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Confusion and its dynamics during device comprehension with breakdown scenarios☆,☆☆

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ABSTRACT

The incidence and dynamics of confusion during complex learning and problem solving were investigated in an experiment where participants first read illustrated texts on everyday devices (e.g., an electric bell) followed by breakdown scenarios reflecting device malfunctions (e.g., "When a person rang the bell there was a short ding and then no sound was heard"). The breakdown scenarios were expected to trigger impasses and put participants in a state of cognitive disequilibrium where they would experience confusion and engage in effortful confusion resolution activities in order to restore equilibrium. The results confirmed that participants reported more confusion when presented with the breakdown scenarios compared to control scenarios that involved focusing on important device components in the absence of malfunctions. A second-by-second analysis of the dynamics of confusion yielded two characteristic trajectories that distinguished participants who partially resolved their confusion from those who remained confused. Participants who were successful in partial confusion resolution while processing the breakdowns outperformed their counterparts on knowledge assessments after controlling for scholastic aptitude, engagement, and frustration. This effect was amplified for those who were highly confused by the breakdowns. There was no direct breakdown vs. control effect on learning, but being actively engaged and partially resolving confusion during breakdown processing were positive predictors of increased learning with the breakdown compared to control scenarios. Implications of our findings for theories that highlight the role of impasses, cognitive disequilibrium, and confusion to learning are discussed.

1. Introduction

The statement, "we problem solve when our world breaks down in front of us", is perhaps an accurate categorization of the factors that facilitate complex problem solving in our everyday worlds. Quite different from formal educational settings, when one is asked to learn concepts, procedures, and problem solving strategies in the context of imagined problems or in anticipation of future applications, real-world problem solving is often triggered by an actual problem that needs to be solved to advance a more immediate goal. For example, toasters, doorbells, dishwashers, and telephones are widely used everyday devices, yet people have surprisingly limited knowledge on how these devices function, presumably because this information is not essential for typical use of these devices. As such, peoples' understanding of everyday devices is restricted to some knowledge of observable parts, basic operational procedures, and general functions. They can rarely articulate the mechanical and electrical principles that govern device functioning and are generally unaware of misconceptions and problems with their explanations (Ahn & Kalish, 2000; Graesser & Clark, 1985; Graesser, Lu, Olde, Cooper-Pye, & Whitten, 2005; Kieras & Bovair, 1984; Rozenblit & Keil, 2002).

The situation can drastically change when a device fails to function as expected or intended, as is the case when a doorbell is depressed but an unexpected "clank" is heard instead of the anticipated "ding". In these situations, an individual is likely to experience cognitive disequilibrium (or cognitive conflict), which is a state that occurs when an individual is confronted with discrepant events, such as deviations from the norms, obstacles to goals, interruptions of action sequences, contradictions, anomalous information, unexpected feedback, and other forms of uncertainty. Cognitive disequilibrium is likely to persist until equilibrium is restored or disequilibrium is dampened by problem solving and reasoning.

The importance of cognitive disequilibrium in learning and problem solving has a long history in psychology that spans the developmental,

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social, learning, and cognitive sciences (Berlyne, 1960, 1978; Chinn & Brewer, 1993; Collins et al., 1975; Festinger, 1957; Graesser & Olde, 2003; Laird, Newell, & Rosenbloom, 1987; Limón, 2001; Miyake & Norman, 1979; Mugny & Doise, 1978; 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 et al., 2005; Lazarus, 1991; Mandler, 1976; Piaget, 1952; Stein & Levine, 1991). What is less clear, however, is the trajectory of cognitive–affective processes that are spawned by cognitive disequilibrium and how these processes impact learning and problem solving. In this paper, we focus on confusion, which is considered to be one of the key affective signatures of cognitive disequilibrium.

1.1. Confusion

What exactly is confusion? Most are familiar with the feeling of being confused, but there is the question of whether confusion should be classified as a bona fide emotion like anger or fear, or an affective state, which is more general than an emotion. D'Mello and Graesser (2014) recently suggested that confusion shares several of the properties commonly attributed to emotion, such as a predictable appraisal structure (Silvia, 2009, 2010) and identifiable facial markers (i.e., furrowed brow — Craig, D'Mello, Witherspoon, and Graesser (2008)), but evidence is lacking on a few additional properties of emotion (e.g., neural circuits partially dedicated to “emotional processing” — Izard (2010)). Although more research is needed before this issue can be settled, what is clear is that confusion is more than a mere cognitive state, a position that has considerable support in the affective science literature (Ellsworth, 2003; Hess, 2003; Keltner & Shiota, 2003; Pekrun & Stephens, 2011; Rozin & Cohen, 2003a,b; Silvia, 2009, 2010). In line with this, we consider confusion to be an affective state.

Similar to other affective states, confusion emerges as a product of an individual's appraisals of relevant events (both internal and external) (Ortony, Clore, & Collins, 1988; Scherer, 2009; Scherer, Schorr, & Johnstone, 2001; Smith & Ellsworth, 1985). According to Mandler's interruption (discrepancy) theory (Mandler, 1990) and goal-appraisal theories of emotion (Stein & Levine, 1991), individuals are constantly assimilating new information into existing knowledge schemas as they pursue goal-directed activities. When new or discrepant information is detected (e.g., a conflict with prior knowledge), attention shifts to discrepant information, the autonomic nervous system increases in arousal, and the individual experiences a variety of possible affective states, depending on the context, the amount of change, and whether the goal is blocked. In the case of extreme novelty, the event evokes surprise. Confusion occurs when the discrepancy or novelty triggers an impasse (i.e., the person encounters an error, gets stuck, and is unsure how to proceed — VanLehn, Siler, Murray, Yamauchi, and Baggett (2003)) that blocks the current goal and possibly results in the individual being uncertain about what to do next.

Once confusion is experienced, the individual needs to engage in problem solving activities in order to successfully restore equilibrium by resolving their confusion. Confusion resolution requires people to stop, think, effortfully deliberate, problem solve, and revise their existing mental models. These activities have the potential to inspire greater depth of processing during training, more durable memory representations, and more successful retrieval (Craik & Lockhart, 1972; Craik & Tulving, 1975). Some evidence for this form of impasse-driven learning can be found in early work on skill acquisition as well as more recent studies on complex learning (Brown & VanLehn, 1980; Carroll & Kay, 1988; D'Mello, Lehman, Pekrun, & Graesser, 2014; Siegler & Jenkins, 1989; VanLehn et al., 2003). For example, in an analysis of approximately 125 h of human–human tutorial dialogs, VanLehn et al. (2003) discovered that comprehension of physics concepts was rare when students did not reach an impasse, irrespective of quality of the explanations provided by tutors. Recent evidence also suggests that confusion is positively correlated with learning, presumably because of activities associated with confusion resolution, such as more effortful elaboration and causal reasoning during problem solving (Craig, Graesser, Sullins, & Gholson, 2004; D'Mello & Graesser, 2011; Graesser, Chipman, King, McDaniel, & D'Mello, 2007).

In addition to confusion that is eventually resolved, unresolved confusion can spawn trajectories of negative affective states (D'Mello & Graesser, 2012). For example, frustration occurs when an individual experiences repeated failures and is stuck. Persistent confusion occurs when confusion resolution fails and an individual is unable to restore equilibrium. This form of unresolved confusion is expected to accompany negligible or poor learning when compared to situations where confusion is immediately or eventually resolved (Bosch, D'Mello, & Mills, 2013). In the VanLehn et al. (2003) tutoring example discussed earlier, students acquired a physics principle in only 33 of the 62 impasses, ostensibly because their impasses were not resolved for the remaining 29 cases. Therefore, it is important to distinguish between productive and unproductive confusion (D'Mello & Graesser, 2012).

To summarize, confusion is an affective state that is highly relevant to learning and problem solving because it can perform two of the key functions attributed to affect: to communicate the result of an individual's appraisal of the world (Schwarz, 2012; Schwarz & Skurnik, 2003) and to motivate instrumental action based on said appraisals (Frijda, 1986; Izard, 2010). Confusion brings appraisals of knowledge to the forefront by signaling a discrepancy in one's model of the world, and is therefore sometimes referred to as a knowledge emotion (Silvia, 2010) or an epistemic emotion (Pekrun & Stephens, 2011). Confusion can motivate effortful cognitive activities in an attempt for the individual to resolve the discrepancy and restore equilibrium. The effect of confusion on the outcomes of a learning or problem solving activity is unlikely to be causal because performance relies on the extent to which confusion is attended to and resolved. Therefore, we would expect confusion to exhibit different dynamics and have differential impacts on performance based on whether it is simply ignored, attended to and successfully resolved, or attended to and left unresolved.

1.2. Overview and motivation of present study

The present study investigated confusion and its resolution in the context of comprehending how everyday devices function (device comprehension) from illustrated texts such as the cylinder lock shown in Fig. 1. We chose this task because of its ecological relevance to everyday life and its long history in the cognitive sciences. It is also a challenging task because it involves the construction of complex mental representations from impoverished information, which is common to many real world tasks.

Device comprehension involves the construction of a device model (Hegarty & Just, 1993; Hegarty, Just, & Morrison, 1988; Kieras & Bovair, 1984), which following Kieras and Bovair (1984), is defined as an accurate conceptual model of a device (to be distinguished from other types of mental models — Johnson-Laird (2006)). A device model is needed to generate inferences about device operations, answer causal questions, diagnose and solve device malfunctions, make conceptual comparisons between device components, and generate coherent explanations of intricate mechanisms.

Hegarty, Narayanan, and Freitas (2002) provide a process-level account in their cognitive model of the stages involved in constructing a device model from illustrated texts. Their model consists of the following five phases: (a) constructing a static device model by decomposing the diagram into simpler parts and connecting these parts in a mental representation, (b) making representational connections from prior knowledge and spatial relations among components, (c) making referential connections between the text and diagram, (d) identifying the causal chain of events, and (e) constructing a dynamic model by mentally simulating the static model (Hegarty & Just, 1993; Hegarty et al., 2002). This model has been used to guide research on the