All Alone with your Emotions: an analysis of student emotions during effortful problem solving activities

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All Alone with your Emotions: An Analysis of Student Emotions during Effortful Problem Solving Activities

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Abstract. We explored the affective states that students experienced during effortful problem solving activities. We conducted a study where 41 students solved 28 logic problems from the law school admissions test. Participants viewed videos of their interaction history and judged their emotions at different phases in the problem solving process (after new problem is displayed, in the midst of problem solving, after feedback is received). Our results indicated that curiosity, frustration, boredom, confusion, and happiness were the major emotions that students' experienced, while experiences of contempt, anxiety, anger, sadness, fear, disgust, joy, and surprise were rare. We also explored interactions between the occurrences of the various emotions at the different phases of the problem. Implications of our results for affect-sensitive learning environments are discussed.

Keywords: affect, emotions, problem solving, intelligent tutoring systems, affect and learning

1 Introduction

Effortful problem solving activities in mathematics, physics, and logic are inevitably accompanied by the natural steps of making mistakes and recovering from them. Students get confused when confronted by contradictions, misconceptions, and salient contrasts [1, 2, 3, 4], they get frustrated by obstacles and challenges that block goals [5, 6], and they experience anxiety when failure is attributed to events outside of their control [7, 8, 9]. Persistent failure might eventually lead to boredom and disengagement [10]. Alternatively, students experience happiness and delight when tasks are completed, eureka moments when challenges are unveiled and major discoveries are made, and flow like states when they are so engaged in problem solving that time and fatigue disappear [10].

The influence of emotions during problem solving activities cannot be underestimated because they can impede or facilitate the problem solving process [11, 12], as well as engender different modes of thinking [13, 14]. Emotions are inextricably bound to cognition and therefore play a principal role in all phases of problem solving by influencing the ways students' perceive and attend to information. Mandler [15, 16] discusses a theory of emotion in which an emotion occurs due to the hindrance of or failure to complete a goal. Consistent with contemporary appraisal theories, the arousal (intense/weak) of an emotion episode is dependent upon how great the interruption is to the person's goal and the valence (positive/negative) depends on the person's evaluation of the interruption [17, 16]. For example, getting stuck and not being able to move past the obstacle would be interpreted as intensely negative because goal attainment is obstructed [5].

At this point in science, there is no comprehensive theory that exhaustively addresses the emotions (e.g. confusion, frustration, etc) that occur during problem solving activities, the temporal dynamics of the emotions, and the manner in which they impact performance. There is some evidence that positive and negative affective experiences do play a modulating role in problem solving. For example, flexibility, creative thinking, and efficient decision-making have been linked to experiences of positive affect [18, 19, 20], while negative affect has been associated with a more methodical approach to assessing the problem and finding the solution [21, 22, 23, 24]. However, Schwarz and Skurnik [14] have challenged the adequacy of basing an entire theory on valence alone, because the relationship between positive and negative affective states and performance outcomes is more complex, and, in some cases counterintuitive. For example, certain negative emotions, such as confusion, could have a positive effect on problem solving [25, 26]. Furthermore, not all positive emotions are linked to successful outcomes. Therefore, Schwarz and Skurnik recommend that investigating the roles that specific emotions play in different phases in problem solving would produce a more comprehensive model of the dynamics of emotions in problem solving activities.

Consequently, we conducted a study that attempted to analyze the emotional rollercoaster that occurs during effortful problem solving activities. We chose to focus on problem solving for a number of reasons. First, many ITSs have some elements of problem solving as part of the system [27, 28, 29]. Although, there has been some research on monitoring emotions during one-on-one tutoring sessions with ITSs [25, 30, 31, 32, 33], the research on systematic investigation of emotion during non-scaffolded problem solving is sparse and scattered. There has been almost no research on the role that emotions play when solving logic problems, except a study by Baker and colleagues [34], who found that engagement/flow, boredom, and frustration frequently occurred while students solve logic problems. Second, problem solving provides an excellent environment for the study of emotions because effortful problem solving activities are rife with contradictions, incongruities, anomalies, and uncertainty – all factors that contribute to rich emotional experiences. Therefore, a model of students' emotions during effortful problem solving activities can be used to inform the development of problem solving modules of contemporary ITSs.

Our study involved 41 participants solving logic problems from the law school admissions test (LSAT). Participants then provided judgments of their emotions via a retrospective emotion judgment procedure [35, 26]. We focused on a three dimensional model of student emotions: (1) Basic emotions (anger, sadness, happiness, disgust, surprise, fear) [36, 37], (2) Learning-centered emotions (confusion, frustration, boredom, anxiety, contempt, curiosity, eureka) [38, 35, 26, 31], and (3) the neutral state with no affective experience.

2 Methods

2.1 Participants

Participants were 41 undergraduate students and were paid $30 for their participation. There were 26 females and 15 males with 32 being Caucasians and nine being African-Americans. They were contacted through career services in order to reach out to those students who would be motivated to do well on graduate school standardized tests. Practice testing for graduate school standardized tests is provided twice a year through career services. Therefore, our sample represented motivated participants whose career goals heavily relied on their ability to solve logic problems in order to perform well on the standardized test and gain admission into law school.

2.2 Manipulation

We experimentally manipulated feedback in order to induce emotional expressions. Feedback was manipulated so that incorrect feedback was provided for approximately 25% of the responses (i.e. providing negative feedback to correct responses and vice versa).

2.3 Procedure

Participants signed an informed consent after they entered the lab. Participants were then instructed that they would be solving 28 logic problems and would be paid two dollars for each correct answer. All stimulus material was displayed on a Tablet PC. The left half of the screen was occupied with a customized program (See Figure 1) that: (A) displayed each problem scenario, (B) asked a specific question pertaining to the scenario, (C) displayed a set of alternatives, (D) allowed participants to select an answer, (E) let participants finalize their choice by clicking next, and (F) provided feedback ("Correct", or "Incorrect"). Effectively solving these logic problems requires a considerable amount of knowledge representation, drawing diagrams, and other related activities. Participants used a software application, Windows Journal™, to take notes and draw. The Windows Journal program was displayed on the right half of the screen (Figure 1).

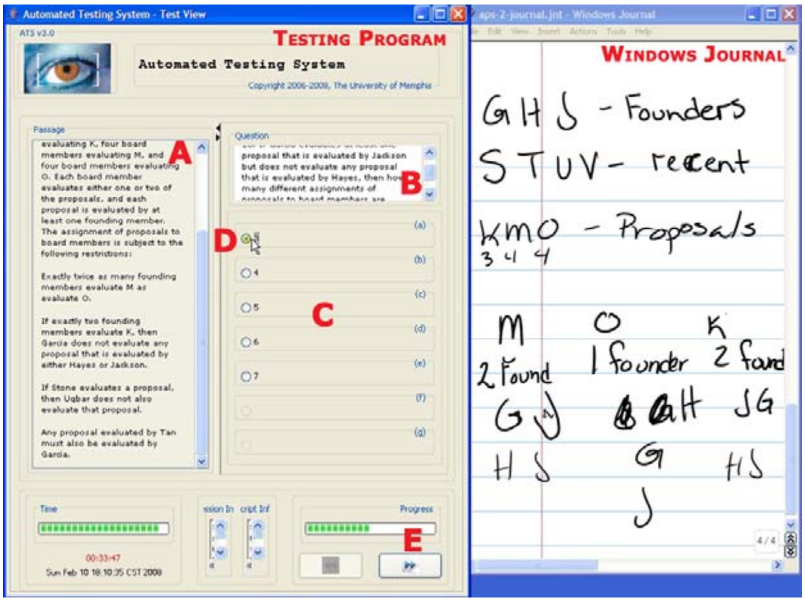

Figure 1. Annotated screen shot of problem solving environment

The experimenter left the room after demonstrating the software interfaces to the participants. Participants interacted with the system for approximately 35 minutes. Although participants were required to solve 28 problems, on average they only solved 19 problems in the allotted time. Therefore the mean completion rate was 67.5% (*SD* = 18.8). Two streams of information were collected during the interaction session. First, the participants face was recorded with a commercial webcam. The recording also included speech and other audio generated during the interaction. A video of the participants screen was also recorded using a commercially available screen capture program (Camtasia Studio™).

Participants were given a 5 minute break after the problem solving phase of the experiment. They then participated in a retrospective emotion judgment protocol [35,26]. The procedure began by synchronizing and displaying the videos of the participants' face and screen that were captured during the interaction. Participants were provided with a list of affective states (anxious, confusion, boredom, contempt, curiosity, eureka, frustration, anger, disgust, fear, happiness, sadness, surprise, and neutral) and definitions and were then required to make affect judgments at pre-specified points when the videos automatically paused. These affect judgments points were: (a) seven seconds after a new problem was displayed, (b) halfway between the presentation of the problem and the submission of the response, and (c) three seconds after the feedback was provided. Furthermore, in addition to these three pre-specified points, participants were able to manually pause the videos and provide affect judgments at any time (voluntary judgments).

3 Results & Discussion

We performed a 3×14 factor repeated measures ANOVA on the proportions of emotions reported by participants. The factors in the ANOVA were *problem phase* with 3 levels (new problem, midpoint of a problem, and after feedback) and *emotion* with 14 levels. Voluntary affective judgments were analyzed separately and are not discussed here. The proportion scores for each participant were constrained to 1.0 within problem phase, so it is not meaningful to consider the main effects of problem phase. The main effect for emotion was statistically significant, $F(13, 520) = 30.989$, $MSe = .788$, $p < .001$, $\eta^2 = .437$, as was the problem phase × emotion interaction, $F(26, 1040) = 15.209$, $MSe = .059$, $p < .001$, partial $\eta^2 = .275$. Therefore, we performed follow-up analyses on the main effect for emotion and the problem phase × emotion interaction.

3.1 Proportion of Affective States that Occurred during Problem Solving (Emotion Main Effect)

Table 1 provides descriptive statistics for the various emotions experienced by the participants when averaged across the different phases in the problem. Bonferroni posthoc tests revealed the following pattern in the data ($p < .05$): (Confusion = Curious = Frustration) > Anger, Anxiety, Contempt, Disgust, Eureka, Fear, Sadness, and Surprise). Boredom and happiness fit this general pattern with a couple of minor exceptions (Boredom = Anxiety and Happiness = Anxiety = Contempt). Simply put, boredom, confusion, curiosity, frustration, and happiness were the major emotions that participants experienced during problem solving. Experiences of anxiety, contempt, eureka, anger, disgust, fear, sadness, and surprise were quite rare.

Table 1. Descriptives of Affective States during Problem Solving

Affective States								
Learning-Centered	**M**	**SE**	**Basic Emotions**	**M**	**SE**	**Non-Affect**	**M**	**SE**
Anxious	0.036	0.006	Anger	0.025	0.007	Neutral	0.317	0.037
Boredom	0.103	0.017	Disgust	0.03	0.006			
Confusion	0.085	0.01	Fear	0.008	0.004			
Contempt	0.028	0.008	Happiness	0.071	0.09			
Curiosity	0.121	0.02	Sadness	0.012	0.004			
Eureka	0.027	0.007	Surprise	0.032	0.006			
Frustration	0.107	0.012						
Sum	0.507		Sum	0.178				

It was enlightening to discover that curiosity was prominently experienced during the problem solving sessions. It would appear that LSAT problems seem to be a form of curiosity-inducing stimulus for participants. Berlyne [39] describes curiosity as a form of deliberate, exploratory behavior which could be expected to emerge in our study because the problems depict unique scenarios that are challenging, exciting, and fascinating and require an exploration of the problem space to arrive at a solution.

However, the same problems that elicit curiosity also have the potential to induce significant levels of frustration (see Figure 2). The high levels of frustration could be attributed to three factors. First we intentionally manipulated feedback, where correct answers were sometimes evaluated as being incorrect. This type of manipulation could cause the higher levels of frustration, but more detailed analyses would be required to confirm this hypothesis. The second potential cause of frustration would arise from the fact that participants were required to solve the problems under stressful time constraints [40]. Furthermore, analytical reasoning problems require a unique set of strategies (causal reasoning, inference generation, etc) that are quite different from traditional classroom activities. Taken together, difficult problems that require non-routine problem solving techniques, time-constraints, and incorrect feedback seem to be the recipe for frustration.

The results also substantiate several decades of research that extol the virtues of confusion in problem solving activities [1, 4, 29]. The high levels of confusion could be attributed to the fact that the problems were riddled with complications, salient contrasts, and other obstacles – all factors that put students in a state of cognitive disequilibrium where they are likely to experience confusion [1, 2, 3, 4]. Confusion is often accompanied by effortful cognitive activities as students try to problem solve and to arrive at a resolution, thus returning to a state of cognitive equilibrium. This can be considered to be a form of productive confusion that forces students to stop and think.

In summary, our results support the hypothesis that emotions play a prevalent role in problem solving because 68% of the sample points involved some sort of emotional expression. Neutral was only reported for 32% of the sampled points. However, these findings should be interpreted with a modicum of caution because our sampling procedure was not random. Instead, we focused on phases in the problem where an emotional expression could be expected. Our next analysis systematically examines the occurrence of the various emotions during the different phases in solving the problems. Nevertheless, the fact that these emotions did occur provides cues into the motivational levels of the participants. Participants were given a monetary incentive of two dollars for each question they answered correctly, which may have influenced their motivation beyond the preexisting desire to do well on an activity that is related to acceptance to graduate school. While monetary-related motivation manipulation may not directly occur in real world learning situations, many real world situations come with a host of other variables that contribute to the desire to be successful. Whether it is parental approval, completion of a class, or acceptance into college, the learning environment cannot be divorced from the realities of the outside world.

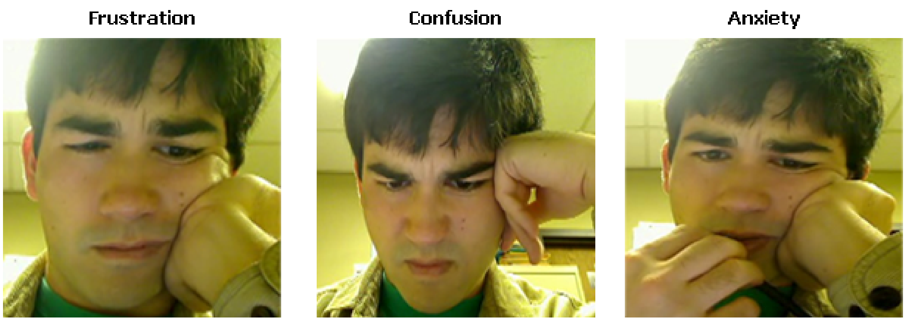

Figure 2. Examples of Affective States

3.2 Interaction of Affective State by Problem Phase

Participants were prompted to make affect judgments at specific points in the problem solving process. These points occurred at the beginning of a new problem, the midpoint of a problem, and after receiving feedback. Bonferroni posthoc tests on the problem phase × emotion interaction revealed several interesting patterns related to the extent to which participants experienced certain emotions at different points in the problem solving process. For simplicity, we restrict our discussion to the more prominent affective states observed. This includes boredom, confusion, happiness, frustration, and curiosity.

The results indicated that boredom was evenly distributed across all three judgment points. Learners' that experience boredom disengage from the active problem solving process. Hence, the different phases of the problem do not have any impact on their emotions. Confusion and curiosity displayed similar patterns of occurrence. These emotions were most frequently displayed in the midst of problem solving, followed by the presentation of a new problem. Experiences of confusion and curiosity were rare after feedback was provided. Our findings compliment earlier research that highlights the merits of confusion during problem solving and deep level learning [25, 35]. Curiosity has been described as "an internal state occasioned when subjective uncertainty generates a tendency to engage in exploratory behavior aimed at resolving or mitigating the uncertainty" [39, pp. 1]. From this description of curiosity, it follows that confusion and curiosity would develop during similar phases in this process. Both affective states are related to acknowledging a discrepancy in knowledge and working towards resolving that discrepancy.

Frustration and happiness were another pair of affective states with similar occurrence patterns. These states were most frequent after feedback was provided, then at the onset of a problem; but rarely occurring at the midpoint of a problem. These affective states seem to be complimentary to confusion and curiosity in that they occur *after* a resolution has been reached (i.e. feedback), as opposed to confusion and curiosity which occur *while* the learner tries to reach a resolution.

Table 2. Proportions of Affective States at Different Stages in Problem Solving

	Affective State									
	Boredom		**Confusion**		**Curiosity**		**Frustration**		**Happiness**	
Problem Phase	*M*	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*
Problem (P)	0.106	0.108	0.092	0.062	0.138	0.142	0.105	0.071	0.055	0.049
Midpoint (M)	0.115	0.108	0.135	0.126	0.186	0.202	0.071	0.081	0.012	0.03
Feedback (F)	0.089	0.146	0.029	0.054	0.038	0.067	0.146	0.142	0.144	0.123
Pattern	P = M = F		M > P > F		M > P > F		F > P > M		F > P> M	

3.3 Basic Emotions Compared with Learning-Centered Emotions

Ekman's [36] basic emotions have been the focus of the majority of emotion research over the last several decades. Although these emotions are ubiquitous to every day experience, several have called into question their relevance to complex learning [e.g. 35, 31]. Therefore, we conducted an analysis to determine the rate at which the basic emotions occur during problem solving. A paired sample t-test confirmed that the basic emotions ($M = .154$, $SD = .104$) occurred at significantly lower rates than the learning-centered emotions ($M = .535$, $SD = .180$), $t(40) = -11.761$, $p < .001$. This finding is on par with several previous studies [41, 30, 35, 26, 31, 42] that indicate that learning activities involve more complex cognitive-affective amalgamations than the six basic emotions [36].

3.4 Relationships between Affective States

We performed a follow-up analysis by correlating the proportionalized occurrences of the various affective states. Anxiety and confusion were positively related ($r = .32$, $p < .05$), indicating that learners who experienced confusion also experienced anxiety and vice versa. Boredom and frustration appear to have a negative relationship ($r = -.34$, $p < .05$), which is consistent with other findings when analyzing this dynamic in learning [43]. These results suggest three distinct student profiles, (a) the anxious and confused student, (b) the bored student, and (c) the frustrated student. Presumably the anxious and confused student is desirable over the frustrated student. Both profiles are preferred over the bored student because any intervention is rendered ineffective when the student disengages. In fact, recent evidence indicates that boredom is the least productive state to be in because episodes of boredom are negatively correlated with learning [25], prolonged [41], and frequently lead to non productive strategies like gaming the system [43].

4 Conclusion

The last decade has witnessed a surge in research activities that aspire to investigate the role of emotions in complex learning. We hope to have expanded this body of knowledge by identifying the affective states that occur during problem solving without the presence of another person to inhibit or influence the expression of emotion. Curiosity, boredom, frustration, confusion, and happiness were the most frequently occurring affective states. With the exception of boredom, the occurrence of these emotions is indicative of a high level of engagement with the material as well as an investment in the problem solving process. Our results also indicated that happiness was the only basic emotion to emerge at a significant level. This suggests that the affective experiences of students during problem solving activities involve more complex, learning-centered affective states.

Our findings represent an incremental step in understanding the nature of students' emotional experiences during problem solving activities. However, they have broader impacts as well. Tutoring in mathematics and science routinely involve periods of unsupervised problem solving. These effortful problem solving activities often involve failure and students get stuck, dispirited, and eventually disengage. There is no sterile deep learning environment that resonates with positive experiences alone. Therefore, our research can inform the development of ITSs that can sense these negative emotions and respond by offering hints to diffuse confusion, empathetic statements to alleviate frustration, motivational statements to avert anxiety, and novel challenges to offset boredom. These affect-sensitive interventions will fortify students with the necessary scaffolds that encourage perseverance to conquer failure and its resulting negative emotions and starting over with hope, determination, and even enthusiasm.

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