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Current Opinion in Behavioral Sciences

Reward, learning and games

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The link between reward and learning has chiefly been studied scientifically in the context of reinforcement learning. This type of learning, which relies upon midbrain dopaminergic response, differs greatly from the learning valued by educators, which typically involves declarative memory formation. However, with recent insights regarding the modulation of hippocampal function by midbrain dopamine, scientific understanding of the midbrain response to reward may be becoming more relevant to education. Here, we consider the potential for our current understanding of reward to inform educational learning, and consider its implications for game-like interventions in the classroom.

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Current Opinion in Behavioral Sciences 2016, **10**:65–72

This review comes from a themed issue on **Neuroscience of education**

Edited by **Dénes Szűcs**, **Fumiko Hoeft** and **John DE Gabrieli**

For a complete overview see the Issue and the Editorial

Available online 7th May 2016

http://dx.doi.org/10.1016/j.cobeha.2016.04.015

Introduction

Reward and education — the search for a relation between reward and educational achievement

Teachers regularly use incentives to engage their pupils, but researchers have had difficulty in developing evidence-based insight to support this practice. Partly, the difficulties derive from identifying clear educational benefits of offering rewards. Some effects of reward on memory were reported in early studies [1–3], whereas other investigations have been inconclusive [4]. Indeed, even the effect of rewards on general performance motivation has been called into question [5]. Loftus [6] reported effects of reward on encoding and suggested these arise from enhanced attention, rather from the reward itself. By showing that reward-associated items were both more remembered and also fixated on more frequently during encoding, Loftus [6] showed that rewards may focus the attention of individuals more on some stimuli than others, which may make them more salient and so memorable. Rewards over longer time scales have also shown unpromising results, with no positive effects arising when 15–16 year olds were offered financial incentives and 'tickets to events' in return for raising their national examination results [7] and negative effects reported for self-regulated learning [8]. The mixed nature of these findings highlights the need for a more sophisticated understanding of reward and learning, to generate more secure principles and hypotheses to test.

In this paper, we focus upon the potential implications for game-based learning of the putative effects of reward on attention and declarative memory formation. Declarative memory formation has a special significance in education, possibly because knowledge that can be made explicit is most conveniently assessable [9]. We begin by considering reward explanations of reinforcement learning behaviour in dynamic environments that require actions to optimise reward and so have a modest resemblance to popular gaming environments. We consider links between reward and attention, and how reward learning processes may explain the putative benefits of gaming environments beyond declarative memory. Finally, we review current efforts to implement this understanding in the classroom.

We should emphasise from the outset that space constraints do not afford a full review of current concepts and understanding of the relationship between reward and memory, but instead we focus on the potential relation between emerging understanding in this area and education. We hope our article outlines the current uncertainties in developing a 'bridge' between neuroscience and education in this area, and may provide a useful prompt for future investigations. (For an excellent review of how reward motivation influences memory, with an emphasis on declarative memory, the reader is directed to Miendlarzewska *et al.* [10•].)

Motivation, reinforcement learning and midbrain dopamine

Discussions aimed at improving dialogue between neuroscience and education have identified reward as an area where new scientific insights might inform educational understanding and improve classroom practice. However, it is important to note that the meaning of terms such as 'reward' differ greatly between its usage in education and its meaning in cognitive neuroscience. In an educational context, rewards are usually material offerings or social symbols of recognition intended to influence behaviour, and motivation can include the desire to reach long-term goals. In cognitive neuroscience, as in the present article, we may consider reward to include both material and social reinforcers, and motivation as being associated with positive and negative affective states or stimuli, and more often with short-term behaviours that may include approach or withdrawal from stimuli [11]. Approach motivation associated with positive stimuli is the phenomenon closest to the educational use of the term 'motivation' (and it is in this sense that the term motivation will be used below). These differences in the use of language are augmented by those characterising different sub-fields within the scientific cognition–motivation literature [12•].

Approach motivation to a positive stimulus is coded by uptake of dopamine (DA) from the midbrain to a region called the ventral striatum and, in particular, a small nucleus of densely populated neurons within this region called the nucleus accumbens. This midbrain dopaminergic activity has been shown to increase when humans are exposed to a variety of pleasures including food [13], money [14] and computer games [15]. This short-term and visceral type of motivation may have much to do with our day-to-day desire to solve problems that reap immediate benefit, but probably less to do with prospects involving delayed gratification, such as the goal of obtaining a professional or academic qualification. Nevertheless, it appears a reasonable hypothesis that moment-to-moment visceral motivations do have influence on children's learning in the classroom.

There is much we do not understand about the mechanisms by which 'off the shelf' games influence the reward system. Studies in the context of putative associations between computer games, addiction and the reward system have compared action-based games involving rewards (e.g. [15]) to studies of DA in reinforcement learning (RL), since these games involve learning how to take actions that optimise reward in a dynamic environment. Rewarded action has been proposed as a potentially important factor in the reported ability of video games to influence cognitive function [62]. Studies of RL may, therefore, provide insight into DA function in games, although an important caveat here is that, although accepted as central, the exact role of DA within RL (and reward-related processes more broadly) remains controversial. RL is a type of learning shared by many animals and considered to support, for example, foraging among natural food sources [16]. Neural processes thought to underlie RL implicate ventral tegmental area (VTA) efferent projections that release DA to a broad range of structures such as prefrontal cortex (PFC), nucleus accumbens (NAc), amygdala, and hippocampus [17]. This dopaminergic pathway (the meso-cortico-limbic circuit) is thought to play a key role in reinforcing rewarding behaviour. When a 'better-than-expected' reward (positive prediction error) is signalled by activation of DA neurons, the resulting cue-reward learned associations produce a change in reward-seeking behaviour [18] helping to optimise our behaviour in a changing environment. In reinforcement learning, it is phasic DA release (i.e. a short term pulse) that is considered to code prediction error and provide this important learning signal. However, the human data for this model is somewhat circumstantial due to ethical difficulties in directly measuring DA transmission and the reliance, instead, on a BOLD neuroimaging signal as a proxy [19]. A first attempt to directly measure DA release in relation to prediction error suggests this may be mediated in a more complex manner by context than originally assumed [20]. Also, both phasic and tonic DA activity appear to be involved in motivational state [21], and both contribute to the extra-cellular DA levels that regulate conditioned responding.

The association between prediction error and RL emphasises the role of recent prior experience on phasic DA response, in terms of the expected value of previous rewards. This expected value takes account of both the magnitude of a possible reward and its probability. Primate studies suggest the variance (or uncertainty) in this probability may influence tonic levels of dopamine, producing a sustained ramping between a cue that a reward may be arriving and delivery of the reward [22]. This effect appears maximal at a reward uncertainty of 50%. Evidence of a similar relationship between DA and reward uncertainty has also been reported in two human studies using fMRI [23,24]. This response to uncertainty has been used to explain our attraction to games of chance [25], although many other factors pertinent to playing video games, such as novelty [26] and social interaction [27], are also likely to play a role in determining midbrain DA release.

Reward and attention

Prediction error forms an important part of associative learning theories involving reward and, although the neurobiological mechanisms by which the DA coding of prediction error contributes to this learning are not well understood [28•], these are thought to involve enhanced attention to poorly predicted (or 'surprising') outcomes. The role of midbrain DA release in orienting attention has some support from animal studies (e.g. [29]), while its role in human attention has generated most interest in dopamine-deficit theories of ADHD, where the failure to develop anticipatory DA release is thought to result in a lack of DA cell activity in response to attending [30]. In active paradigms, such as naturalistic scenarios involving action selection, saccades may have a bidirectional relationship with the task. They can be influenced by the nature and values of the ongoing actions and may influence the task by selecting sensory information that most strongly impacts on the observer's actions (see [31] for review).