the current state of scientific evidence on mindfulness-based interventions and their impact on learning.

1. Introduction

High School Students are facing new challenges. They have easier access to distracting technology, many are overburdened with testing (Hart, 2015[1]), and there is mounting pressure to perform academically because professions are increasingly specialised. This is in addition to maintaining complex social relationships both online and offline. Students now report that their greatest issues of personal concern are associated with the demands of school, including coping with stress, study problems, time management, college and university admission, anxiety, and depression (Reynolds, 2013). Many structural changes to schooling may be necessary in order to address these problems and to prepare students for a rapidly changing and increasingly interconnected world (Howels, 2018; Laukkonen, Biddell, & Gallagher, 2019). In particular, interventions that jointly support learning and well-being are sorely needed in order to deal with the challenges that students are experiencing. Mindfulness interventions in education may provide one fruitful approach. William James (1890[2]) often considered the 'father of modern psychology', wrote that:

> *"The faculty of voluntarily bringing back a wandering attention, over and over again, is the very root of judgment, character, and will. No one is compos sui [a master of themselves] if he have it not. An education which should improve this faculty would be the education par excellence. But it is easier to define this ideal than to give practical directions for bringing it about."*

We propose that scientific progress has matured sufficiently that we may begin to go beyond 'the ideal', where evidence can be integrated and practical directions provided. Scientific publications about mindfulness have been growing exponentially since the 1990s (Barrett, 2016[3]). In 2018, there were more than 2,900 publications containing mindfulness in the title, and many more articles in popular media (Van Dam, 2018[4]). Much like exercise, the range of positive outcomes associated with mindfulness practice is striking (Keng, 2011[5]; Sun, 2015[6]). But unlike exercise, evidence-based mindfulness practice is currently taught in only a small minority of schools worldwide. This is despite the fact that the key benefits associated with mindfulness practice pertain directly to the concerns described by students. For example, it is well-established that mindfulness can improve well-being, and reduce stress, anxiety, and depression (Chiesa, 2009[7]; Hofmann, 2010[8]; Zoogman, 2015[9]). However, since the primary motive of schools is learning, in this review we aim to go beyond mental health and well-being to investigate whether mindfulness can also benefit learning and academic performance. We also aim to provide practical advice regarding the implementation of mindfulness in educational contexts.

We begin with an introduction to mindfulness as it is defined and studied in a contemporary scientific context. In service of a concise review with considerable breadth, in most cases we have chosen not to provide detailed descriptions of specific experiments (except to provide illustrative examples). Instead, we review and synthesise the present state of the field in its broadest sense (from mechanisms, to the laboratory, to the field). Due to addressing the research at multiple levels of analysis, the reader will need to decide for themselves which evidence they find most convincing. For instance, some may be more trusting of laboratory experiments while others may be more convinced by field studies or neuroimaging. In different areas of research there is also some variability in the way that mindfulness is defined. For example, cognitive-neuroscience research focuses more on the effects of different styles of meditation (Lutz, 2008), whereas clinical psychology often has a broader definition that may encompass a number of different practices. When notable changes in definition occur, we describe these in the relevant section. Broadly speaking, the paper is divided into five parts shown in Table 1. Throughout this short review, we also highlight important limitations and considerations in interpreting the existing literature.

Table 1. This review addresses five topics relating to mindfulness and learning.

Mindfulness in the laboratory	Mindfulness in the school	Other learning interventions	Neuroscience of mindfulness	Implementation & Best Practices
Attention & mind-wandering	Applied interventions in schools	Retrieval practice & learning interventions	Brain imaging techniques	Scaleability & instruction
Emotion regulation & stress reduction	Feasibility & generalisability	Feedback & uniqueness	Brain regions & function	Standardisation
Working memory	Prosocial behaviour	Common challenges	Different practices	Diversity
Cognitive flexibility & creativity	Academic performance	Interaction & integration	Short term & long term effects	Digitalisation & financing

1.1. What is a mindfulness-based intervention?

To be mindful is to pay attention "... in a particular way: on purpose, in the present moment, and nonjudgmentally" (Kabat-Zinn, 1994[10]). This oft-cited working definition can be broken down into at least two mechanisms or actions: (1) paying attention to a chosen object or activity occurring in the present moment (such as the breath or bodily sensation), and (2) an attitude of non-judgmental openness to whatever is noticed or discovered in one's inner experience, including thoughts, emotions, sensations, and perceptions (Shapiro, 2006). Other elements of mindfulness commonly referenced include an attitude of curiosity about one's experience, self-compassion for any perceived 'failures' during practice, and the inhibition or 'releasing' of mind-wandering and rumination (as a corollary of paying attention to the present moment). As experience in mindfulness practice grows, then it is also possible to 'let go' of paying attention in an effortful way, and one is said to rest more naturally and effortlessly in present moment awareness (Lutz, 2006). Likewise, instructions may also change over time, such that a more broad, effortless, and inclusive attention to all of one's present-moment experience is encouraged (Lutz, 2008; Lutz, Jha, Dunne, & Saron, 2015). There is ongoing debate about the best way to define mindfulness, and many different definitions exist (for a detailed analysis, see Chiesa et al., 2013). Nevertheless, the basic elements described here are generally accepted as representing a category of mental states that can be investigated scientifically, successfully contrasted to other mental states

such as mind-wandering (Mrazek, Smallwood, & Schooler, 2012; Mrazek et al., 2013), and developed through practice. If there is a notable deviation in definition within any particular study, we have aimed to make a note of it.

Over the course of the last 50 years, many mindfulness-based interventions (MBIs) have been developed. These interventions range from direct training in mindfulness (e.g., Mrazek et al., 2013), to using mindfulness as a component in concert with other therapeutic techniques derived from clinical psychology, such as Mindfulness-Based Cognitive Therapy (Segal, Williams, & Teasdale, 2018), Dialectical Behaviour Therapy (Dimef & Linehan, 2001), and Acceptance and Commitment Therapy (Hayes, 2009[11]). MBIs are often used in research (and in practice) on both healthy and clinical populations. Perhaps the most well-known of the MBIs is an eight-week training program called Mindfulness-Based Stress Reduction (MBSR), developed by Jon Kabat-Zinn in the 1970s. The program uses various exercises and instructions that together aim to gradually increase mindfulness through education, attention to various regions of one's body, physical postures and stretching, daily mindfulness practice of at least 45 minutes, and one full day (seven-hours) of practice (Grossman, 2004[12]). To date, over 1400 studies have been published with MBSR in the title, and there is a growing evidence base for the effectiveness of MBSR programs in reducing stress, depression, anxiety, substance use, chronic pain, eating disorders, ADHD, insomnia, and the program has also been successfully used by healthy populations to increase well-being and reduce stress and anxiety (for reviews, see Fjorback et al., 2011; Praissman, 2008; and Sharma & Rush, 2014).

There has been comparatively much less discussion on the relationship between MBIs and learning outcomes. There are, however, many reasons to suspect that such a relationship would exist. Mindfulness is a form of attention training, and attention is essential for most types of learning (Mack, 2003). Mindfulness can also assist with emotion regulation (Arch & Craske, 2005), reducing mind-wandering (Mrazek et al., 2013), and improving executive functioning (Tang et al., 2012), which all play an important role in learning. With this in mind, it seems timely to review the state of evidence on direct and indirect effects of mindfulness on learning. We begin by contextualising mindfulness within the broader framework of Social and Emotional learning (SEL).

1.2. Mindfulness in context: Social and emotional learning

There has been growing excitement and promise surrounding SEL interventions in schools (Durlak et al., 2011). SEL is defined by the Collaborative for Academic, Social, and Emotional Learning as "...the process through which we [1] understand and manage emotions, [2] set and achieve positive goals, [3] feel and show empathy for others, [4] establish and maintain positive relationships, and [5] make responsible decisions." Of the many possible interventions that target the broad constructs within SEL, what unique contribution to learning can mindfulness have? Answering this question definitively will require carefully designed experiments that directly compare learning outcomes following different SEL interventions versus mindfulness practice. Initial efforts in this direction suggest that specific training in mindfulness can have benefits above and beyond a standard SEL intervention on measures of cognitive control, stress, empathy, perspective-taking, emotional control, optimism, prosociality, and more (Schonert-Reichl et al., 2015). Aside from empirical work, there are also conceptual factors that help to differentiate mindfulness from other SEL and well-being interventions.

It is possible that mindfulness is a foundational capacity that can either drive or undermine the success of other SEL interventions. For example, if a student is participating in an SEL exercise that involves conflict resolution and teamwork, then the capacity to *pay sustained attention* during the exercise is likely to be valuable—if not necessary—for the success of the intervention. Likewise, appropriate social behaviour requires paying attention to social cues (Picket, 2003), and attention is also important for recognising and differentiating emotions and reducing ruminations that perpetuate them (Teper, Segal, & Inzlicht, 2013). The enhancing effects of mindfulness practice observed in such diverse fields ranging from athletic performance (Sappington & Longshore, 2014), to problem solving (Ostafin & Kassman, 2012), to empathy (Shapiro, Schwarts, & Bonner, 1998), also point towards the idea that mindful attention may be a kind of building block for many other capacities to develop. Ultimately, controlled experiments will be necessary to differentiate the unique impact of mindfulness compared to other SEL interventions (for further discussion see Lawlor, 2014). By reviewing research targeting mindfulness specifically, one contribution of this review is to shed light on how mindfulness may uniquely contribute to a well-rounded education in concert with other SEL interventions.

2. Mindfulness and Learning in the Laboratory

The effects of mindfulness on learning in laboratory settings includes an extensive and diverse literature. In this section more than the others, we have had to condense the research significantly, and discussing specific studies is not possible in the service of a short review. Therefore, here we have chosen to target experiments and reviews that are particularly relevant to key aspects of cognition for learning, such as mind-wandering, cognitive flexibility, emotion regulation, executive functioning, and stress reduction.

2.1. Attentional control and mind-wandering

Attention is key to successful learning, yet high levels of distraction are widely prevalent in schools (Lindquist, 2011[13]). In addition to social and educational content, students face a constant influx of perceptions, thoughts and feelings. They must learn to filter through these potential distractions to identify and attend to learning opportunities (Smallwood, 2007). One particularly prevalent form of distraction in the classroom is mind-wandering. While mind wandering can also have positive effects, for example, on creative thinking (Zedelius & Schooler, 2015), mind-wandering in class has been repeatedly shown to be detrimental to students' learning; in particular to their retention of newly learnt information, their reading comprehension, and overall academic performance (Mrazek, Phillips, Franklin, Broadway, & Schooler, 2013; Wammes, et al, 2016). Mind-wandering can be particularly maladaptive when it manifests as rumination or worry, and students have been found to mind-wander in class in ways that lead to increased stress and worse mood (Mrazek, et al., 2013).

Whilst distraction in the classroom has been shown to result in detriments to learning, viable solutions to this problem are still needed. Students are often asked to pay attention, but are rarely taught how to do so. Teachers often attempt to retain their students' attention by strategically altering educational tools and the learning environment, often selecting activities that are sensitive to students' limited attention spans (Jensen, 1998; Sammons, 1995; Sylwester & Cho, 1993). Although altering educational tools and the learning environment can be helpful, careful observation of most classrooms reveals the ongoing challenge of gaining and sustaining students' undivided attention.

A growing body of work suggests that in adults, mindfulness training may improve many components of attentional control, including efficient allocation, vigilance, and the inhibition of distractors (MacLean et al., 2010; Slagter et al., 2007; Tang et al., 2007). It is not surprising then, that brief mindfulness interventions have been shown to reduce both subjective accounts and behavioural markers of mind-wandering (Mrazek, Smallwood, & Schooler, 2012; Levinson, Stoll, Kindy, Merry, & Davidson, 2013). In one study, just ten minutes spent practicing mindful breathing resulted in reduced mind-wandering during an immediately subsequent task (Mrazek, Smallwood, & Schooler, 2012). Working memory and reading comprehension also show improvements following mindfulness practice, and highly distractible students show particular improvements as a function of reduced mind-wandering (Mrazek, et al, 2013). Furthermore, mindfulness training improves people's capacity to notice when text intermittently becomes meaningless, which is a measure found to closely index mind-wandering during reading (Zanesco et al., 2016). These results cumulatively suggest that mindfulness-based interventions may be key to stimulating cognitive and attentional abilities with important educational relevance and that one underlying mechanism may be a reduction in mind-wandering.

2.2. Cognitive flexibility and creativity

Mindfulness practice has also been shown to improve cognitive flexibility (Moore & Malinowski, 2008), the ability to identify multiple different perspectives, for example in visual illusions (Hodgins, & Adair, 2010), and the ability to shift flexibly between them as required (Zelazo & Frye, 1998). Adapting to new information, learning new ways of looking at the world, and seeing things from various perspectives are all based on the capacity for cognitive flexibility. Cognitive flexibility may be particularly valuable for changing one's mind during the learning process, for example when new information conflicts with what one currently believes. Perhaps drawing on its effects on cognitive flexibility, mindfulness has also been associated with enhanced creativity in long-term meditators (Colzato, Ozturk, & Hommel, 2012), and in undergraduate students after one week of meditating for 30 minutes per day (Ding, et al, 2014). The students also showed increased positive affect and decreased negative affect following the week of meditation, in comparison to an active control group (relaxation training) that showed no improvement in divergent thinking or affect. Ding et al., (2014) also conducted path analyses showing that improvements in mood associated with the meditation training may be contributing to the students' divergent thinking ability.

2.3. Emotion regulation and executive control

Emotional awareness and emotion regulation are also important for learning. Emotions can guide learning by influencing perception, attention and motivation (Immordino-Yang, & Damasio, 2007). Emotions also play a role in facilitating encoding and retrieval of relevant information (Tyng, Hafeez, Mohamad, & Aamir, 2017), and are themselves important sources of information during decision-making (Schwarz, 2010; Laukkonen et al., 2018). Practicing mindfulness meditation may increase sensitivity to early affective cues (Teper, Segal, & Inzlicht, 2013), thereby facilitating self-regulatory executive control at early levels of the emotional response and may thereby improve emotional regulation. Consistent with this view, Arch & Craske (2006) found that 15 minutes of mindful attention to the breath showed more positive responses to neutral images, decreased negative responses and emotional volatility, and were more willing to view negative stimuli than control conditions (mind-wandering or worrying). As discussed above, meditation practice has also been associated with improvements in executive control, such as attentional control and cognitive flexibility. According to mediation pathway analyses, the increased executive control capacities related to meditation practice (particularly inhibitory control) can be accounted for by heightened emotional acceptance and (to a lesser extent) performance monitoring (Teper & Inzlicht, 2013).

2.4. Stress reduction

Successfully coping with stress can also have important implications for learning and well-being. While short-term acute stress can boost learning and memory, longer term chronic stress impairs attention, motivation, learning, memory and overall psychological well-being (Eysenck, Derakshan, Santos, & Calvo, 2007; Liston, McEwan, & Casey, 2009; Vogel, & Schwabe, 2016; McEwan, 1998). Thus, another way that mindfulness may indirectly improve learning is by reducing chronic stress (Goleman, & Schwartz, 1976; Jacobs, et al. 2013, see also reviews of the effects of MBSR, Fjorback et al., 2011; Sharma & Rush, 2014), and the frequency and intensity of negative moods (Chambers, et al, 2008; Jain, et al, 2007; Ding, et al, 2014).

2.5. Summary

Taken together, laboratory experiments provide evidence indicating that mindfulness may positively impact learning, through reducing mind-wandering (Mrazek, Smallwood, & Schooler, 2012; Levinson, Stoll, Kindy, Merry, & Davidson, 2013), increasing cognitive flexibility and creativity (Moore & Malinowski, 2008; Hodgins, & Adair, 2010; Colzato, Ozturk, & Hommel, 2012; Ding, et al, 2014), improving emotion regulation (Teper, Segal, & Inzlicht, 2013; Arch & Craske, 2006, and see also Hill & Updegraff, 2012) and as a result improving inhibitory control (Teper & Inzlicht, 2013), and reducing chronic stress (Goleman, & Schwartz, 1976; Fjorback et al., 2011; Praissman, 2008; Jacobs, et al. 2013; Sharma & Rush, 2014). However, we recommend some caution in interpreting these results as conclusive. Relatively few studies employ active control conditions (i.e., a comparison group that engages in another activity that is not mindfulness, e.g., exercise or relaxation). In some cases it is also difficult to determine whether differences between experienced meditators and novices (e.g., Moore & Malinowski, 2009; Teper & Inzlicht, 2013) are a consequence of meditation practice or some other difference (e.g., motivation). The nature of mindfulness-based interventions can also vary considerably across studies (Van Dam et al., 2018). Despite these caveats—which we discuss in more detail later—it is important not to lose sight of the otherwise promising results from a diverse literature discussed above.

3. Mindfulness and Learning in the School

Mindfulness interventions have also received significant and growing attention in applied settings and educational contexts outside the laboratory. In the decade between 2005 and 2014, at least 28 peer-reviewed studies have reported the outcome of MBIs on school students under the age of 18 (reviewed by Felver, Celis-de Hoyos, Tezanos, & Singh, 2016). Other studies show that college-age learners also benefit (Shapiro, Schwartz, & Bonner, 1998), as do parents and teachers (Harris, Jennings, Katz, Abenavoli, Greenberg, 2016). The current evidence suggests that the benefits of MBIs are generalisable across student gender, ethnicity, age, and socio-economic status (Felver et al., 2016). A singular best-practice is yet to emerge in school-based programs, which indicates the variety of ways mindfulness programs can be implemented, and suggests room for developing greater structure and standardisation in future individual interventions.

3.1. Interventions improve student, parent, and teacher well-being

To date, the aim of most MBI studies has been to document the benefits of mindfulness practices on measures of student well-being. The most commonly reported student outcomes include a reduction of negative or antisocial behaviours (especially disruptive classroom behaviour, affective disturbances, and low executive function and attentional control) and an increase in positive or prosocial behaviours (classroom engagement, emotion regulation, and social-emotional competence). Older students also report increases in empathy levels, and reportedly maintain reduced stress through exam periods (Shapiro et al., 1998). These results are typical following short-term training, with interventions typically lasting 2-24 weeks (or 4 to 60 sessions; Felver et al., 2016).

Training approaches have included mindfulness-based stress reduction (e.g., Kabat-Zinn, 1990), embodied mindfulness through Yoga (e.g., Shapiro et al., 1998), or variations on mindfulness-based cognitive-behavioural therapies (e.g., Segal et al., 2002). The variety of approaches to mindfulness training suggests that MBIs can be flexible enough to extend to a variety of demographics and sub-populations; studies that focused on samples with disabilities, attentional deficit disorders, or sub-clinical levels of high blood pressure have all demonstrated improvement in subjective well-being in educational contexts (Felver et al, 2016).

Teachers and parents can also benefit from mindfulness practices. One study (Harris et al., 2016) conducted a yoga and mindfulness intervention with 64 educators across 16 weeks. The intervention included two cohorts of middle school educators, randomly assigned to the active intervention group or the wait-list control group. The educators were assessed for a variety of social-emotional competencies, subjective well-being, and resting-state physiological measures. Compared to the control group, the active intervention of daily yoga and mindfulness sessions resulted in positive benefits on educators' self-reported mindfulness, affect, and distress, as well as physiological measures of stress, blood pressure, and cortisol. The educator intervention did not report on the direct benefit to students' educational performance. Identifying the link between MBIs, student and teacher well-being, and student academic performance remains an important avenue of future investigation. Another limitation of the current study was the use of a wait-list control group. Future studies should include a control group that undergoes an intervention that does not include mindfulness, to more definitely attribute observed effects to the mindfulness component of the intervention.

3.2. Mindfulness programs are feasible, enjoyable, and improve reading scores

The overall consensus from MBIs suggests positive results on participant well-being. Although fewer studies have focused on the link between mindfulness and academic performance directly, recent results provide preliminary evidence for a positive association between MBIs and cognitive functioning. For example, a two-year study in pre- to post-kindergarten children showed benefits on memory, planning, and organisation after the first year (Thierry et al., 2016). At the end of the study, the children showed improved vocabulary and reading abilities compared to the business-as-usual control group. Yet, in the absence of an *active* control group, one cannot exclude the possibility that observed effects reflect non-specific effects of the intervention, for example, related to doing an extra group activity. The results of MBI studies appear to generalise to older students too, with a small (N=11) cohort of 16-18 year old students demonstrating a full grade-point improvement compared to the control group at a three-month follow-up (Bennett & Dorjee, 2016). The general pattern of brief MBI studies shows an increase in verbal ability and memory recall, an effect that appears to generalise across age and gender (see also Bennett, Egan, Cook, Mantzios, 2018). These results suggest a promising early trend for the involvement of mindfulness programs in educational settings across various cohorts.

A study by Bakosh, Snow, Tobias, Houlihan, & Barbosa-Leiker (2016) examined the quarterly grade-point averages of four third-grade classrooms across two schools (N=191). Students in the intervention group (n=93; 47 females) received audio tapes with guided awareness and attention-focusing practices, specifically curated toward social and emotional learning concepts. Students in the control group (n=98; 45 females) simply continued normal curriculum activities. Significant improvements were observed in the treatment group's reading scores across the school year; an important finding since reading scores by the third-grade are strong predictors of overall high school completion rates (Feister, 2010). The study showed that reading scores at third-grade level can be improved with a short (10-min) daily instruction on focusing attention to bodily sensations or open awareness. Since the discourses were pre-recorded, the intervention required no curriculum changes or intensive training sessions, and no expert psychologists. The teachers involved in the study both implemented and participated in the guided mindfulness program as part of their usual daily curriculum.

The study by Bakosh and colleagues suggests that mindfulness interventions might be particularly well-suited to improving students' reading skills within a standard classroom setting. The results of MBI programs more generally are suggestive of high feasibility, efficacy, and generalisability of mindfulness in educational contexts. Additionally, informal feedback from student and teacher participants suggest that the studies are typically well-received and often enjoyable.

3.3. Standardisation: the next step

Felver and colleagues (2016) point out important methodological differences between the many current school-based MBIs, which make direct comparisons across studies difficult. Their systematic review reveals that the evidence base for MBIs in schools often lacks rigorous empirical validation and experimental control, which reduces the ability to draw strong conclusions from current school-based studies. However, it is worth noting that it is inherently more difficult to attain the same experimental control in field settings relative to laboratory experiments, which is why it is necessary to have both. Felver and colleagues (2016) suggest that future interventions will benefit from a greater standardisation in the

design, structure, measurement, and implementation of mindfulness interventions. Two notable problems are: 1) a multitude of approaches to and definitions of mindfulness, with few standardised guidelines for MBI implementation, and 2) a diversity of outcome measures, and some inconsistency between studies on the measurement of outcomes. Although the existing evidence is highly suggestive of a positive impact of mindfulness on learning (Thierry et al., 2016; Bennett & Dorjee, 2016; Mrazek et al., 2013)—especially when taken together with the laboratory studies discussed earlier—further work will be necessary to infer a direct causal link in school settings.

4. How does Mindfulness Compare to other Interventions?

To help put mindfulness in context, in this section we consider another intervention employed in schools to improve learning, and how it compares both theoretically and practically with MBIs. Discussing another example can help us to understand the research process that takes a phenomenon from its discovery to eventual application in the classroom, and it can also be revealing about the ways that mindfulness may interact with other interventions. For this discussion we will draw mostly on evidence from recent experiments in cognitive and educational psychology, with school and university students as target populations.

Our example for comparison is *retrieval practice*, a review technique that was first studied a century ago and that has recently attracted new interest, alongside other techniques such as spaced practice and elaborative interrogation, due to its apparent promise for use in education (for accessible reviews, see Dunlosky, Rawson, Marsh, Nathan, & Willingham, 2013; and Pashler et al., 2007). Deliberately retrieving a memory can increase its strength and protect it against forgetting. Retrieval practice is simply any activity that involves this kind of deliberate remembering. Taking a test, answering a teacher's question in class, explaining something to a friend, or self-testing using flashcards are all examples of retrieval practice. The technique seems to be very effective for memorisation, with studies often finding that it improves performance on delayed tests of knowledge by 10-20 percentage points (e.g., McDaniel, Agarwal, Huelser, McDermott, & Roediger, 2011; McDermott, Agarwal, D'Antonio, Roediger, & McDaniel, 2014).

4.1. Research can address specific concerns about implementation

As research on retrieval practice has continued, several concerns about its effects have been raised, each of which has some analogy to concerns about mindfulness. The first concern was that retrieval practice may just be another form of re-exposure; when a student successfully retrieves a piece of information, it comes to mind just as it would if they had read it or heard someone explain it, so naturally it strengthens memory. The second concern was that retrieval practice might produce a rigid kind of learning, helping students to get better specifically at repeating exact answers, and leaving them unable to transfer what they retained to different tasks. The third concern was that retrieval practice might be ineffective for some students, or for learning in some subject areas. Each of these concerns have since been addressed experimentally, showing that retrieval practice has unique benefits above simple re-exposure (Roediger & Karpicke, 2006), causes transferable learning (Pan & Rickard, 2018), and can help various student populations (Dunlosky et al., 2013).

Mindfulness has faced analogous concerns. Are the benefits of mindfulness exercises caused by its unique features, or would any calm or quiet activity have the same effects? How well can skills developed during mindfulness practice be transferred and applied in new situations? And is mindfulness helpful for everyone, or are their certain age groups or other populations that do not benefit?

More work is needed, but mindfulness research is beginning to address these questions. For example, a recent meta-analysis (Dunning et al., 2019) found that for improving executive function in adolescents, MBIs, while effective, were not always superior to other interventions. That being said, individual studies comparing MBIs to closely matched activities have made some promising findings. In two such studies, several sessions of

mindfulness practice were compared to equivalent time in quiet conditions, spent either practicing yoga postures (Quach, Jastrowski Mano, & Alexander, 2016) or listening to an audio book (Zeidan, Johnson, Diamond, David, & Goolkasian, 2010). In each case, only the mindfulness exercises produced improvements in measures of sustained attention. Regarding generalisability, there is some evidence that MBIs for executive function are more effective for older rather than younger adolescents (Dunning et al., 2019).

As our example of retrieval practice shows, dealing with concerns of this kind is a normal part of the process of determining the practical value of a new intervention. Research on MBIs is gradually moving through this process. Using the specific example of retrieval practice, we can also consider how mindfulness might interact with other techniques or activities. In general mindfulness would be expected to complement rather than replace or interfere with direct learning activities. However, in some cases there may be reasons to expect mindfulness practice to *enhance* other interventions (or be enhanced by them). In what follows, we offer some speculation about such interactions in the case of retrieval practice (as an illustrative example).

4.2. Mindfulness may interact positively with other learning activities

Retrieval practice seems to be most effective when the information being practiced is difficult to retrieve—that is, when the retrieval attempts involve deliberate thought (Carpenter, 2009; Carpenter & DeLosh, 2006; Finley, Benjamin, Hays, Bjork, & Kornell, 2011). This kind of retrieval involves several conscious processes, including attending to information that can guide the search (e.g., the content of a question on a practice test), monitoring ideas that come to mind during the search and perhaps using these to guide further searching, selecting among the products of the search, and deciding when to stop searching (Baddeley, Eysenck, & Anderson, 2015).

Because some retrieval processes are under conscious control, instructions about how to retrieve can alter the effects of retrieval practice. In one study (Chan, McDermott, & Roediger, 2006), researchers divided their learners into two groups and gave them different instructions. One group was told to search broadly during retrieval practice, allowing any relevant information to come to mind even if it did not seem like a correct answer. The other group was told to search narrowly and to try to think only of the exact correct answer. On a later test, both groups showed a benefit of retrieval practice, but the broad search group enjoyed an additional benefit—they also showed improved performance with related material that they had not directly practised. The broad search strategy seems to have helped them notice relationships within the learning material. Given these effects, it seems plausible that learners more skilled at controlling their attention would be more able to control their retrieval attempts and benefit more from them.

The mindful attitude of non-judgement could also facilitate or enhance retrieval practice. An intriguing finding is that remembering information can improve learning even if the information remembered is incorrect. Many studies have now found that incorrectly guessing the answer to a question before receiving the correct answer as feedback produces better learning than simply reading the answer without first attempting retrieval (Grimaldi & Karpicke, 2012; Kornell, 2014; Kornell, Hays, & Bjork, 2009). At the same time, learners show a reluctance to make errors—for instance, in experiments they tend to prefer easier but less effective study techniques (Bjork, Dunlosky, & Kornell, 2013). Mindfulness interventions could plausibly help students to become more tolerant of challenge (and errors) by allowing them to practice a non-judgemental attitude and by establishing this attitude as something that teachers could remind them of during other activities.

The points of alignment we have just discussed suggest a further benefit. Retrieval practice may be an example of a learning activity that could double as a mindfulness exercise. Retrieval activities could be used as occasions to remind learners of important elements of mindfulness, and possibly the memory search process itself could serve as an opportunity to practice mindful awareness. Indeed there is currently some indirect evidence that retrieval may promote a mindful state, or at least a state of heightened concentration. The process of memory retrieval seems to be somewhat resistant to distraction (Craik, Govoni, Naveh-Benjamin, & Anderson, 1996), and a recent study has found that distractions interfere more with learning from passive study than from retrieval practice (Mulligan & Picklesimer, 2015). This possible compatibility between retrieval and mindfulness illustrates the general point that mindfulness interventions could potentially be integrated into learning activities themselves, reducing the competition for time between mindfulness and other content.

5. The Neuroscience of Mindfulness

The neuroscience of mindfulness is revealing unique insight into the mechanisms of mindfulness. Over the past two decades, with the advent of modern neuroimaging methods such as MRI and M/EEG, scientific interest in the neural changes that may underlie effects of mindfulness practice has rapidly increased. These neuroimaging methods provide complementary information about brain function and structure. Functional magnetic resonance imaging (MRI) measures neural-activity driven changes in blood flow and oxygenation with high spatial (where in the brain), but relatively low temporal (when in time) precision. Electroencephalography (EEG) and its magnetic counterpart (MEG) on the other hand directly measure neuronal activity with millisecond temporal precision, but relatively low spatial precision and cannot measure activity from subcortical regions. EEG and MEG activity is characterized by prominent oscillations at various frequencies, driven by synchronous changes in excitability of neural networks. Lastly, structural MRI provides a detailed picture of brain anatomy.

Most of the neuroimaging studies on mindfulness practice have so far been conducted in adults, and current consensus is that while initial findings indicate that mindfulness is associated with both functional and structural changes in the brain, methodologically more rigorous studies are necessary if we are to gain a full understanding of the neural mechanisms underlying the effects of mindfulness meditation (Fox et al., 2016; Lomas et al., 2015; Mooneyham et al., 2016; Slagter et al., 2011; Tang et al., 2015). Of particular importance is the implementation of proper controls, given that it is impossible to blind participants to the nature of the study (mindfulness) and this can induce well-known confounding placebo and Hawthorne effects (Davidson & Kaszniak, 2015; Slagter et al., 2011). Another important factor is that mindfulness is an umbrella term and often encompasses two different practices: attention with a specific focus and non-reactive monitoring of experience. An important distinction in the field of contemplative neuroscience is therefore between focused attention (FA) practice and open monitoring (OM) (Lutz et al., 2008).

5.1. Different practices are associated with different neural activity

FA practice entails the voluntary focusing of attention on a chosen object, while OM cultivates non-reactive monitoring of the content of experience from moment to moment. These practices are distinct at the psychological level and hence can be expected to have dissociable effects at the neurophysiological level (Lutz et al., 2008). In the below, we focus on the results of recent meta-analyses and systematic review papers on the effects of FA and OM on brain and cognitive functioning, rather than on results from individual studies, given large variety between studies e.g., in the amount of meditation experience and age of the participants, in meditation traditions, and in tasks used to measure brain and cognitive functioning (Fox et al., 2015, 2016; Lomas et al., 2015).

In line with the notion that FA and OM recruit different psychological processes, a recent meta-analysis found that brain activation in fMRI studies depended on the specific type of meditation practice under investigation (Fox et al., 2016). Only a single brain region, the insular cortex, a brain region key to interoceptive body awareness, was recruited by four types of practice: FA, OM, mantra recitation and compassion/loving-kindness meditation. FA was in addition associated with activations in regions associated with the voluntary

regulation of thought and action, including the dorsal anterior cingulate cortex and the premotor cortex extending into the dorsolateral prefrontal cortex. Notably, FA was also associated with deactivations in the default mode network. This network of brain regions plays a critical role in thinking about self and others and future and past events (Smallwood et al., 2013). This latter finding is in line with the notion that FA may reduce mind-wandering. OM meditation was also related to changes in brain activity in regions key to the control of thought in action, which partially overlapped with FA practice, including the pre-supplementary motor/dorsal anterior cingulate cortex, premotor/dorsolateral prefrontal cortex, supplementary motor area, and left inferior frontal gyrus. Mindfulness meditation has also been associated with changes in neural anatomy in different parts of the brain, including regions related to meta-awareness (frontopolar cortex), exteroceptive and interoceptive body awareness (sensory cortices and insula), memory consolidation and reconsolidation (hippocampus), and self and emotion regulation (anterior and mid cingulate; orbitofrontal cortex), as measured with structural MRI (Fox et al., 2015).

Little is still known about how much meditation experience is necessary to induce functional and structural changes in the brain. This requires following the same individual over extensive periods of time to establish the time course of meditation-induced effects. Such longitudinal studies are also critical for establishing meditation as the causative factor of effects observed in cross-sectional studies comparing expert practitioners to controls, which could also reflect preexisting differences between groups, for example in proclivity towards paying attention to inner mental life.

5.2. Neural evidence that mindfulness improves attention

Studies using EEG have also reported practice-related changes in brain activity. One more consistent finding is increased oscillatory activity in the alpha and theta band—i.e., specific wavelengths of electrical activity recorded from the scalp—during mindfulness practice, which has been taken to reflect a state of relaxed alertness (Lomas et al., 2015). Mindfulness has also been reported to have effects that endure outside the practice context. For example, 3 months of intensive OM practice was found to change performance on an attentional blink (AB) task, even though participants were not engaged in formal practice during the task (Slagter et al., 2007). In the AB task, participants have to identify two target stimuli (e.g., two numbers) presented very closely in time, amongst a rapid stream of other stimuli (e.g., letters). Typically, when one number follows another number very closely in time (within about 500ms), participants fail to perceive the second number, as if their attention temporarily "blinks". Theories of this so-called attentional blink phenomenon typically assume that the AB is due to an overallocation of resources or attention to the first target. 3 months of OM practice was associated with a smaller attentional blink to the second stimulus, suggesting that participants were able to perceive more often a stimulus that would ordinarily go unnoticed. Notably, this improvement in seeing the second number was accompanied by a reduction in attentional processing of the first number at the neural level, as shown by EEG. Because participants were not engaged in formal meditation during task performance in this study, these results provide support for the idea that one effect of an intensive training in OM might be a general reduction in the propensity to "get stuck" on an event, as reflected in less elaborate processing, and the development of present moment awareness.

5.3. Summary

Thus, the scientific literature provides many examples of mindfulness-related changes in brain function and structure. Yet, as pointed out above, these findings should be interpreted carefully, as while the field has certainly matured (van Dam et al., 2018), longitudinal studies that track the same individual over longer periods of time with active controls are necessary to provide more direct evidence for the effects of mindfulness and a full understanding of the neural mechanisms underlying these effects. Also, most of the neuroscientific studies on mindfulness have so far been conducted in adults, and currently, relatively less is known about how mindfulness may affect the developing brain (Sanger & Dorjee, 2015).

6. Discussion

In a relatively short time, research on mindfulness and attention training has grown from a niche field of research to a well-established body of evidence that reveals the promise of mindfulness for improving many variables central to human flourishing. Though the majority of research has focused on health and well-being, our review indicates a growing literature particularly in experimental psychology and cognitive science that points promisingly towards a positive impact of mindfulness on learning, memory, emotional regulation, attention, cognitive flexibility, creativity, and executive functioning (Mrazek et al., 2013; Mrazek, Smallwood, & Schooler, 2012; MacLean et al., 2010; Slagter et al., 2007; Tang et al., 2007; Moore & Malinowski, 2008; Ding, et al, 2014; Jacobs et al., 2013). Early work in school settings is also encouraging (Felver et al., 2016; Thierry et al., 2016; Bennett & Dorjee, 2016), and mindfulness may well play a complementary role with other well-established learning interventions, such as retrieval practice. The neurological consequences of mindfulness practice are also beginning to demonstrate that the brain can change in specific ways that reflect reductions in mind wandering (Fox et al., 2016), improved attention (Slagter et al., 2011), and the voluntary regulation of emotion, thought, and behaviour (Fox et al., 2015). Like all interventions currently targeting well-being and learning, experimental control, longitudinal studies, and standardisation of mindfulness training will improve the quality of the evidence.

When is it appropriate to advance an intervention from research to practice? Some scientific consensus about the evidence-base underlying a new intervention is certainly important. To this end, most meta-analyses indicate a robust and consistent positive impact on well-being, stress, depression, and anxiety (Grossman et al., 2004; Fjorback et al., 2011; Praissman, 2008; Sharma & Rush, 2014), with analogous results specifically in the context of groups under the age of 18 (Zoogman et al., 2014). Since adolescents spend most of their time in school and their mental health has been steadily declining (NHS, 2018), it is perhaps reasonable to suggest that interventions which show marked benefits to mental health ought to be implemented in schools. One possible objection is that schools are primarily designed for learning, and that it is simply not within the scope or resources of most educational institutions to be overseeing student well-being. MBIs may be in a unique position in the sense that they have the potential to improve student well-being, health, *and* learning.

Other pragmatic considerations are also necessary. For example, what are the opportunity costs to teaching mindfulness practice in a school? Is there an intervention that would yield better results more quickly? How can training be made available in a scalable and affordable way? Aside from SEL interventions (Durlak et al., 2011), we do not know of another intervention (except perhaps exercise) that has similarly promising benefits to health and learning. It is outside the scope of this review to consider every factor involved in a decision to implement MBIs in educational contexts, and each institution is going to have unique constraints. But considering the extant evidence, the relative lack of adverse effects compared to other interventions (Zoogman et al., 2014; Goyal et al., 2014), and the urgency of supporting students who are struggling (NHS, 2018), there is perhaps greater risk in delaying implementation than in acting prematurely. A particularly fruitful approach may be to combine the initial phases of implementation with experimental protocols and measures (including waitlist controls), in order to advance the state of knowledge while also providing the necessary training. Implementation in schools would also provide new opportunities for longitudinal studies that would be a valuable extension to the

predominantly cross-sectional research currently available. With this approach, MBIs could be iteratively improved, the evidence base strengthened, while also delivering the benefits to students who need them. It will also be important to determine which students, and what age groups, will most benefit from MBIs, and which students may be at risk of unpleasant reactions (Creswell, 2017). Below, we address in more detail practical factors of scalability, instruction, personalisation, digitalisation, and best practices for implementation.

6.1. The challenges and opportunities of bringing well-being interventions into schools

The adoption of school-based well-being interventions—of which MBIs are one example—is a relatively new phenomenon (Bywater and Sharples, 2012). Several national organisations have emerged to promote the widespread delivery of well-being interventions in schools, including the Social and Emotional Aspects of Learning (SEAL) programme in the UK, and the Collaborative for Academic, Social, and Emotional Learning (CASEL) in the US. Organisations like these can facilitate the adoption of well-being interventions by providing schools with guidance, recommendations, and support. Yet despite the growth of these organizations and the proliferation of well-being curricula over the past two decades, progress in the effective implementation of evidence-based well-being interventions within schools remains slow (Bywater and Sharples, 2012).

There are numerous challenges to the widespread adoption and effective implementation of new school-based interventions. Common challenges include creating buy-in among key stakeholders, securing funding for new initiatives, identifying evidence-based interventions, considering the opportunity cost of new programs, providing the necessary training to staff, ensuring effective implementation, assessing outcomes, and securing the sustainability of new programs. Consideration of how to best provide mindfulness training in school settings can serve as a useful illustration of many of these challenges, as well as potential solutions.

6.2. How can evidence-based mindfulness training be made available to schools at scale?

Our review suggests that millions of students worldwide could benefit from evidence-based MBIs, but how can this training be made available to students at scale? Multiple approaches exist, each with their own strengths and limitations. The most widely researched approach to bringing mindfulness into schools is having trained mindfulness instructors provide in-person training directly to students. This can be an effective approach for schools with access to these experts and the financial resources to pay them. However, many schools do not have this access and even fewer schools can afford to train all of their students in this way.

Another viable approach is to have experts train teachers who, in turn, teach mindfulness to their students. This approach can improve the well-being of teachers (Roeser et al., 2013), and it can allow teachers to become long-term providers of mindfulness training within their schools. However, extensive training is often required before teachers have the knowledge and skills to teach mindfulness effectively to students (Crane, Kuyken, Hastings, Rothwell, & Williams, 2010). Teachers can also face challenges in delivering a standardised intervention with high fidelity of implementation, which makes it difficult to ensure that their students are receiving optimal training (Forman et al., 2013).

A digital approach to mindfulness training can help address many of these issues. One key advantage of digital mindfulness-based interventions (d-MBIs) is their accessibility. D-MBIs can reduce geographical, logistical, and financial constraints that would otherwise prevent access to training (Asuncion et al., 2010). d-MBIs can also be effectively standardised. Even a great curriculum will fail to provide benefits if it is delivered ineffectively. Digital training provides the opportunity to standardise key elements of course content and presentation, thereby ensuring that all users receive the same high-quality instruction (Clarke, Kenney, & Hermens, 2004; Puzziferro & Shelton, 2008).

A third advantage of d-MBIs is the opportunity for personalised learning. Digital training can provide content that is tailored to the abilities and interests of individual users, which has been shown to heighten both engagement and learning outcomes (Dixson, 2010; Wang, 2014). Finally, d-MBI's can increase efficacy. Research suggests that well-designed digital training can elicit equal or even greater outcomes compared to in-person instruction (Bernard et al., 2004; Dixson, 2010; Maki & Maki, 2008). For instance, one study examining 273 adults living in the UK found that both d-MBI's and face-to-face mindfulness interventions were equally effective in helping reduce perceived levels of depression, anxiety, and stress (Krusche, Cyhlarova, & Williams, 2013).

However, these advantages of d-MBIs depend on effective design and execution, which is challenging to achieve. Of the numerous mindfulness apps that now exist, most fail to apply best practices in digital learning and have received only modest ratings in terms of engagement, functionality, and information quality (Mani, Kavanagh, Hides, & Stoyanov, 2015). To be successful, d-MBIs must creatively apply best practices in digital learning including: (1) tailoring instruction to a well-defined audience, (2) applying best practices in educational psychology to ensure effective learning, (3) addressing audience diversity through personalisation of program content, (4) designing content that maximises student engagement, and (5) anticipating and addressing common challenges (Mrazek et al., 2019).

6.3. Best Practices for Teaching Mindfulness in Schools

Successful implementation of mindfulness training in school settings is not without challenges. Yet given appropriate foresight and planning, it is realistic. Best practices to consider include:

Choosing Advocates & Building a Shared Vision. Outside experts and consultants can be useful, but implementing change in school settings typically requires the sustained effort of individuals working within those environments ("Social and Emotional Learning | CASEL - Casel Schoolguide," n.d.). These advocates can engage other key stakeholders to create a shared vision regarding the integration of mindfulness into the school. In these conversations, it is important to clearly communicate potential benefits while also setting realistic expectations. Schools should also consider how mindfulness initiatives can align with local, regional, or national policies on mental health, social-emotional learning, and student well-being.

Adopting a Whole-School Approach. While targeted MBIs for special populations can be appropriate, mindfulness has universal relevance for students, teachers, and administrators. Engaging the entire school community entails greater logistical challenges than a limited roll-out, but it also stands to benefit all stakeholders while leading to a more sustainable integration of mindfulness. Beginning with professional development for staff is a strategic first step, as it can create buy-in among key stakeholders while also preparing staff to model mindfulness for students (Roeser, Skinner, Beers, & Jennings, 2012).

It is also important to identify the most appropriate place in the overarching school curriculum to provide students with mindfulness training. Often the ideal place is where all students will have access, where the training will not unduly compete for limited academic time, and where the training is appropriately situated in the context of similar topics like mental health or social-emotional learning.

Identifying Appropriate Resources. Numerous resources and curriculums now exist to help schools train teachers and students in mindfulness. A school's location and resources will often determine whether a digital course, in-person training, or combination will be most suitable. Identifying a program that is truly secular in nature will help facilitate the support of parents and the community at large.

Many existing programs are tailored to specific age groups, which is essential because the most effective ways to teach mindfulness to students vary tremendously by age. It is also important to select resources that are accessible to students with special needs, including students who have a history of trauma. Although mindfulness training is an established intervention for addressing trauma (Follete, Palm, & Pearson, 2006; Kimbrough et al, 2009), some specific forms of intensive mindfulness practice are not appropriate for individuals with a history of traumatic events (Lindahl et al., 2017). Numerous strategies exist to address this risk (Treleaven, 2018), and schools should seek resources that utilize best practices to provide trauma-sensitive mindfulness training.

Schools should also prioritise evidence-based resources that have a strong track record in school settings. However, it is important to recognise that most published research on specific mindfulness programs within school settings is preliminary and has limited generalisability. The success or failure of a given resource in one context is an imperfect predictor of how that resource will perform in other contexts (Zenner, Herrnleben-Kurz, & Walach, 2014).

Measuring & Optimising Fidelity of Implementation. Even the best laid plans can run into issues in environments as dynamic and complex as schools. Poor fidelity of implementation is a well-known challenge to school-based interventions of all kinds (O'Donnell, 2008). To increase effectiveness, schools would ideally pilot the training with a smaller group of students to identify and address obstacles. It can also be beneficial to collect systematic feedback from students and teachers, particularly with respect to barriers to effective implementation.

Conclusion. The goal of this review was to go beyond 'the ideal' (James, 1890[2]) of mindfulness as a foundational capacity for learning by reviewing the state of scientific evidence, and to provide practical advice regarding implementation in schools. Systematically integrating mindfulness training into a school setting entails a learning curve that can be daunting. However, evidence for the benefits of mindfulness training suggests that it is likely worth the investment, and the best practices outlined here may ease the transition.

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