Potential Neural Correlates of Social Learning:

Implications for the Undergraduate Lecture Course

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Abstract

Although institutions of higher education are the primary producers of neuroscientific research in fields highly relevant to education research such as attention, memory, and learning, many of the findings from these areas have not translated into educational practice. Instead, in most universities the primary vehicle of information transfer is still the passive lecture. One highly relevant finding from education research is the efficacy of active learning in a 'flipped classroom' model, in which the lecture portion happens outside the classroom, and in-class time is used for discussion and problem-solving. Increasingly it is the in-class social aspect of active learning that has been most heavily implicated the success of this model. In this paper, I aim to advocate that neuroscience research into the social benefits of learning can provide great benefit to educators aiming to optimize the college classroom. To connect education research with neuroscientific findings, I will propose that two neural networks underlie the role of social behavior in enhanced memory formation. First, the activation of the mentalizing default mode network through social activity helps to encode novel information. Second the social activity which increases dopaminergic release both the nucleus accumbens and the hippocampus activates dopamine's beneficial effect on learning through associative long-term-potentiation. In addition, enhancing social activity has many appealing benefits to educators by increasing professor's understanding of student ability, reducing student stress, and enhancing a sense of student community. Lastly, I will provide future directions for integrative neuroeducation research to specifically examine this proposed social benefit of learning in an undergraduate classroom.

Keywords: memory, education, neuroeducation, undergraduate, active learning, social learning, lecture, educational pedagogy, working memory

Background

The lecture class is perhaps one of the oldest features of higher education, going back well over eight-hundred years. In the early middle ages, books were rare and precious commodities — each one taking hundreds of hours of labor to create (Friesen, 2011). Early lectures consisted predominantly of reading books verbatim to transmit this valuable and limited information to a classroom full of students, whose handwritten notes often served as 'books' in their own right and were frequently resold (Friesen, 2011). While subsequent centuries saw the advent of increasingly sophisticated technologies such as the printing press, radio, television, and the internet, the basic format of a lecture course remains the same. In a modern college setting, most large classes follow the same recognizable format: twice a week students file into a large lecture hall to listen to their professor speak for 50-80 minutes. These courses typically have 1-3 mid-semester exams and one final examination, often these exams are responsible for the majority or the entirety of the grade earned (Varao-Sousa & Kingstone, 2015).

Introduction

Despite their role as the backbone of undergraduate student education, lectures have been shown to be comparatively ineffective in multiple measures of student learning. Overall, students remember less than 50% of new information presented in a lecture after twenty-four hours. Although an average student may score a 70-80% on a final examination, after six months, less than 10% of that information has been retained (Freeman et al., 2014). In addition, students often appear to be 'learning to the test' by scoring well on in-class examinations that emphasize a specific way of solving specific problem types, while doing poorly on so-called 'concept inventories' that require critical thought (Vickrey et al., 2015). Particularly hard-hit by the passive nature of lectures are science, technology, mathematics, and engineering (STEM)

classes, which tend to be based more heavily on rote memorization of course materials for reproduction on an examination (Vickrey et al., 2015). While students in small discussion-based classrooms score higher on all the metrics of retention mentioned above and are overall more satisfied with their courses (Springer, Stanne, & Donovan 1999). the immense costs in both additional space and teaching personnel are prohibitive for most universities. Although large classrooms may be inevitable, educators have a responsibility to ensure those courses are as optimized for student learning as possible. While many avenues of neuroscientific learning will likely yield benefit for course design, I advocate that social learning is an optimal area in which education and neuroscientific research can collaborate to find successful, user-friendly, and cost-effective strategies to improve the traditional lecture-based course.

Section II – Supportive Evidence from Educational Research

The idea of flipping the classroom has been prominent in education research for decades (Freeman et al., 2014). While there are multiple variations on flipped classroom designs, they all share a few basic principles. The 'lecture' component of the class is assigned as homework prior to the class, most commonly as an audio or video file and more rarely as an interactive online assignment or textbook reading. In class, students are assigned to work on problem sets or discuss the material in groups, with the professor as a facilitator who 'checks in' with groups by answering questions and offering guidance (Freeman et al., 2014). By flipping the classroom, social learning becomes a central feature of the curriculum.

Multiple studies from educational research have confirmed that flipping the classroom is a highly effective mode of teaching. A meta-analysis of 255 studies looking at flipped/active STEM undergraduate classroom found that compared to a traditional lecture class, students performed 6% better on examinations — the difference between B and a B+ in letter grades.

While student's already doing will continued to succeed, students earning less than a C- dropped by 10%, students previously at the 50th percentile rose to the 68th percentile (Freeman, 2014). In other words, flipped classrooms paired with active learning appears to have a 'rising tides float all boats' effect, in which those at the top maintained high comprehension, middling students improved, and previously failing students were much more likely to succeed.

Section III – Optimizing Working Memory for Encoding Novel Information

Neuroscience can best contribute to this discussion by finding neural correlates to support and enhance the educator's goal of optimizing the college classroom for student learning. One fruitful area of interest is in understanding how the initial encoding of new information is consolidated into long-term memory – necessary for retaining the information learned in a college course after completion. This initial encoding process is mediated by a complicated cognitive process called working memory (WM), controlled predominantly by the prefrontal cortex (Michael, 2010). Unlike short-term memory, WM allows students to hold and manipulate three to four meaningful chunks of information at a time, while also sorting and integrating the new information with previous knowledge from long-term memory (Michael, 2010). Successfully entering and being engaged by WM is a necessary precursor for any information to eventually be remembered. Since WM capacity is limited an optimized course should aim to reduce undue strain on this network and enable the optimal encoding of new information (Cowan, 2013). Two factors known to increase inhibitory mental fatigue and decrease the efficacy of working memory are high information flow rate and uniformity in stimuli (Sarter, Givens, & Bruno, 2001). Unfortunately, a traditional lecture course relies upon both (Cowan, 2013).

Section IV: The Role of the Mentalizing/Default Mode Network in Social Learning

The hyper-social nature of human beings is one of our most unique attributes as a species. The 'social brain' theory of evolution posits that this is no accident, and that those individuals capable of engaging in increasingly complex social relationships were more likely to survive and pass on those social genes (Dunbar 2009). This evolutionary biology-based theory links the enhancement in advanced social regions in the human brain with improvements in language, reasoning, and complex thought (Rilling, 2006). One primary facilitator of social behavior is the mentalizing network (MN), which is responsible for reading the mental states of other people and responding to social situations appropriately. Reliably, the dorsomedial prefrontal cortex in Brodmann areas (BA) 8 and 9, the medial prefrontal cortex (mPFC) in BA10, the adjacent posterior cingulate cortex, the temporoparietal junction, and the anterior temporal cortex are implicated in this network (Liberman, 2012). Interestingly, BA10 is the only brain region definitively known to be larger in humans than other primates, and is correlatively larger in social than non-social primates (Rilling, 2006).

Several educational research studies show that the 'social encoding' of information, i.e. by 'quizzing' a friend, results in higher retention rates of novel information than when subjects studied alone (Mitchell, 2004). Interestingly, the mentalizing network activated by social processing overlaps almost in its entirely with the default-mode network, which is active whenever one is not actively focusing on a task — hence its label as 'default' (Mitchell, 2004). While psychology has long understood that humans are predisposed to unprompted social cognition when not otherwise occupied (Mason 2007) – it is only recently that neuroscientists have claimed that the overlap between the MN and DM networks may be responsible (Yoshida, 2010; Sadaghiani, 2010). Necessarily, activation of this the mentalizing/default-mode network (MDMN) is inversely correlated with tasks that require intense, centralized focus (Fox et al.,

2005). It is likely that by involving another individual in the learning process, students inadvertently are using the mentalizing/default mode network to encode novel information (Mitchell, 2004). I propose that while MDMN-dependent tasks such as mind wandering and chatting during class have been long-dismissed as detrimental to the learning process, harnessing MDMN activation can enhance memory.

Section V: Neurological Differences between Collaborative and Cooperative Learning

While I have been treating social interaction as a cohesive whole, humans engage in a wide variety of social activities that likely rely on the activation of many brain regions. One finding from educational research is particularly pertinent when considering how to best activate the MDMN in a lecture course setting – the distinction between collaborative and cooperative learning. While both approaches require that students communicate with each other in small groups, cooperative learning is the more structured of the two techniques. In a cooperative activity, students may only engage in a social activity for a short time, for example to discuss a problem for five minutes with those students who happen to be seated near them. In cooperative learning there is a clear short-term goal for the group, and usually the task has low stakes which do not affect final course grades (Freeman et al., 2014). Collaborative learning on the other hand, requires long-term coordinated social activity, for example to meet with teammates multiple times over the course of a month to work together on a presentation. This learning mode requires more than one interaction within the same social group, less professor facilitation, and usually has higher-stakes that affect final course grades (Coppola 1996).

While both collaborative and cooperative learning strategies likely activate the generalized MDMN, it is possible these responses are neurologically distinct. Recent evidence indicates that there indeed are neurological differences in short-term vs. long-term social

interactions, as some MDMN regions have higher activity in response to interactions with familiar individuals than strangers while interactions with strangers can heighten fear response and activate different fear circuitry (Wagner, Haxby, & Heatherton, 2012). While attention may be heightened when interacting with strangers, increased self-monitoring in stranger interactions can potentially decrease long-term memory formation (Farmer & Kashdan, 2012). Although co-opting the MDMN to decrease inhibitory mental fatigue may be an effective way to enhance memories, more research is necessary to determine how to best optimize social activities in a college lecture setting to take advantage of the neurological benefits.

Section VI: Limitations of MDMN/Social Learning and Future Directions

There are still many unanswered questions regarding the overlap between the mentalizing and default-mode networks – while they share many brain regions, some studies have posited that regions may differ in activation between social and non-social activation of the MDMN (Li, 2014). Similarly, while there are some regions of common activation highlighted earlier, various studies contradict themselves on if other areas are activated in both networks (Li, 2014). Additionally, while the MDMN may have important implications for understanding social learning, there has not been any research done to explicitly link the MDMN with learning in a social context, or consequently with the role of socially-induced MDMN activation in reducing inhibitory mental fatigue. This is where new research must focus.

Lastly, while educational research has differentiated between collaborative and cooperative learning, and some tentatively applicable research from social neuroscientific findings supports this distinction, the explicit neurological differences, if any, between these learning modes are currently unstudied. Since the MDMN is functionally unique to humans, it is highly difficult to conduct these types of studies in animal models. Instead, I propose that fMRI,

specifically modern statistical techniques such as multi-voxel pattern analysis, is the technique best suited to record functional interconnectivity among brain regions associated with the MDMN during a social learning task (Haynes, 2006). Research into this potential link will elucidate currently unknown connections, and correspondingly impact the educational literature to advocate for the use of social learning in college courses.

Section VI: Enhancement of Learning through Dopamine-Dependent Social Reward

While the effects of MDMN activation may account for some enhanced learning in social situations, the effect of social reward through dopaminergic innervation of the nucleus accumbens (NAc) is also well worth investigating in further detail. I propose that the rewarding effect of dopamine following social interaction facilitates enhanced encoding, consolidation, and reconsolidation of information. Dopamine is generally accepted to be the chief mediator of the brain's reward circuitry, with importance given to the mesolimbic pathway — connecting dopaminergic neurons in the ventral tegmental area (VTA) to the NAc.

Historically, the NAc has been heavily implicated through decades of animal and human addiction research as a core region responsible for drug-based motivation and reward (Salgado & Kaplitt, 2015). More generally and more recently, this region has been found to be of interest in other forms of rewarding behavior, prominently including social interactions. Of chief interest in understanding reward is motivation, which is most frequently categorized into intrinsic and extrinsic. Intrinsic motivation requires seeking an experience because of the reward it provides on its own, i.e. eating a cookie, whereas extrinsic motivation relies on seeking an experience because it may eventually bring about a reward, i.e. studying for an exam to be rewarded by a good grade. (Cerasoli, 2014). If a lecture course can successfully activate the intrinsic reward network pathway instead, it is possible students will learn more effectively.

For well over two decades, social interaction has been categorized as an intrinsic reward (Chevallier, 2014). Intrinsic social reward is observed as early as an infant's preference for face-like objects over non-faces, continues as a toddler strongly prefer collaboration over individual attainment of a reward, and grows more nuanced into adulthood (Chevallier, 2014). The bulk of socially relevant neuroscientific research has been conducted in animals, and has been limited to socio-sexual behaviors like pair-bonding. However, recently, same-sex and non-aggressive social behavior has been more carefully examined (Gunaydin et al., 2015). Interestingly, the same mesolimbic dopaminergic reward pathway that activates in response to more well-characterized intrinsically motivating stimuli, such as cocaine or mating, has been shown to predict broader social interactions in animals (Gunaydin et al., 2015). In humans, this pathway has recently been shown to activate similarly in social acceptance/avoidance paradigms as in non-social reward behaviors (Lin, 2012).

Of relevance to social learning in a classroom context, college-age adults are strongly and intrinsically motivated to cooperate with their peers, even at a disadvantage to themselves (Klein, 2009). In contrast, most traditional academic work such as studying, completing problem sets, and attending lectures is extrinsically motivated (Baker, 2004). Perhaps unsurprisingly, education research has shown that information learned due to intrinsic motivation leads to better information recall, enhanced conceptual learning, and better overall academic performance (Baker, 2004). Taken together, this research indicates that in conjunction with psychological and sociological research, neuroscientific findings support that social interactions are indeed intrinsically encoded by the brain similarly to more standard 'rewarding' stimuli. Linking the social aspect with memory, research shows that learning within an intrinsically motivated context enhances later recollection of the unrelated information (Shohamy & Adcock, 2010).

Importantly, the activity of the VTA-NAc network prior to a motivationally-charged event predicted if the event was later recalled. In a seminal fMRI study, a motivationally relevant stimulus – in this case a monetary incentive – activated the VTA-NAc-hippocampus in a way that positively correlated with enhanced memory formation (Adcock et al., 2006).

The hippocampus completes the dopaminergic reward pathway by encoding and storing new both episodic and semantic memory learned during motivating events (Gunaydin et al., 2014). Robust research in animal models has shown that activation of dopaminergic projections from the VTA to the hippocampus is necessary to enable long-term potentiation of CA3 hippocampal neurons, long thought to be essential in memory formation (Bird & Burgess, 2008). This connectivity is not just unidirectional; instead, it seems that the hippocampus can in turn regulate VTA activity (Bird & Burgess, 2008). Not only is dopamine necessary for the initial encoding of memories, it also plays a central role in the modulation of memories in subsequent recollections. While most of this research has been limited to episodic research, the ability to integrate information from numerous experiences into a cohesive, non-episodic representation is essential for learning from a college class. Here too, fMRI studies in humans show reliance on VTA-hippocampal connectivity and by extension a central role for dopamine (Shohamy & Wagner, 2008).

While so far the bilateral connections between the VTA and NAc as implicated in reward and the VTA and hippocampus as implicated in memory have been discussed, the hippocampus and NAc are also functionally and anatomically connected as the VTA projects modulatory dopaminergic synapses to the hippocampus, the hippocampus projects excitatory glutamatergic synapses to the NAc, and NAc projections eventually modulate VTA activity (Russo & Nestler, 2013). Recent research using resting-state fMRI shows correlated activity among these three

brain regions at rest, providing further evidence for the intrinsic interconnectivity of this circuit (Kahn & Shohamy, 2012). The strong connectivity of the VTA-NAc-hippocampal circuit, combined with dopamine's critical role in intrinsic social motivation, points to an as-of-yet unstudied connection between social activity and enhanced memory formation. Since reward from social activity utilizes the same well-characterized circuitry as more conventionally studied motivational cues such as monetary reward or drug-induced rewards, it is reasonable to hypothesize that activation of this circuitry through social contexts can enhance memory.

Section VIII: Limitations of Social Reward-Based Learning and Future Directions

From the evidence laid out in the previous section, I propose that the beneficial effects of social activity on memory enhancement can be explained by the strong motivational salience of social interactions and corresponding activation of the VTA-NAc-hippocampal circuit. Certainly, there is much work to be done to examine this hypothesis. First, it must be determined if social learning in a context mimicking a college classroom activates the same VTA-NAc-hippocampal dependent circuity as other forms of social and non-social rewards. If this result is found, then the potential differences in circuitry activation between collaborative and cooperative learning must be examined. Studying this circuitry shares many of the same experimental difficulties as studying the MDMN's role in social learning, however, due to the subcortical nature of the present structures it is much more difficult to use EEG techniques, limiting human research into this area predominantly to fMRI.

Clearly, conducting a study on social interaction in an fMRI scanner is a difficult task. While there are many potential ways to work around this limitation, I propose a study 'bookended' by fMRI with a social learning paradigm in the middle. If the theory holds, when re-exposed to the non-motivationally relevant fact learned during a social learning paradigm in

the fMRI scanner, the participant should show higher activation in the VTA-NAc-hippocampal network, not dissimilar from the pattern of activation one would expect from a cocaine addict's neurological response to seeing a photo of cocaine (Prisciandaro, 2012). Optimally, variations on this design could examine if social learning is dependent on multiple encounters with the target information, familiarity with the other half of the social interaction, and for any other educationally relevant factors.

While informative, human fMRI studies examining cannot explore highly relevant causal or molecular questions. Fortunately, unlike the MDMN, the VTA-NAc-hippocampal circuit in humans is highly conserved from rodent models. Unlike in humans, researchers can manipulate specific neurotransmitters to separate the effect of dopamine from other socially relevant neurotransmitters, such as oxytocin, vasopressin, and serotonin (Crockett, 2013). Essentially, if intrinsically motivated social experience can strongly encode non-social target information, what molecular and synaptic mechanisms are responsible? Answering a complex question that links molecular alterations in synaptic plasticity with an advanced animal behavior is an exceedingly difficult task, and answering such a question should serve as the long-term goal for this avenue of research. I propose a working hypothesis, that unrelated non-social target information is more strongly encoded due to associative long-term potentiation (LTP) in hippocampal circuitry.

While LTP is localized to each individual synapse if only one synapse is responding, it has long been known that a strongly activated synapse can induce a weakly activated neighboring synapse to undergo LTP as well, strengthening both synapses linking their responses (Fanselow, 2005). Relevant research into the effects of associative LTP in the amygdala during Pavlovian fear conditioning have already demonstrated precedent for the pairing of conditioned and unconditioned stimuli through associative LTP (Gewirtz, 2000). Hypothetically, if

dopaminergic inputs strongly responding to a social context are synapsing on the same postsynaptic neuron as a time-encoded weakly activated input carrying the non-social information, both synapses would undergo LTP and therefore strengthen the non-social target information. These potential human and animal lines of study represent only a small number of potential areas of investigation at the intersection of intrinsically rewarding social interactions with key brain reward circuitry and their impact on memory. While currently unstudied, this hypothesis provides an intriguing future direction for understanding the neural correlates underpinning the success of social learning in classroom contexts – and correspondingly applying those findings to further optimize classroom settings.

Section VII: Connections between the MDMN and the Social Reward networks

While this review has so far treated the MDMN and the VTA-NAc-hippocampal network as separate entities, some research indicates that they are not functionally distinct. Although not discussed in the previous section, the mPFC heavily implicated in the MDMN is also a crucial component of reward circuitry by receiving dopaminergic afferents from the VTA and sending glutamatergic efferents to the NAc (Adcock et al., 2006). While the effects of the VTA-NAc-hippocampal circuitry on the MDMN has not been studied, it is likely, given the uniquely human nature of the MDMN, that it represents higher-order conscious processes, while the VTA-NAc-hippocampal network serves as an automatic motivationally dependent response (Bodden, Dodel, & Kalbe, 2009). Clearly, the mPFC is a highly heterogeneous region that is responsible for myriad executive functions, and its role in both reward circuitry and the mentalizing network could be unrelated. However, some preliminary studies have found that social behavior is reliant on both circuits working in tandem, with the subcortical circuitry providing fast evaluative responses and the MDMN adding human-specific nuance (Barrett, 2013). Nascent research into

this field shows promising connections between these two circuits, which may ultimately lead to an integrative cognitive and biological theory of social learning for educational purposes.

Section VIII: Other Benefits of Social Learning

While the focus of this paper has been explicitly on the possible neural correlates of why social interaction can enhance simultaneously exposed target information, educational research has shown that there are other often unconsidered benefits to implementing social learning in the classrooms. By, for example, completing 'homework' in class, professors can interact more directly with students and observe the reasoning process at work when solving complex problems. Educational research examining physics undergraduate classrooms has shown that professors often grossly overestimate student understanding of core concepts based on their ability to do complicated problems, as many students simply memorize how to solve the problem for a test without understanding the underlying basic concepts (Henderson et al., 2004). By deploying professors and teaching assistants among student groups working on problems, educators can observe reasoning processes and not simply end results.

By having a closer understanding of student knowledge in a more hands-on approach, professors can identify problem areas of confusion and target 'mini-lessons' to common stumbling blocks. One overlooked benefit of having professors interact with students solving problems is the ability to more accurately gauge problem-set difficulty. Students consistently rate the amount of time they spend on assigned work higher than professor estimations (Ashby & Tomkins, 1996). An explanation for this gap comes from the 'curse of knowledge,' a concept of cognitive bias in psychology that proposes the more expert an individual is on any given topic, the harder it is to understand the problems novices face (Birch & Bloom, 2007).While more research from a neuroscientific perspective is sorely needed in this field, it is possible that

observing novices work out problems could help professors better understand the initial learning process, and correspondingly determine better ways of explaining concepts for the first time.

While the effect of social behavior on stress and the effect of stress on memory rightly deserves its own discussion, their relevance to this topic requires a brief treatment. In the broadest possible terms, while acute stress can sometimes be beneficial to memory formation, in contrast, chronic stress can be harmful to information recall (Kim, Pellman, & Kim, 2015). The effect of social interaction on stress in is complex, and most research done so far comes from a psychology-based, not a neuroscientific, approach. From the existing literature, social learning has been shown to reduce exam stress/anxiety, and social interactions have predominantly been associated with a reduction in harmful chronic stress (Kim, Pellman, & Kim, 2015; Durlak et al., 2012; McEwen, 2012). For social learning to be truly optimized, the impact of social activity on stress and the effect of stress on memory must be examined cohesively so that the implementation of social learning enhances positive rather than negative stress-based effects on learning.

Although not rigorously studied, it is easy to imagine that encouraging academically motivated socialization in large college courses can 'open the door' for extra-curricular friendships to flourish. Many sociological experiments on undergraduate populations link stronger social bonds to myriad positive outcomes, including increased student happiness, improved levels of student well-being, lower rates of anxiety and depression, and more successful career outcomes post-graduation (Dawson, 2006; Sujie, 2013). If implemented on a university-wide scale, increases in social interaction in the classroom could create an even stronger positive impact in fostering a strong and connected undergraduate community.

Section IX: The Future of Social Learning in the Undergraduate Classroom

Ultimately, this review proposes two potential neural correlates underlying the positive benefits of social learning on student educational outcomes in the undergraduate classroom. These highlighted areas of interest require much further study, specifically on how the effects of the MDMN, the VTA-NAc-hippocampal network, and connections between the two may explain how social learning functions on a neurological level. While limited, the research presented above indicates progress in the field and points to promising future directions. Hopefully, such research will bolster support for science-based learning approaches in the undergraduate classroom. Combined with evidence from educational research, neuroscientific contributions are poised to become a powerful advocate for the implementation of social learning in college courses. For the field to exist past the hypothetical, it is essential that neuroscientists, education researchers, educators, and students foster an open dialogue in pursuit of updating outdated passive teaching paradigms and optimizing the large undergraduate student classroom for true student learning.

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