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Dynamics of affective states during complex learning

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ABSTRACT

We propose a model to explain the dynamics of affective states that emerge during deep learning activities. The model predicts that learners in a state of engagement/flow will experience cognitive disequilibrium and confusion when they face contradictions, incongruities, anomalies, obstacles to goals, and other impasses. Learners revert into the engaged/flow state if equilibrium is restored through thought, reflection, and problem solving. However, failure to restore equilibrium as well as obstacles that block goals trigger frustration, which, if unresolved, will eventually lead to boredom. The major hypotheses of the model were supported in two studies in which participants completed a 32–35 min tutoring session with a computer tutor. Their affective states were tracked at approximately 110 points in their tutoring sessions via a retrospective affect judgment protocol. Time series analyses confirmed the presence of confusion–engagement/flow, boredom–frustration, and confusion–frustration oscillations. We discuss enhancements of the model to address individual differences and pedagogical and motivational strategies that are inspired by the model.

1. Introduction

Efforts to learn difficult subject matter at deeper levels of comprehension involve a complex coordination of cognitive processes and affective states. Cognitive processes that underlie inference generation, causal reasoning, problem diagnosis, conceptual comparisons, and coherent explanation generation are accompanied by affective states such as irritation, frustration, anger, and sometimes rage when the learner makes mistakes, struggles with troublesome impasses, and experiences failure. On the other hand, positive affective states such as flow, delight, excitement, and eureka are experienced when tasks are completed, challenges are conquered, insights are unveiled, and major discoveries are made. Simply put, emotions are systematically affected by the knowledge and goals of the learner, as well as vice versa (Mandler, 1976, 1999; Stein & Levine, 1991). Cognitive activities such as causal reasoning, deliberation, goal appraisal, and planning processes operate continually throughout the experience of emotion. For example, flexibility, creative thinking, efficient decision-making, and conceptually-driven relational thinking have been linked to positive affect, while negative affect has been associated with narrower localized attention and stimulus-driven referential processing (Clore & Huntsinger, 2007; Fielder, 2001; Fredrickson & Branigan, 2005; Isen, 2008; Schwarz, in press).

The inextricable link between affect and cognition is a fundamental assumption adopted by the major theories of emotion. Although the contemporary theories of emotion (Barrett, 2009; Frijda, 2009; Izard, 2007; Russell, 2003; Scherer, 2009) convey general links between cognitive processes and affective states, they do not directly explain and predict the sort of emotions that occur during complex learning (described below in Scope of the Model subsection), such as attempts to master physics, biology, or critical thinking skills. Fortunately, theoretical frameworks that predict systematic relationships between affective and cognitive states during complex learning are beginning to emerge in the fields of psychology (Deci & Ryan, 2002; Dweck, 2002; Immordino-Yang & Damasio, 2007), education (Buff, Reusser, Rakoczy, & Pauli, 2011; Csikszentmihalyi, 1990; Huk & Ludwigs, 2009; Linnenbrink, 2006; Meyer & Turner, 2006; Schutz & Pekrun, 2007), and artificial intelligence in education (Calvo & D'Mello, 2011; Conati & Maclaren, 2009; Forbes-Riley & Litman, 2010). Emotion research in education during the last century mainly focused on test anxiety or motivation-based traits, whereas researchers in the last decade have begun to investigate a much broader set of *academic emotions*.

Pekrun (2010) has classified academic emotions into four categories that include achievement emotions, topic emotions, social emotions, and epistemic emotions. *Achievement* emotions (e.g., contentment, anxiety, and frustration) are linked to learning

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activities (e.g., homework, taking a test) and outcomes (e.g., success, failure), whereas *topic* emotions are aligned with the learning topic (e.g., empathy for a protagonist while reading classic literature). On the other hand, *social* emotions such as pride, shame, and jealousy are not directly related to the topic but reflect the fact that educational activities are socially situated. Finally, *epistemic* emotions arise from cognitive information processing, such as surprise when novelty is encountered or confusion when the student experiences an impasse. According to the control–value theory, these academic emotions arise from cognitive appraisals of control over the learning task and value in the learning activity, with reciprocal connections between the emotions, their antecedents, and their consequents (Pekrun, 2006).

The emerging research on student emotions in classrooms focuses on a broad array of affective responses that are elicited in a number of learning contexts. Other research has focused on a more in-depth analysis of a smaller set of emotions that arise during deep learning in more restricted contexts and over shorter time spans, from 30-min to 1.5 h (Baker, D'Mello, Rodrigo, & Graesser, 2010; Conati & Maclaren, 2009; Forbes-Riley & Litman, 2010; Rodrigo & Baker, 2011; Woolf et al., 2009). These learning contexts include a multitude of computer environments, such as preparation for high-stakes test taking, problem solving, reading comprehension, and essay writing. The emotions that appear to be prominent in these learning sessions include boredom, engagement/flow, confusion, frustration, anxiety, curiosity, delight, and surprise (see Calvo & D'Mello, 2011).

The definitions of most of these learning-centered affect states are well known, but confusion and engagement/flow require some clarification. Although most would agree that confusion is not a 'basic' emotion (e.g., anger, disgust, sadness, fear) (Ekman, 1992), there is some debate about classifying confusion as either an emotion (Keltner & Shiota, 2003; Rozin & Cohen, 2003; Silvia, 2009), an epistemic affective state (Pekrun, 2010), or a mere cognitive state (Clore & Huntsinger, 2007). The present paper considers confusion to be an epistemic affective state and refers to the entire set of states under consideration in this article (boredom, confusion, etc.) as affective states or cognitive-affective mixtures instead of emotions perse.

Engagement/flow is a cognitive-affective state that sometimes has a short time span, but at other times forms part of Csikszentmihalyi's (1990) conception of flow (Baker et al., 2010). It is important to point out that a learner can be engaged without necessarily experiencing flow; for example, being engaged in order to avoid failure when one is anxious. Quite different from this form of engagement, we conceptualize engagement/flow as a state of engagement with a task such that concentration is intense, attention is focused, and involvement is complete. However, it need not involve some of the task-related aspects which Csikszentmihalyi (1975) associates with flow, such as clear goals, balanced challenge, or direct and immediate feedback. It also may not involve some of the aspects of Csikszentmihalyi's conceptualization that refer to extreme intensity to the extent that there is time distortion or loss of self-consciousness. Such intense flow experiences would be welcome, but are rare in the learning environments under investigation in the present study.

The identification of the affective states that occur during learning is critical, but it could be argued that merely knowing *what* states occur has limited utility. What is missing is a specification of *how* these states evolve, morph, interact, and influence learning and engagement. An analysis of mood states during a learning session will not suffice, because states such as confusion, frustration, and delight arise and decay at much faster timescales (a few seconds) compared to moods (several minutes or a few hours) (Ekman, 1984; Rosenberg, 1998). Furthermore, an analysis that focuses on whether a learner is generally in either a positive or negative mood during an *entire* learning session is also unsatisfactory, because learners oscillate between positive and negative states throughout the session. What is required is a fine-grained analysis of the rapid dynamics of both positive and negative affective states that naturally occur during effortful learning activities. The present paper presents such a model and reports two studies that empirically test its major predictions.

2. A model of affective dynamics during learning

The proposed model highlights the critical role of cognitive disequilibrium in driving deep learning and inquiry. Cognitive disequilibrium is a state of uncertainty that occurs when an individual is confronted with obstacles to goals, interruptions of organized action sequences, impasses, contradictions, anomalous events, dissonance, incongruities, unexpected feedback, uncertainty, deviations from norms, and novelty. The importance of cognitive disequilibrium in learning and problem solving has a long history in psychology that spans the developmental, social, and cognitive sciences (Berlyne, 1978; Chinn & Brewer, 1993; Collins, Warnock, Aiello, & Miller, 1975; Festinger, 1957; Graesser & Olde, 2003; Laird, Newell, & Rosenbloom, 1987; Miyake & Norman, 1979; Piaget, 1952; Schank, 1999). The notion that cognitive disequilibrium extends beyond cognition and into emotions has also been acknowledged and investigated for decades (Festinger, 1957; Graesser, Lu, Olde, Cooper-Pye, & Whitten, 2005; Lazarus, 1991; Mandler, 1976; Piaget, 1952). What is less clear, however, is the trajectory of cognitive-affective states that are spawned by cognitive disequilibrium and how these trajectories impact learning and problem solving. It is this trajectory of affective states that is the focus of the present paper.

The proposed model posits that the complex interplay between external events that trigger impasses and obstacles that block goals, coupled with goal appraisal (Mandler, 1999; Stein & Levine, 1991), cognitive disequilibrium (Chinn & Brewer, 1993; Graesser, Lu, et al., 2005; Graesser & Olde, 2003; Piaget, 1952), and impasse resolution (Siegler & Jenkins, 1989; VanLehn, Siler, Murray, Yamauchi, & Baggett, 2003), is the key to understanding the affective states that underlie complex learning. The model is presented in Fig. 1 in the form of a state transition network. The nodes (circles) in the figure represent the affective states (in parentheses) and their presumed causes (in bold). Links represent situations that trigger transitions between the different states. Solid links represent primary components of the model, whereas other (dashed) links are secondary.

The model assumes that learners are typically in a prolonged state of either (a) engagement/flow as they pursue the superordinate learning goal of mastering the material in the learning environment or (b) disengagement (boredom) when they abandon pursuit of the superordinate learning goal. When learners are deeply engaged, they attempt to assimilate new information into existing knowledge schemas. When new or discrepant information is detected, attention shifts to the discrepant information, the autonomic nervous system increases in arousal, and the learner experiences a variety of possible affective states, depending on the context, the amount of change, and whether important goals are blocked (Mandler, 1984, 1999; Stein & Levine, 1991).

Learners experience cognitive disequilibrium when they are confronted with a contradiction, anomaly, system breakdown, or error, and when they are uncertain about what to do next (Carroll & Kay, 1988; Graesser, Lu, et al., 2005; Graesser & Olde, 2003; Siegler & Jenkins, 1989; VanLehn et al., 2003). Confusion is a key signature of the cognitive disequilibrium that occurs when an impasse is detected (Link 1A). Learners must engage in effortful problem solving activities in order to resolve the impasse and restore