Attention Matters: How Orchestrating Attention May Relate to Classroom Learning

Arielle S. Keller,[†] Ido Davidesco,[‡] and Kimberly D. Tanner[§*]

[†]Neurosciences Graduate Program, Stanford University, Stanford, CA 94305; [‡]Department of Educational Psychology, Neag School of Education, University of Connecticut, Storrs, CT 06269; [§]Department of Biology, San Francisco State University, San Francisco, CA 94132

ABSTRACT

Attention is thought to be the gateway between information and learning, yet there is much we do not understand about how students pay attention in the classroom. Leveraging ideas from cognitive neuroscience and psychology, we explore a framework for understanding attention in the classroom, organized along two key dimensions: internal/external attention and on-topic/off-topic attention. This framework helps us to build new theories for why active-learning strategies are effective teaching tools and how synchronized brain activity across students in a classroom may support learning. These ideas suggest new ways of thinking about how attention functions in the classroom and how different approaches to the same active-learning strategy may vary in how effectively they direct students' attention. We hypothesize that some teaching approaches are more effective than others because they leverage natural fluctuations in students' attention. We conclude by discussing implications for teaching and opportunities for future research.

INTRODUCTION

Imagine a spotlight on a large stage that represents your attention. Not everything on the crowded stage can fit within your spotlight of attention at all times, so some selection must be made for what is most important. If we move beyond simply asking whether that spotlight is turned on or turned off, we can start to think about *what* that spotlight is focused on at a given moment and ask questions about *how* the spotlight came to be focused where it is. In fact, the possibility still remains open that the spotlight never *really* "turns off" anyway; our attention is always somewhere, though it may not always be on the text we are staring at (take note of how many times your attention shifts away while reading this article). In fact, shifts of attention toward off-task internal thoughts, known as mind-wandering, are estimated to occur during 10–60% of waking hours (Seli *et al.*, 2018), comprising a substantial portion of our conscious experience.

How do you know whether your students are "paying attention" in class? Although it may seem obvious in some cases (e.g., you see a sleeping student), it may be much more challenging to tell in other cases. When students stare off into space, are they considering the material you just presented? Are they thinking of questions or applying the concepts you described to new scenarios? Are they considering what to have for lunch? Thinking back to your own experience as a student, what was going through your mind during class? Was it challenging for you to focus on an instructor during a lecture?

Many types of attention are occurring in classrooms all the time, and fluctuations between external attention (e.g., on the instructor's voice) and internal attention (e.g., connecting new material to prior knowledge) may be more beneficial for learning than we might have assumed. Here, we describe a framework for categorizing and understanding different types of attention in the classroom, formulated across two key

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*Address correspondence to: Kimberly D. Tanner (kdtanner@sfsu.edu).

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dimensions: external/internal and on-topic/off-topic. These dimensions are described in greater detail in the following sections. Anchored in this framework, we can hypothesize about why active-learning strategies may be effective, and how different active-learning approaches may differ in how they guide students' attention. Given that attention is essential for learning and memory (Baddeley *et al.*, 1984; Craik *et al.*, 1996; Muzzio *et al.*, 2009), it follows that a more nuanced understanding of attention in the classroom could help us better characterize the many ways that students learn or become distracted. Specifically, we hypothesize that teaching strategies that leverage the natural fluctuations of attention described here may yield better learning outcomes.

HOW MIGHT DIFFERENT TEACHING STRATEGIES LEVERAGE STUDENTS' ATTENTION?

There is ample evidence that teaching methods that include some form of active learning (e.g., think–pair–share, group discussions) can produce superior learning gains compared with lecture-only teaching methods (e.g., Freeman *et al.*, 2014). But how? And why does the impact of active learning appear to vary across classrooms and instructors? Although there has been relatively little research investigating the mechanisms leading to active-learning outcomes, some potential hypotheses have been offered. One possibility is that instructors act as "cognitive coaches" during active learning, structuring opportunities for exploration, confusion, and resolution that directly lead to more student learning in class. Another possibility is that active-learning classrooms provide more opportunities for social interaction among students that could result in increased social networks among students and indirectly more out-of-class learning. Like most complex phenomena, the underlying mechanisms of the positive effects of active-learning strategies are likely multiple, involving both of these ideas and many more.

An alternative hypothesis for why active-learning strategies are more effective than lecturing is that they leverage natural fluctuations in students' attention. Throughout this feature, we will explore the idea that teaching strategies that actively guide shifts in students' attention yield better learning outcomes than those that ignore attentional fluctuations.

Consider the following four scenarios and notice the subtly different ways in which a clicker question—a commonly used active-learning strategy—might be implemented in a classroom. Take note of where and how students' attention may be directed at each point in time.

Scenario 1: Prioritized Lecturing

The instructor lectures for 40 minutes, then shows a clicker question at the end of class to check students' comprehension of the material. Because time is short, the instructor simply reads the question and asks students to think about it before the next class.

Scenario 2: Multiple Demands on Attention

The instructor shows a clicker question and asks students to turn to a neighbor to discuss which answer they would choose and why. The classroom is briefly quiet and a slow rise in noise occurs as pairs and groups of students begin talking. As students are discussing, the instructor shouts to them that they should click in as they talk and projects the graphic results live on the screen. Some students hear this instruction, while others do not. Some students notice the changing graph on the screen and appear to be shifting their answers in response. Upon seeing that half the class has weighed in, the instructor begins analyzing the results for the class.

Scenario 3: Focusing on the Grade

The instructor shows a clicker question and asks the class to be silent for 2 minutes to read the question, consider their own ideas, and click in a response. The instructor reminds students that correct responses will receive full credit and incorrect responses partial credit. As the quiet passes and the number of student responses is maximized, the instructor proceeds to share the correct answer with students along with an explanation about why each of the other answer choices is wrong.

Scenario 4: Orchestrated Attention

The instructor shows a clicker question and asks the class to be silent for 2 minutes to read the question, consider their own ideas, and click in a response. As the quiet passes and the number of student responses is maximized, the instructor observes the classroom. After students have clicked in, the instructor asks students to turn to a neighbor to discuss which answer they would choose and why, instructing the student with the longest hair to speak first and for each student to spend ~30 seconds explaining his or her answer choice. Just before students begin to talk, the instructor assures the class that getting the correct answer is not important, but rather hearing a colleague's explanation and sharing one's own is the point. After pair discussions have wrapped up and the instructor has offered some additional information relevant to the question at hand, students are invited to reconsider the question and click in an answer again.

As we describe the following framework for conceptualizing attention in the classroom, keep these example scenarios in mind. We will return to these scenarios later to unpack how each one might direct students' attention in different ways.

A FRAMEWORK FOR UNDERSTANDING ATTENTION IN THE CLASSROOM

For decades, researchers have tried to understand exactly what attention is, and how to categorize its various subtypes. Some researchers categorize attention as either top-down (i.e., endogenous, volitional) or bottom-up (i.e., exogenous, automatic; Posner and Cohen, 1984), while others think about goal-directed attention as being selective, sustained, or divided (McDowd, 2007). Others make use of Posner's tripartite model of attention, which emphasizes distinctions among alerting, orienting, and executive attention (Posner and Petersen, 1990). Chun *et al.* (2011) put forward one such taxonomy of attention that may be particularly useful for understanding attention in the classroom; it is rooted in the distinction between internally focused and externally focused attention. Acknowledging the many possible ways to consider different types of attention, our goal here is to understand classroom learning. As such, we have chosen to focus on two key dimensions that readily delineate attention in the classroom: 1) internal/external attention (Chun *et al.*, 2011), and 2) on-topic/off-topic attention, each of which is described below (see Figure 1).

External attention, often referred to as perceptual attention, is described by Chun *et al.* (2011) as the selection and modulation of sensory information. When you stare out into a crowded

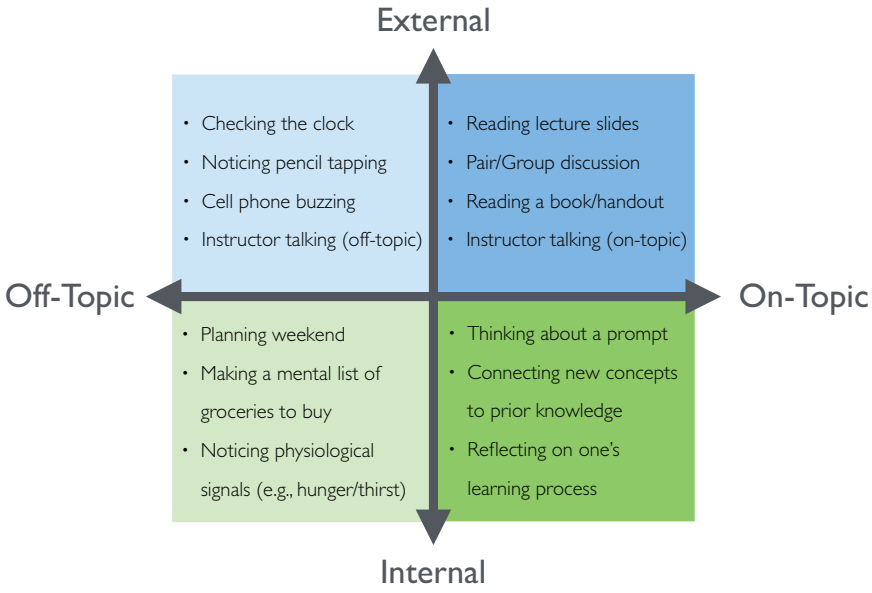

FIGURE 1. Diagram depicting two dimensions for describing attention in the classroom: external/internal attention and on-topic/off-topic attention. Examples of potential classroom scenarios falling into each of the four quadrants are provided.

city street looking for a taxi, your brain is able to filter out irrelevant information and heighten your focus on large, yellow, moving objects to reach your goal. Research on external attention has shown that the brain has methods of both boosting signals representing relevant information and suppressing signals representing irrelevant information, functions that are critical for navigating our crowded, complex environments. Only a tiny portion of what our eyes *see* in the world is actually consciously *perceived* by our brains, and without this ability to filter sensory information, we may be unable to focus on what is important amid sensory overload.

In contrast to external attention, *internal attention* is described as the selection and modulation of internally generated information, such as the contents of memory. While external attention allows us to sample new sensory information from the environment, internal attention lets us process information even in the absence of sensory stimuli. For example, even without looking at the text on this page, you could be thinking about this new concept of internal attention, perhaps recalling memories of your own experiences in the classroom or coming up with a mnemonic device to help you remember this taxonomy.

Additionally, in the context of classrooms, attention can be directed toward course-relevant (on-topic) information or not-course-relevant (off-topic) information. In most cases, the distinction between on-topic and off-topic attention is relatively clear. For example, examining a diagram on a handout would be considered on-topic attention, while making a mental list of groceries would be considered off-topic attention. However, there may be other scenarios in which the distinction between on- and off-topic attention is less clear, such as when a student recalls information learned in another course that might lead to the realization of important cross-disciplinary connections. Moreover, defining a particular internal thought or external stimulus as on- or off-topic may depend on one's perspective as student or instructor. For our purposes, we will consider more overt examples of on-topic attention that are directly tied to content learning, while acknowledging that many forms of non–content related attention may still be important and in the service of student learning (e.g., an instructor talking about his or her pathway into science).

By considering external/internal attention and on-topic/off-topic attention as two orthogonal dimensions, we propose that classroom attention can be categorized into four quadrants (see Figure 1). Using this framework, we move beyond the assumption that on-topic attention is *necessarily* external and provide insight into the types of internally focused experiences that may facilitate learning. In the following sections, we describe what attention looks like in each of the four quadrants of Figure 1 and provide connections between active areas of research and the classroom.

On-Topic External Attention

When you notice a student with eye gaze locked on your PowerPoint slides, nodding occasionally, posture maintained, you may feel a sense of relief and assume that this student is clearly "paying attention" in the colloquial sense. One might assume that this student is the most engaged and the most likely to retain the information being conveyed, as he or she portrays the ways we have been socialized to show that we are engaged. Certainly, by focusing eye gaze on slides and listening actively to an instructor's voice, one might maximize the brain's ability to take in new information. But is it always the case that this is most beneficial for learning? Perhaps our assumption that eye contact is a natural and comfortable way to engage attentively does not hold for all students equally.

Cognitive science research on memory and attention suggests that diligently going through lecture slides and rereading material over and over the night before an exam may allow for short-term recall but does not foster long-term memory or understanding (Capeda *et al.*, 2006). Instead, deeper processing of the material, tying new material to prior knowledge, and actively retrieving information from memory seem to be more effective for long-term learning. Perhaps, then, external on-topic attention in the classroom is *necessary* but not *sufficient* for effective learning. This may provide some explanation for why lecture yields inferior learning compared with even the most modest active-learning approaches (Freeman *et al.*, 2014). If so, then it makes sense to balance out pedagogical techniques that emphasize external attention (lecture slides, videos, etc.) with other techniques, as discussed in the section *On-Topic Internal Attention*.

On-Topic Internal Attention

Thinking beyond the idea of "paying attention" and trying to understand, in particular, what students are "paying attention

to" may allow us to better conceptualize what is happening in students' brains during a class session as they form complex networks of understanding. When a student's gaze drifts away from the lecture slides, it is not *necessarily* the case that the students' attention is now off-topic. On the contrary, it seems likely that moments of prompted quiet thinking time are beneficial for learning (Owens *et al.*, 2017).

Evidence supporting this idea comes readily from research demonstrating the utility of active-learning practices in the classroom (Tanner, 2013; Johnson *et al.*, 1991, 1998; Goodwin *et al.*, 1991), particularly those that allow students a chance to think, digest new information, identify their confusions, or connect new concepts with what is already known. For example, the "think" phase of a think–pair–share activity is likely crucial to allow students to contemplate the question at hand before discussing with their colleagues. These forms of on-topic, internally focused attention are perhaps just as important for learning as on-topic, externally focused attention. Additionally, on-topic internal attention can allow students the chance to practice metacognition, that is, reflecting on their own thinking and learning (Tanner, 2012).

Off-Topic External Attention

A clock ticks, a pencil taps, a truck starts blaring its backup signal outside. All sorts of external stimuli can grab our attention automatically, often beyond our ability to control it. Amid so many possible distractions, it is actually astonishing that our brains are able to maintain focus on goal-relevant information (e.g., listening to an instructor's voice). Usefully, this ability to focus does not prevent us from noticing the sudden appearance of potentially threatening information. The classic example used is that of a hunter-gatherer searching for tiny berries in a bush. To survive effectively, the searcher must maintain sharp focus on the goal-relevant information (round red objects) but not *so* focused that they do not notice the preying tiger. For students in a classroom, the threat of tigers may not be so dire, but sudden noises or changes in environmental stimuli could be indicative of useful information that is worth a shift in attention.

Recent work shows that *four times every second* our brains shift between a state of sharp focus and a state of broad awareness of our surroundings (Fiebelkorn *et al.*, 2018; Fiebelkorn and Kastner, 2019). We obviously do not consciously switch our attention to new external stimuli that frequently, but our brains do seem to give us the option to switch attention that often, a capability that likely evolved under evolutionary pressures to stay alert while maintaining what feels to us like continuous, steady focus. In the classroom, there may be ways that we can optimize on-topic attention by continuously drawing attention back to the material when distractions arise (for more on shifting attention, see *How Instructors May Leverage Attention*).

Off-Topic Internal Attention

Similarly to how loud noises can draw our attention externally, salient internal experiences can draw attention internally. Suppose a student has a family member in the hospital for surgery today. As much as the student tries to volitionally direct attention toward a lecture slide or worksheet, the student's attention may be drawn back to the topic of his or her family member repeatedly over the course of the class session. Sometimes, off-topic thoughts, worries, or ruminations take priority over on-topic information, and our brains are well adapted to redirect our focus toward those high-priority thoughts. Maybe the student who appears to be "zoning out" is actually rehearsing material for another course, or stressed about an exam next period. Off-topic, internal attention can come from many sources and can be difficult to identify or act upon.

As noted before, mind-wandering makes up a substantial part of our day-to-day lives. Off-topic mind-wandering may sometimes be distracting, resulting in poorer task performance, decreased learning, lower grade point average, poorer memory for lecture material, and less motivation to learn (Risko *et al.*, 2012; Randall *et al.*, 2014; Wammes *et al.*, 2016; Unsworth and McMillan, 2017). However, off-topic mind-wandering could potentially provide a useful source of material for more creative thinking and reflection, perhaps allowing students to bring new ideas and perspectives to the topic at hand. It is important to note that studies have investigated both intentional and *unintentional* mind-wandering (Robison *et al.*, 2020), because these off-topic thoughts may not always be under conscious control. By understanding the ubiquity of mind-wandering in the classroom, one can think more carefully about the many possible ways to guide students' attention in the classroom, as discussed in *How Instructors May Leverage Attention*.

One well-documented source of impaired performance in the classroom (Shih *et al.*, 1999) is stereotype threat, which occurs when one is at risk of confirming a negative stereotype about one's social group (Steele and Aronson, 1995). Recent theories have posited that stereotype threat yields under performance by sapping working memory resources. Put another way, stereotype threat may redirect internal attention from on-topic (considering the material) to off-topic (considering one's identity, abilities, and social environment), making it more challenging to perform the task at hand (Pennington *et al.*, 2016). By understanding the ways that implicit or explicit biases can affect students' attention, we can develop better strategies for reducing these influences.

HOW MIGHT DIFFERENT PEDAGOGICAL APPROACHES AFFECT ATTENTION?

Having explored a framework for understanding attention in the classroom along the dimensions of external/internal and on-topic/off-topic, we now return to the clicker question scenarios described earlier. Our goal is to better understand how different approaches to the same teaching method (in this set of scenarios, asking a clicker question) might differentially affect students' attention. In Figure 2, we depict each example scenario, diagramming how students' attention might be allocated from moment to moment in each scenario. Understanding that students' attention is heterogeneous, we note that, in these scenarios, we have streamlined our depictions to reflect the *expected area of focus* for the majority of students at each moment. While at any moment, a particular student's attention may be drawn toward off-topic stimuli (e.g., noticing a distracting pencil tapping sound or realizing that one is hungry), we focus here on the fluctuations of attention that we posit may be most related to the variability in learning outcomes with the use of active-learning techniques such as clicker questions.

In scenario 1, "Prioritized Lecturing" (Figure 2A), the instructor focuses on lecturing, with no attempts to guide

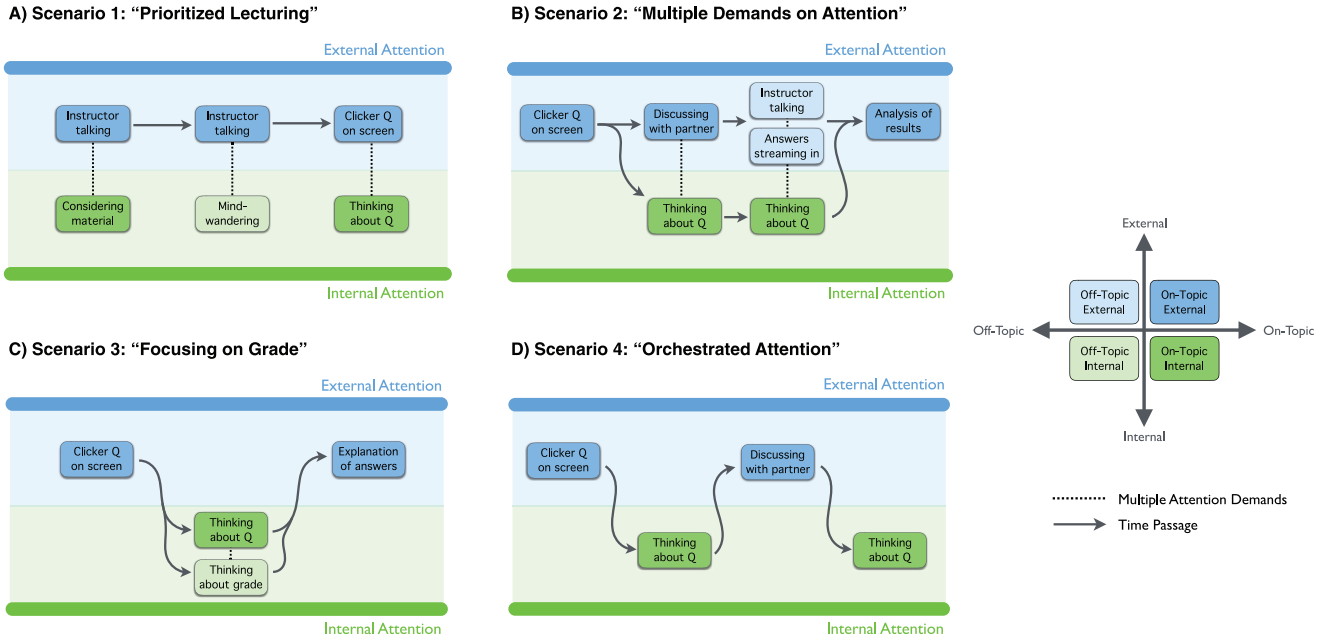

FIGURE 2. Depictions of how students' attention may be allocated during each of the four clicker question scenarios described in the section *How Might Different Teaching Strategies Leverage Students' Attention?* above. Blue boxes represent instances of external attention, while green boxes represent instances of internal attention. Dark-colored boxes depict instances of on-topic attention, while light-colored boxes depict instances of off-topic attention. Arrows indicate fluctuations of attention over time, while dotted black lines represent moments when there are multiple, simultaneous demands on attention. Depictions are streamlined to reflect the expected area of focus for the majority of students at each moment, with the understanding that students' attention is more heterogeneous than shown here.

students' attention in a directed manner. The instructor in this scenario may assume that students' attention remains external and on-topic at all times. However, as anyone who has ever attended a lecture-style class can attest, it is obvious that this is not the case 100% of the time, especially with increasing lecture duration. Research on attention in the classroom suggests that students' attention veers away from the material as early as within the first 30 seconds of a lecture, with increasing frequency of attentional lapses as the lecture goes on (Bunce *et al.*, 2010). In Figure 2A, we depict this pattern of drifting attention between internal and external focus during a long lecture, including dashed black lines to indicate times when demands on attention might be split between external (lecture) and internal (on-topic consideration of the material or off-topic mind-wandering). We hypothesize that, in this scenario, the emphasis on continuous external attention over long time periods may be hindered by the natural tendency for attention to fluctuate. This could result in variability in where students' attention is allocated at a given moment, potentially leading to more variability in learning outcomes.

In scenario 2, "Multiple Demands on Attention" (Figure 2B), there are several instances when the instructor presents students with multiple demands on attention simultaneously. In this example, students are not given a set time for quiet thinking before discussing the clicker question with a partner, so attention may either be external (to the pair discussion) or internal (as they think about the question). Next, as the instructor shouts for students to click in their questions while they talk, the number of demands on attention increases further. Some students' attention may still be internal to think about the question, while the attention of others may be external, listening to the instructor shouting or watching other students' answers stream in. With more available distractions and greater variability in how each student may be allocating attention, we hypothesize that there may be a wider distribution of learning outcomes across students.

In scenario 3, "Focusing on Grade" (Figure 2C), the instructor reminds students about the grading policy while they are considering the clicker question. This approach may create a distraction of internal attention, with students caught between focusing their internal attention on-topic (on the question at hand) and off-topic (thinking about their grade). One testable hypothesis is that students who are already underperforming or worried about their grade are at an even greater disadvantage in this scenario, while students who are confidently excelling in the class are given a further advantage, widening the gap in student performance.

In the final example, scenario 4, "Orchestrated Attention" (Figure 2D), students are first given two minutes of silence to think about the question, followed by guided pair discussion with turn-taking. By allocating dedicated time for internal and external attention, the instructor provides structure for the exercise that takes advantage of the natural fluctuations between internal and external attention. The instructor in this scenario also provides guidance about how to take turns in the pair discussion, further streamlining switches of attention so that students' attention is more coordinated. This instructor also explicitly reminds students of the goal of the exercise,

encouraging them to focus their attention on hearing a colleague's explanation and sharing their own reasoning rather than focusing on getting the correct answer. Following pair discussions, the instructor provides some additional material and redirects students' attention internally again to reconsider their answers to the question. We hypothesize that the instructor's scaffolding for how to allocate attention back and forth between internal and external attention effectively orchestrates these shifts of attention and keeps students' focus on-topic in a more streamlined manner, which could potentially lead to improved learning outcomes.

From these examples, we can develop a testable hypothesis for why these different approaches to the same clicker question strategy might differ in the learning outcomes they yield. We hypothesize that one mechanism underlying the educational gains associated with active-learning strategies could be that they take advantage of natural fluctuations between external and internal attention. While standard lecture format may ignore fluctuating attention, active-learning strategies entertain the idea that attention fluctuates and these fluctuations may be leveraged to optimize learning. Moreover, there is substantial variability in how beneficial active-learning strategies can be and quite a lot of room to improve. It is possible that implementations of active learning are most beneficial when they make room for multiple types of attention (e.g., internal and external) and guide shifts of attention deliberately. Indeed, the instructor's role in guiding attention in the classroom need not be limited to orienting students to external content, but could also be leveraged to direct students' attention toward their own ideas and reflections, as well as to embrace the right to direct one's own attention and learning to meet one's individual goals (an idea that is central to active learning).

HOW INSTRUCTORS MAY LEVERAGE ATTENTION

There are many ways that instructors could use our proposed framework to consider attention in their classrooms. Simply by recognizing that attention fluctuates naturally and by considering how and when students' attention might be directed internally/externally and on-topic/off-topic during a particular class session, instructors may design teaching moments more thoughtfully. As described in prior sections, we hypothesize that active-learning strategies may benefit student learning by coordinating fluctuations between internal and external attention across students, allowing students the time to focus externally on the information presented and internally to consider new information more deeply and connect it with their prior knowledge. Instructors may explore this idea in their own classrooms by comparing the effectiveness of class sessions with more deliberate attention switches to those in which students' attention is expected to be entirely external/on-topic or entirely internal/on-topic for the duration of class time.

Some additional approaches to considering attention in the classroom are as follows. First, we hypothesize that, when multiple demands are placed on students' attention at once (e.g., listening to an instructor emphasize grading policies for a given prompt while attempting to think internally about said prompt), this may make it more challenging for students to learn. In contrast, we anticipate that teaching strategies that direct students' attention to one area of focus at a time will yield better learning outcomes. Second, we hypothesize that quiet moments of directed internal attention are critical for the learning process, allowing students to mull over new ideas and connect new information to prior knowledge. Although it may be intimidating from the instructor's perspective to have stretches of silent thinking built into class time, as evidenced by the relative lack of silence in recordings of classroom sound (Owens *et al.*, 2017), we predict that moments of internal attention interspersed throughout a class session may benefit student learning. Any of the aforementioned suggestions for instructors–guiding fluctuations of attention, reducing multiple demands on attention, and leveraging moments of internal attention–may help to explain the variability in effectiveness of different implementations of the same teaching strategy. For example, the "think" part of the think–pair–share activity might sometimes be conducted without explicit attentional guidance, at other times conducted amid multiple demands on attention, and sometimes even left out entirely, jumping straight into the "pair" and "share" portions. It may be the case that these subtle variations on the same technique could yield dramatically different learning outcomes.

How might one effectively guide students' attention in the classroom amid perpetual external or internal distractions? There may be some contexts in which attentional redirecting is straightforward (e.g., ringing a bell to indicate that the class should focus back together after group discussions have veered off-topic), while in other contexts it may be quite challenging (e.g., knowing whether a student who is looking directly at the slides is actually thinking about something else). Mindfulness meditation has been shown to improve this ability to refocus attention on goal-relevant (aka on-topic) information (Chiesa *et al.*, 2011) accompanied by changes in brain oscillations (Kerr *et al.*, 2011). This is achieved by actively rehearsing this skill (e.g., focusing on one's breath, nonjudgmentally acknowledging distracting thoughts when they arise, and refocusing attention on breath). This suggests that the ability to refocus on on-topic information when off-topic information captures attention automatically is *malleable* rather than fixed. This understanding may help us as instructors to nonjudgmentally encourage students to practice refocusing attention, rather than assuming that certain students are inattentive due fixed personality traits; adopting this approach means we are essentially adopting a growth mindset (Dweck, 2008) around attention abilities.

Additionally, knowing *what* to pay attention to can be challenging. Students who are new to a college classroom environment may not be as adept as more senior, experienced students at knowing what information is important and should be paid attention to during a class. Instructors can use a number of possible strategies to guide attention in a more directed manner, such as through the use of active-learning strategies, to make where students ought to allocate attention in the classroom more explicit. By signaling to students when key concepts are presented, highlighting critical links among different concepts, and providing clear instruction about when and how internal attention is to be engaged with specific prompts, one could ease this burden and help students learn *how* to guide their spotlight of attention optimally in the classroom. This use of language to provide explicit instruction about where to allocate attention is a common form of "instructor talk," or noncontent language used by instructors in classrooms (Seidel *et al.*, 2015; Harrison *et al.*, 2018), that may facilitate student learning.

HOW DO RESEARCHERS MEASURE ATTENTION IN THE CLASSROOM?

The framework we have described gives rise to many open research questions: How often do students switch between external/internal and on-/off-topic attention? How do these switches relate to student learning? How do active-learning pedagogies affect or leverage attentional fluctuations? What factors explain student variability in classroom attention? And how does the use of technology (e.g., cell phones) affect students' attention? To address these and related questions, education researchers need tools for measuring various types of attention in the classroom. In the next sections, we review various self-report and physiological measures of attention that can be readily implemented in a classroom setting.

Self-Report Measures of Attention

Traditionally, students' attention has been assessed using self-report and classroom observations. Early studies using note-taking and classroom observations to assess students' attention (e.g., Johnstone and Percival, 1976) seemed to suggest that students' attention declines 10–15 minutes into a lecture. However, the empirical basis supporting this claim is extremely limited (Bradbury, 2016), perhaps due to limitations in how attention was assessed. For example, the amount of note-taking each student engages in is confounded by motivation and learning strategies, and observer-reported measures of attention are limited to explicit student behaviors (a student might appear engaged by staring at the instructor while contemplating lunch options).

To try to get a more direct measure of attention, some researchers have asked students to report on their own attention. Bunce *et al.* (2010) had students use clickers to report attentional lapses throughout a class session and to indicate the duration of these lapses. in this study, students reported attentional lapses as early as 30 seconds into the lecture (much faster than had been previously reported), and this pattern continued throughout the entire lecture at shorter and shorter cycles. Critically, students reported fewer attention lapses during demonstrations and clicker questions and during lecture periods immediately after these activities than during continuous lecture. However, self-reported attention also has its limitations. Students might be unaware of their own attention lapses, and their reports can be biased. Further, asking students to report how attentive they are throughout a lesson is artificial and can even take their attention away from the material at hand (Smallwood and Schooler, 2015; Seli *et al.*, 2018; Weinstein, 2018; Robison *et al.*, 2020). A more objective measure of attention might be retention of class content, but retention is confounded by many other factors (e.g., students' prior knowledge). It is also very challenging to capture the dynamic nature of students' attention using an achievement test.

Physiological Measures of Attention

More modern approaches have leveraged biological measurements of attention. Once restricted to laboratory settings, measurements such as eye tracking and electroencephalography (EEG) have more recently been developed for use in classroom settings. Here, we briefly review the use of these two techniques to measure attention in the classroom.

Eye tracking has revealed that eye movements play an integral part in the management and allocation of attention (e.g., Rizzolatti *et al.*, 1994). Because gaze shifts are tightly linked to attention shifts, gaze is widely used experimentally as a proxy for the locus of attention (Chelazzi *et al.*, 1995). Recent research suggests that looking away from a speaker in a multispeaker environment negatively impacts speech comprehension (Shavit-Cohen and Zion Golumbic, 2019). Thus, in a classroom setting, looking away from the instructor or the student speaking in a group discussion could indicate an attention shift (e.g., from external to internal attention), though as described previously, eye gaze alone is not a perfect measure of students' attention and may be a biased form of evaluation. Most eye-tracking research is currently confined to laboratory settings, but recent developments in portable eye-tracking technology allow measuring students' eye gaze in real-world classrooms (Fuhl *et al.*, 2016). Future research could explore how students' gaze shifts in classrooms relate to other measures of attention and to learning outcomes.

EEG measures the brain's electrical activity from electrodes placed on the scalp. Even through the skull, EEG can be used to pick up oscillatory voltage signals that can be decomposed into different frequency bands. Prior research suggests that EEG activity in one particular frequency band, known as the *alpha band* (8–13 Hz) is associated with attention shifts (Payne and Sekuler, 2014; Van Diepen *et al.*, 2019). For example, in a recent study, EEG was measured while people listened to long stories. Power within the alpha band was found to be higher in periods that people subjectively reported being "zoned-out," and these periods of the story were later poorly recalled (Boudewyn and Carter, 2018). As with eye tracking, until recently, EEG was confined to laboratory settings due to its cost, limited portability, and the time-consuming preparation process. However, recent advances in low-cost, portable, wireless, and dry (i.e., gel-free) EEG technology now allow for the collection of brain data outside the laboratory in real-world classrooms (Debener *et al.*, 2012; Dikker *et al.*, 2017; Poulsen *et al.*, 2017; Bevilacqua *et al.*, 2019).

What have measurement tools like EEG revealed so far about teaching and learning in the classroom? Recent findings have demonstrated that learning may be maximized when the brain activity of students in the class becomes synchronized (Cohen *et al.*, 2018; Davidesco *et al.*, 2019). When students' patterns of brain activity look alike, they demonstrate better memory for the material than when each brain is doing something different. Most prominently, these findings were observed when there was synchrony in students' brain activity in the alpha band, which, as mentioned earlier, is associated with attentional processes (Davidesco *et al.*, 2019). It has been postulated that brain synchrony across students may be important, because it reflects shared attention (i.e., all students are focusing on the same thing; Dikker *et al.*, 2017). Future research in this domain may further inform us about how brain synchrony differs depending on the teaching strategy implemented (see Davidesco, 2020, in this issue).

Expanding on this research, we propose that shifts between internal and external attention may underlie brain synchrony across students. In other words, when students are engaged, their fluctuations between internal and external attention are in sync, potentially leading to higher brain synchrony and better

learning. On the other hand, if students independently fluctuate between external and internal attention at different times, brain synchrony will be lower, potentially correlating with suboptimal learning. Teaching strategies may differ in how well they synchronize students' brain activity in the classroom by differing in how they guide switches between internal and external attention across students. Future research may investigate our hypothesis that the positive impact of active-learning strategies on student learning may be partially mediated by synchronizing attention, and thus brain oscillations, across students.

CONCLUSION

How many times did your attention shift away while reading this article? Even with strong motivation to focus, it is natural that many types of attention are occurring in the classroom all the time, including fluctuations between internal and external attention, as well as on-topic and off-topic attention. Considering attention from this perspective may help us better understand the variety of ways in which students pay attention in the classroom and the ways in which different teaching strategies can guide students' attention. Importantly, by guiding attention in the classroom, instructors can both orient students to external content and direct students' attention internally toward their own ideas and reflections. We hypothesize that purposefully structuring attentional shifts may be beneficial for learning, an idea that may be tested in future studies. We hope that this research will provide a better understanding of the mechanisms underlying active-learning benefits and shed light on why active-learning is more successful in some implementations than others.

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