Learning and Instruction 55 (2018) 22–31

Contents lists available at ScienceDirect

Learning and Instruction

journal homepage: www.elsevier.com/locate/learninstruc

When generating a prediction boosts learning: The element of surprise

Garvin Brod[a,b,*], Marcus Hasselhorn[a,b], Silvia A. Bunge[c]

[a] German Institute for International Educational Research (DIPF) & IDeA Center for Individual Development and Adaptive Education, Frankfurt am Main, Germany
[b] Department of Psychology, Goethe University Frankfurt, Frankfurt am Main, Germany
[c] Department of Psychology & Helen Wills Neuroscience Institute, University of California, Berkeley, USA

ARTICLE INFO

Keywords:
Knowledge activation
Hypothesis generation
Prediction error
Memory
Eye-tracking

ABSTRACT

Using both behavioral and eye-tracking methodology, we tested whether and how asking students to generate predictions is an efficient technique to improve learning. In particular, we designed two tasks to test whether the surprise induced by outcomes that violate expectations enhances learning. Data from the first task revealed that asking participants to generate predictions, as compared to making post hoc evaluations, facilitated acquisition of geography knowledge. Pupillometry measurements revealed that expectancy-violating outcomes led to a surprise response only when a prediction was made beforehand, and that the strength of this response was positively related to the amount of learning. Data from the second task demonstrated that making predictions about the outcomes of soccer matches specifically improved memory for expectancy-violating events. These results suggest that a specific benefit of making predictions in learning contexts is that it creates the opportunity for the learner to be surprised. Implications for theory and educational practice are discussed.

1. Introduction

Activating students' prior knowledge has been identified as the cornerstone of high-quality instruction (Alexander, 1996; Ausubel, 1968; Bransford, Brown, & Cocking, 2000). Activating prior knowledge in the learner strongly improves their comprehension and memory of new material (Bransford & Johnson, 1972). Thus, a key question for educators is how to best activate relevant prior knowledge in their students. Various techniques to activate prior knowledge in students have been proposed (for an overview, see Krause & Stark, 2006). One technique is to ask students to make a prediction (also called 'generate a hypothesis') before receiving the new information. This technique has been successfully employed in studies that investigated ways to improve students' learning of various materials, including learning from text (Fielding, Anderson, & Pearson, 1990), physics (Champagne, Klopfer, & Gunstone, 1982; Crouch, Fagen, Callan, & Mazur, 2004; Inagaki & Hatano, 1977), and biology (Schmidt, De Voider, De Grave, Moust, & Patel, 1989).

It has been suggested that making a prediction requires accessing prior knowledge and connecting it to the new information being learned (Schmidt et al., 1989). Furthermore, it may stimulate curiosity for the correct answer (Inagaki & Hatano, 1977) and, if the answer was not correctly predicted, trigger conceptual change because the learners realize that there is a flaw in their concept (cf. Anderson, 1977, p. 427). Not surprisingly, then, asking students to make a prediction forms part of many prototypical instructional curricula (e.g., Champagne et al., 1982; Hardy, Jonen, Möller, & Stern, 2006).

However, despite its widespread use, very little is known about the mechanism(s) by which making a prediction may improve learning. In addition, a potential caveat to the prediction method is that students spend a lot of time and effort generating a prediction and might thus remember their wrong prediction instead of the correct result, as theorized by proponents of errorless learning (e.g., Baddeley & Wilson, 1994). Another caveat is that learners might not experience meaningful conflict despite having made a wrong prediction, thereby leading to no conceptual change (Limón, 2001). Thus, knowledge of the specific mechanisms by which making a prediction affects learning seems crucial to resolve these opposing views.

A relevant line of work that has recently gained momentum in cognitive psychology research concerns the effects of guessing on learning. Kornell, Jensen Hays, and Bjork (2009) showed that testing can be beneficial for memory even during novel learning, when participants can only guess the answer and nearly all guesses are incorrect. They argued that this so-called *errorful* generation instantiates a special case of the well-known generation effect (Slamecka & Graf, 1978) and may promote learning because it requires great retrieval effort. Study methods that make use of this effect (e.g., flashcards) have been shown to substantially enhance memory retention (the so-called *testing effect*, see Karpicke & Roediger, 2008; Pyc & Rawson, 2009). Kornell et al.'s (2009) finding has sparked considerable interest and has been

* Corresponding author. German Institute for International Educational Research, Schloßstr. 29, 60486 Frankfurt am Main, Germany.
E-mail address: garvin.brod@dipf.de (G. Brod).

https://doi.org/10.1016/j.learninstruc.2018.01.013
Received 2 June 2017; Received in revised form 2 January 2018; Accepted 31 January 2018

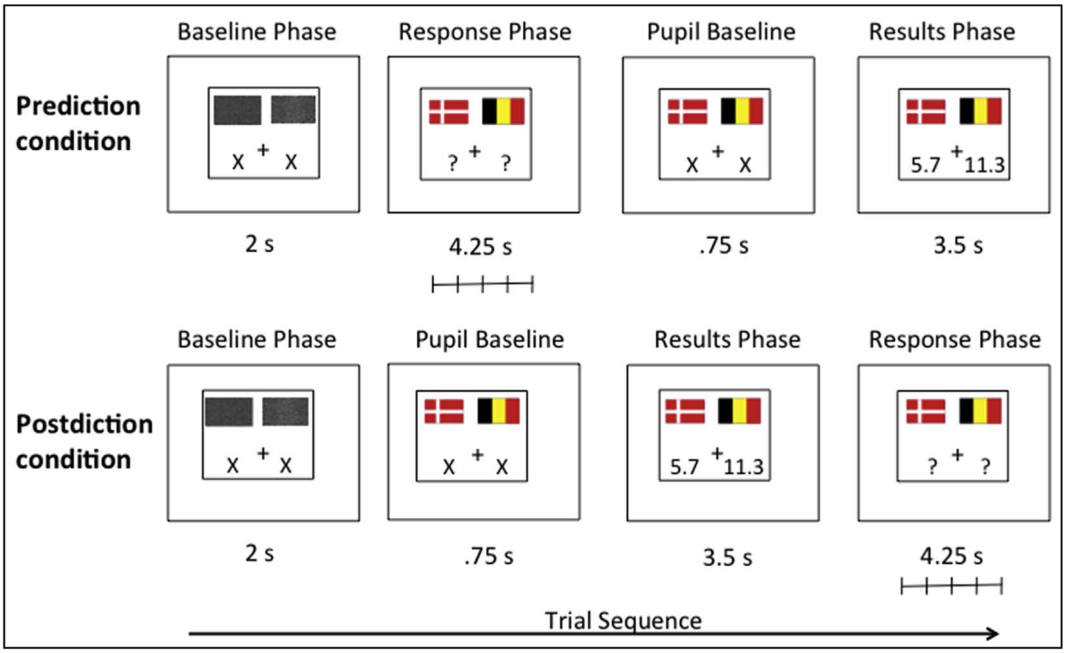

Fig. 1. Schematic overview of the common study phase of the two paradigms, exemplified by the geography task. One exemplary trial is depicted per condition (note that, for illustrative purposes but unlike in the real experiment, the same countries (Denmark, Belgium) are used here for both conditions). Each trial consisted of four different slides presented in the depicted order (duration times per slide are presented below the screens). In the prediction condition (upper half), participants had to make a prediction first (i.e., and then saw the correct population sizes (in millions), whereas in the postdiction condition, they first saw the population sizes and then had to make a post-hoc statement regarding which results they would have predicted. Participants were only able to respond when the question marks appeared on the screen, using the same five-point scale for both conditions: Far left: clearly the left country, Left: probably the left country, Middle: don't know, Right: probably the right country, Far right: clearly the right country. Details regarding the purposes of the 'Baseline Phase' and 'Pupil Baseline' can be found in section 2.4. For illustrative purposes, the background is shown in white and the print in black. For the real experiment, the background was gray and the print was white, so as to reduce luminance contrasts. The following details were changed for the soccer task (not shown due to copyright regulations): country flags were replaced by club logos; country populations were replaced by scores; and the labels of the five-point scale were adapted to the scores: Far left: > 1 goal difference victory for the left team, Left: 1 goal victory for the left team, Middle: draw, Right: 1 goal victory for the right team, Far right: > 1 goal victory for the right team.

replicated and extended by various labs (Grimaldi & Karpicke, 2012; Huelser & Metcalfe, 2012; Potts & Shanks, 2014). A boundary condition that seems to be emerging from these studies is that, for guessing to be beneficial, timely corrective feedback is crucial, giving participants an opportunity to encode the correct answer (Vaughn & Rawson, 2012). Other than that, however, this line of work has focused mainly on the retrieval effort explanation as to why making a guess is beneficial for memory.

Another related line of work concerns the role of surprise – i.e., the emotional response to outcomes that do not match expectancies (see Ekman, 1992) – in enhancing learning. This work is grounded in now-classic research on reinforcement learning showing that discrepancies between what is expected and what occurs trigger learning (Rescorla & Wagner, 1972), as well as in a rich neuroscience literature suggesting that prediction errors play a universal role in driving learning throughout the human brain (for an overview, see Bar, 2007; Henson & Gagnepain, 2010). From a cognitive psychology perspective, Fazio and Marsh (2009) showed that increased attention is allocated to surprising feedback, which then leads to better memory (see also Butterfield & Metcalfe, 2006). In line with this account, a recent study demonstrated that the degree to which expectancies are violated predicts later memory (Greve, Cooper, Kaula, Anderson, & Henson, 2017).

In a new line of work, Stahl and Feigenson (2015) demonstrated that 11-months-old infants show enhanced information-seeking and hypothesis-testing behaviors and learning for objects that appeared in episodes that violated expectations as compared to ones that were consistent with expectations. Recently, they demonstrated this benefit of surprise in children (aged 3–6) as well (Stahl & Feigenson, 2017). These findings led the authors to suggest that expectancy-violating events present special opportunities for learning. The facilitatory role of surprise for learning is in line with recent research showing that inducing confusion in a learner, for example by presenting contradictory information, leads to enhanced learning and transfer performance (D'Mello, Lehman, Pekrun, & Graesser, 2014). Confusion is suggested to occur after a surprise reaction when the expectancy-violating new information cannot be resolved right away, inducing a cognitive disequilibrium (D'Mello et al., 2014). In sum, this line of work has shown that expectancy-violating events can trigger learning, which might be due to the surprise response that is evoked by these events.

Based on these prior studies on surprise, we hypothesize that one specific mechanism by which making a prediction is beneficial for learning is that it enables a learner to be surprised by events that refute the prediction. Many processes that are known to improve learning, including effortful retrieval, self-generation of a solution, curiosity, and learning from feedback, are invoked when generating a prediction. Here, we sought to test whether predicting outcomes boosts subsequent learning when controlling for various potentially confounding factors.

Further, we sought to assess the extent to which surprise accounts for the benefit of prediction on learning. However, a common problem in research on surprise is how to measure and compare it across individuals, because asking participants to report their level of surprise in response to an outcome is prone to systematic distortions (Schützwohl, 1998). One way to measure surprise objectively is via the pupillary response. Dilation of the pupil has been repeatedly shown to signal surprise (e.g., Kloosterman et al., 2015; Preuschoff, t Hart, & Einhauser, 2011) and reflects the release of the neurotransmitter norepinephrine in the brainstem's locus coeruleus, which regulates arousal (for an overview, see Aston-Jones & Cohen, 2005). Thus, surprise can be measured indirectly using pupillometry.

Here, we report the results of an experiment with two tasks involving university students. These experimental tasks probed different domains of knowledge, but both involved a within-subject experimental design that contrasted a condition in which participants had to make a prediction (henceforth called 'prediction condition') with a condition in