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# Dynamics of Student Cognitive-Affective Transitions During a Mathematics Game

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## Abstract

Researchers of interactive learning environments have grown increasingly interested in designing these systems to become more responsive to differences in students' cognitive-affective states. They believe that the detection of and adaptation to student cognition and affect may boost student learning gains and enhance the quality of students' overall learning experience. A growing body of research focuses specifically on the study of cognitive-affective dynamics, defined as the natural ways in which a student's cognitive-affective states change over time. These types of studies help designers identify desirable (virtuous) cycles that they want to foster and undesirable (vicious) cycles that they want to dissuade. In this study, the author examined the dynamics of the cognitive-affective states exhibited by Filipino students as they used the pre-algebra game MATH BLASTER 9-12. The author focused on the cognitive-affective states of boredom, confusion, delight, engagement, frustration, neutrality, and surprise. Using quantitative field observations, the author determined which of these states tended to persist or transition into other states over time. It was found that boredom was the only state that tended to persist. Boredom tended not to lead to engagement. Students who were confused were not likely to stay confused but were likely to transition into engagement. Students who were delighted were not likely to become confused. From these findings and based on comparisons with related work, it is concluded that boredom is a persistent and undesirable state. Confusion is not persistent and is desirable because it leads to further engagement with the content.

## Keywords

affect, boredom, cognition, cognitive-affective dynamics, confusion, delight, engagement, frustration, games, math, MATH BLASTER 9-12, mathematics, pre-algebra, surprise

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To capture students' attention and interest, teachers sometimes ask students to play educational games. Studies from as far back as the 1960s show that students find games more interesting than traditional methods of instruction (Randell, Morris, Wetzel, & Whitehill, 1992). The fantasy, sensory stimuli, challenge, mystery, and sense of control that games provide (Garris, Ahlers, & Driskell, 2002) foster a state of flow (Csikszentmihalyi, 1990; Paras & Bizzocchi, 2005), thereby increasing motivation, a mediator of time-on-task and learning (Vogel, Greenwood-Ericksen, Cannon-Bowers, & Bowers, 2006). Recent research has shown that, among grade school students learning geography, games increase intrinsic motivation, decrease extrinsic motivation, and increase achievement (Tuzun, Yilmaz-Soylu, Karakus, Inal, & Kizilkaya, 2009). Mechanical engineering students using games voluntarily spend more time on task, leading to deeper learning (Coller & Scott, 2009).

The use of games for education, however, is not without critique. Some games have been accused of pursuing motivation at the expense of learning (Lepper & Cordova, 1992). An overexposure to drill-and-practice games either as warm-up activities or as rewards sometimes leads students to undervalue them as primary modes of instruction (Bragg, 2007). Furthermore, although games can increase motivation in students in both genders (Papastergiou, 2009), they do so for different reasons. In a study of pre-school students using a math game, researchers found that boys tended to value winning and losing, while girls tended to value relationships among animated characters (Wei & Hendrix, 2009).

Despite these cautionary tales, games can be both motivating and educationally effective, particularly among less able students. Studies have shown that games are most beneficial when used by students with poor academic performance (Virvou, Katsionis, & Manos, 2005) or poor motivation (Rebolledo-Mendez, du Boulay, & Luckin, 2006). Games can even be used to develop the social skills in children with autism or other special needs (Griffiths, 2002).

At the crux of educational games' effectiveness is their ability to influence student cognitive-affective states. Hence, educational game researchers and developers have become increasingly interested in creating game environments that adapt to student affect. They believe that games that can detect and adapt to changes in student affect may become more effective at boosting student learning gains and the quality of students' overall learning experience. In 1979, Orbach suggested that studying the distribution of students' motivational profiles would enable simulation and game designers to write in-game character roles following that distribution. Players can then choose game roles that most closely match their personalities, thereby making a closer personal connection with the game. More recently, Conati and Klawe (2002) asserted that educational games can be made more effective by providing them with the ability to explicitly monitor affective states that are relevant to student learning—for example, boredom, frustration, and excitement. These systems could then generate calibrated interventions when necessary without interfering with the aspects of the game that make it fun.

Some empirical evidence supports the claim that maintaining student affect is beneficial to learning. Embodied agents that show empathy to frustrated users reduce the users' stress level (Predinger & Ishizuka, 2005). Rebolledo-Mendez et al. (2006)

provide evidence that motivational scaffolding—words of encouragement, for example—led students to exert more effort.

Building systems that can recognize student emotions is a complex task. Among other things, this undertaking requires extensive studies on the mapping between emotional states and the factors that may be used to detect them (Conati, 2002). To this end, studies use a variety of methods, including the use of biometrics sensor readings (see Conati, 2002), interaction logs (see Rebolledo-Mendez et al., 2006), and quantitative field observations (to be discussed in the Methodology section). These studies establish the baselines as well as biases for the creation of emotionally intelligent games.

Recently, a growing body of research focuses specifically on cognitive-affective dynamics, defined as the natural ways in which cognitive-affective states change over time. These types of studies can help designers identify desirable (virtuous) cycles—transitions that lead to greater learning—that they want to foster and undesirable (vicious) cycles—transitions that degrade learning—that they want to dissuade. Vicious cycles are of particular interest to educators as negative relationships or experiences may have a greater effect on decision making than positive experiences or relationships. Labianca and Brass (2006) refer to this phenomenon as negative asymmetry.

## Goals

In this pilot study, we use quantitative field observations to collect the cognitive-affective states exhibited by Filipino students as they used the pre-algebra game MATH BLASTER 9-12 (1997). In the analysis, we determined which of these states tended to persist or transition into other states over time. We ask whether certain cognitive-affective states tend to persist. Are students more likely to progress from one state to another? Are some transitions between states less likely to occur? We compare our findings with findings from earlier studies, reflect on the implications of these findings on the development of educational games, and suggest ways of extending this line of research in the future.

## Participant Profile

The research team that gathered the data for this study were the faculty and students of the Ateneo de Manila University, Quezon City, Philippines. For convenience, the study took place in the Ateneo de Manila University's Grade School, an all-boys school located in the same campus as the college. Four sections of seventh-grade boys participated in this study. Each section had 40 to 42 students, for a total of 164 participants. The average age of the participants was 12.8 years, and their modal age was 13 years. Each student was assigned to one laboratory computer.

The participants were asked to play MATH BLASTER 9-12, a set of pre-algebra drills embedded in an adventure game for 40 minutes. None of the students had prior experience with MATH BLASTER 9-12. All of them were computer savvy and regularly played video games. MATH BLASTER 9-12 was in English, but all the boys were fluent in the language.

## Description of the Game Environment

MATH BLASTER 9-12 was selected for five reasons:

1. Consultation with the math teachers of the targeted students indicated that this level of math was appropriate. We later found out from the students that the level was much too simple.
2. We needed a math game that had enough content to fill a 40-minute period.
3. We needed a math game that made use of features such as fantasy and sensory stimuli such as music and animation.
4. Budgetary constraints prevented us from purchasing more current games.
5. The extended trial version of MATH BLASTER 9-12 was available legally and free of charge from the Internet.

The scenario of the game is that a galactic commander is stranded on a planet of monkeys. To help the commander escape, the player has to collect medallions that the commander can then offer to the monkey king. In order to win the medallions, the player has to engage in pre-algebra games that require him or her to add, subtract, multiply or divide positive and negative whole numbers, decimals, or fractions.

The participants were asked to focus on three activities within the game: Crater Crossing (Figure 1), Banana Splat (Figure 2), and Bridge Builder (Figure 3). These activities were selected because they required the direct and immediate application of basic arithmetic operations.

1. In Figure 1, Crater Crossing, the participants had to jump on pods whose solutions ranged from  $-14$  to  $-1$ .
2. In Figure 2, Banana Splat, the participants have to throw a banana at the flying monkey carrying the number that completes the equation,  
$$-9 - -5 - \underline{\quad} = -13.$$
3. In Figure 3, Bridge Builder, participants had to complete a bridge by selecting the combination of fractions and decimals that add up to 1.

The students were not asked to play the two other games within MATH BLASTER 9-12, Monkey Maker and Cube Quest. Monkey Maker required students to build monkeys from available parts, within a limited number of moves. Cube Quest, on the other hand, involved traversing a maze by pushing buttons and switches in the correct order to open and close the appropriate doors. While both of these games used logic, the direct use of arithmetic was limited.

## Observation Methods

The observations were carried out by a team of eight observers, working in pairs (Figure 4). The redundancy enabled us to compute for the interrater reliability of the observations. The higher the level of agreement between observers, the more likely it

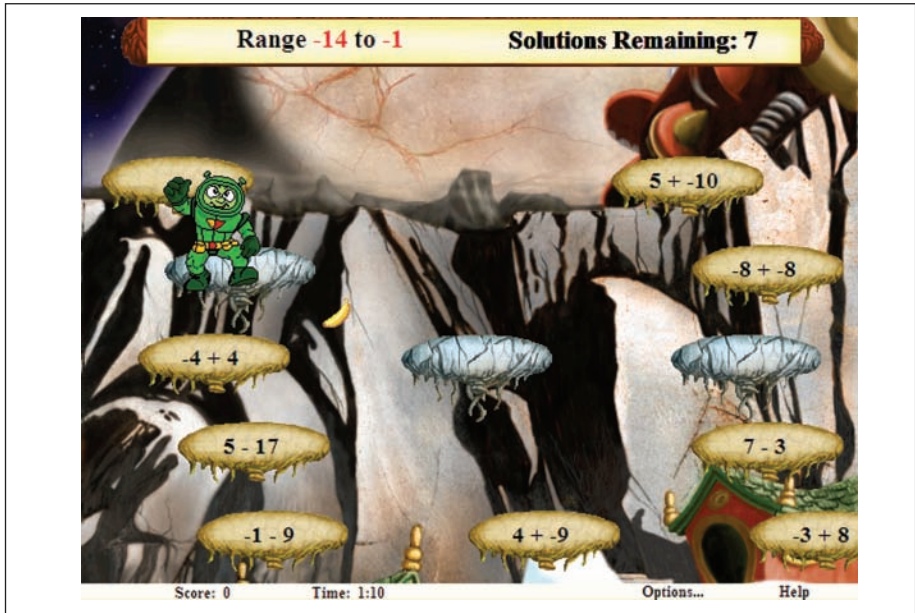


Figure 1. Crater crossing



Figure 2. Banana splat



**Figure 3.** Bridge builder

is that the observations they wrote down were an accurate reflected of the cognitive-affective state that the student exhibited.

The observers were master's students in education or computer science. Most had teaching experience. The observers trained for the task through a series of preobservation discussions on the meaning of the cognitive-affective categories and through an earlier observation exercise conducted at a different school. Observers were oriented with examples of actions, utterances, facial expressions, or body language that would imply an affective state. Furthermore, observers practiced the coding categories during a pilot observation period prior to this study.

Each pair of observers was instructed to observe 10 students in rotation. To elaborate: At the start of the observation period, both observers focused on the first student for a 20-second time period. After the 20-second time period, the observers moved on to the second student, recorded their observations, and so on. Once the observers completed the observation for the tenth student, they cycled back to the first student. Each student was observed once every 200 seconds.

During each 20-second period, each observer independently coded the student's cognitive-affective state. The cognitive-affective categories were drawn from D'Mello, Craig, Witherspoon, McDaniel, and Graesser (2005) and Rodrigo, et al. (2007):



**Figure 4.** Two observers at work

1. *Boredom*—slouching, and resting the chin on his palm, statements such as “Can we do something else?” and “This is boring!”
2. *Confusion*—scratching his head, repeatedly looking at the same interface elements, statements such as “I don’t understand?” and “Why didn’t it work?”
3. *Delight*—clapping hands or laughing with pleasure, statements such as “Yes!” or “I got it!”
4. *Engagement*—immersion and focus on the system, a subset of the flow experience described in Csikszentmihalyi (1990), leaning toward the computer or mouthing solutions to himself while solving a problem.
5. *Frustration*—banging on the keyboard or pulling at his hair, statements such as “This is annoying!” or “What’s going on?!?”
6. *Surprise*—jerking back suddenly or gasping, statements such as “Huh?” or “Oh, no!”
7. *The Neutral state*—when the student did not appear to be displaying any of the cognitive-affective states above, or the student’s state could not be determined for certain.

If the student exhibits two or more distinct states during a 20-second period, the observers only coded the first state. To illustrate: Suppose that, at the start of the 20-second period, a student was asking a teacher or classmate for help with the software. At that point in time, the student is considered to be confused. If the student's problem is solved and he returns to work, he is considered to have transitioned into engagement. In cases such as these, only the first affective state, confusion, was recorded. We adopted this sampling technique to collect a uniform number of observations per student and to minimize sources of discrepancy and disagreement between observers.

It was essential for the observers to look at the same student at the same time so that they perceived the same student actions, activities, and expressions. If they were looking at different students or if they were looking at the same student at different times, the student may already be exhibiting a different cognitive-affective state. To ensure synchronicity, a timed PowerPoint presentation cued the observers whenever they had to switch to another student.

Because we had four pairs of observers, only 40 of the 164 participants were observed. The students were chosen at random. They were not told who among them were under observation.

The data from one pair of observers were discarded because of interrater reliability issues. Therefore, for the subsequent analysis, we used only data from 30 students. The level of agreement among the remaining raters was acceptable, with Cohen's  $\kappa = .77$  (Cohen, 1960), indicating that they did not agree by chance.

## Results and Discussion

We collected 12 observations per observer for 30 students, for a total of 720 observations. We summarized these observations and compared them against results from three earlier studies that used the same methodology.

The first study (Rodrigo et al. 2007) made use of THE INCREDIBLE MACHINE (2001), a simulation problem-solving game. THE INCREDIBLE MACHINE presents users with problem scenarios—helping a mouse get to a block of cheese, funneling balls into a bin, and so on—which the user has to solve using a combination of tools that the scenario provides.

The second study (Rodrigo, Baker, et al. 2008) made use of Aplusix (Nicaud, Bouhineau, & Chaachoua, 2004), an intelligent tutoring system for algebra. Aplusix gives the users an algebra problem to solve. At each step of the solution, Aplusix indicates whether the user is correct or not.

The third study (Rodrigo, Rebolledo-Mendez, et al. 2008) made use of Ecolab (Luckin & du Boulay, 1999) and MEcolab (Rebolledo-Mendez, 2003). Ecolab is an intelligent tutoring system for ecology, teaching students about food chains and food webs. MEcolab is Ecolab with a motivational agent added. If the software detects that a student is becoming demotivated, MEcolab's agent appears, offering verbal encouragement.



**Table 1.** Incidence of Cognitive-Affective States While Playing MATH BLASTER

Affective State	MATH BLASTER
Boredom	22%
Confusion	2%
Delight	12%
Engagement	63%
Frustration	0%
Surprise	0%
Neutral	1%

### *Incidence of Affective States*

Table 1 shows that engagement (63%) was the most commonly observed cognitive-affective state. This finding is consistent with quantitative field observations conducted on THE INCREDIBLE MACHINE (2001; Rodrigo et al. 2007), Aplusix (Nicaud et al., 2004; Rodrigo, Baker, et al. 2008), Ecolab (Luckin & du Boulay, 1999; Rodrigo, Rebolledo-Mendez, et al., 2008) and MEcolab (Rebolledo-Mendez, 2003; Rodrigo, Rebolledo-Mendez, et al., 2008), in which engagement was to occur 62%, 68%, 61%, and 67% of the time, respectively.

The second most frequently observed state was boredom (22%). This is high compared with boredom observed in THE INCREDIBLE MACHINE (7%; Rodrigo et al., 2007), Aplusix (3%; Rodrigo, Baker, et al., 2008), Ecolab (15%; Rodrigo, Rebolledo-Mendez, et al., 2008), and MEcolab (12%; Rodrigo, Rebolledo-Mendez, et al. 2008). After the data were collected, the students told us that the game was too easy and that the math level of the game was simple for them. We suspect that this is why boredom was high.

Students using MATH BLASTER 9-12 exhibited delight 12% of the time. This percentage is again high compared with the delight observed in THE INCREDIBLE MACHINE (6%; Rodrigo et al., 2007), Aplusix (5%; Baker, D’Mello, Rodrigo, Graesser, 2010), Ecolab (3%; Rodrigo, Rebolledo-Mendez, et al., 2008), and MEcolab (4%; Rodrigo, Baker, et al. 2008b). The high incidence of delight may be attributed to the game format of the software we chose. MATH BLASTER 9-12 made use of animation, sounds, a storyline, and cartoon characters to engage the student. Aplusix, Ecolab, and MEcolab were content-heavy intelligent tutors, while THE INCREDIBLE MACHINE was heavily oriented toward problem solving. It is possible that MATHBLASTER 9-12’s use of media and fantasy were what invoked more delight.

Confusion and neutrality were relatively rare. Frustration and surprise were not observed at all.

### *Analysis of Cognitive-Affective State Transitions*

We now analyze how a student transitions from one state to another. In conducting these analyses, we take into account the base rates of each category. Engagement was

the dominant category within our observations; hence, engagement is likely to be the most common cognitive-affective state that follows any other cognitive-affective state. In order to appropriately account for the base rate of each cognitive-affective category in assessing how likely a transition is, we adopt D'Mello et al.'s (2005) transition likelihood metric,  $L$ . D'Mello et al.'s  $L$  gives the probability that a transition between two states will occur, given the base frequency of the destination state. Thus, if engagement occurred 70% of the time, then a 70% probability exists for any given cognitive-affective state to transition into engagement. If confusion transitions to engagement 70% of the time, the transition is no better than chance. If, however, confusion transitions to engagement 85% of the time, this transition may be significant.

$L$  is computed as follows:

$$L = \frac{\Pr(NEXT | PREV) - \Pr(NEXT)}{(1 - \Pr(Next))},$$

$L$  is scaled between 1 and  $-\infty$ . A value of 1 means that the transition will always occur; a value of 0 means that the transition's likelihood is exactly what it would be given only the base frequency of the destination state. Values above 0 signify that the transition is more likely than it could be expected to be given only the base frequency of the destination state, and values under 0 signify that the transition is less likely than it could be expected to be given only the base frequency of the destination state.

For a given transition, we calculate a value for  $L$  for each student and then calculate the mean and standard error across students. We can then determine if a given transition is significantly more likely than chance (0), given the base frequency of the next state, using the two-tailed  $t$  test for one sample.

In Table 2, horizontal rows represent previous cognitive-affective states, and vertical columns represent cognitive-affective states 180 seconds later. The first number in each cell is the mean value of D'Mello's  $L$  across students, the number in parenthesis is the standard error. Cells with insufficient sample size are left blank. Cells with heavy borders represent transitions that were statistically significant ( $p \leq .05$ ) or marginally significant ( $.05 < p \leq .10$ ). We found four significant transitions and one marginally significant transition. The overall pattern of significant and marginally significant transitions is unlikely to be due to chance ( $p = .03$ , computed using a 100,000-run Monte Carlo simulation; Metropolis & Ulam, 1949).

We found marginal significance to the likelihood that a student who is bored will stay bored 180 seconds later. A student who is bored is unlikely to transition into engagement 180 seconds later. A student who is confused is not likely to remain confused. He is, however, likely to transition into engagement. Finally, a student who is delighted is not likely to transition into confusion.

Boredom's vicious cycle was a finding that is consistent with quantitative field observations conducted in THE INCREDIBLE MACHINE, Aplusix, and Autotutor (Baker et al., 2010), as well as findings from Ecolab and MEcolab (Rodrigo, Rebolledo-Mendez, et al., 2008). This implies that boredom is a truly undesirable

**Table 2.** The Transitions Between Cognitive-Affective States

	BOR	CON	DEL	ENG	FRU	SUR
BOR	0.16 (0.09), $p = .07$	-0.01 (0.01), $p = .47$	0.08 (0.08), $p = .31$	-0.48 (0.19), $p = .01$		
CON	-0.16 (0.11), $p = .18$	-0.02 (0.00), $p < .01$	-0.09 (0.05), $p = .11$	0.63 (0.25), $p = .03$		
DEL	-0.02 (0.09), $p = .84$	-0.02 (0.00), $p < .01$	0.15 (0.10), $p = .16$	-0.22 (0.25), $p = .40$		
ENG	-0.02 (0.04), $p = .63$	-0.01 (0.01), $p = .42$	-0.01 (0.03), $p = .70$	0.10 (0.09), $p = .24$	0.00 (0.00), $p = .67$	
FRU						
SUR						
NEU						

Note: BOR = boredom; CON = confusion; DEL = delight; ENG = engagement; FRU = frustration; SUR = surprise. The first number in each cell is the mean value of D'Mello's  $L$  across students, the number in parenthesis is the standard error.

state. Even games such as MATH BLASTER and THE INCREDIBLE MACHINE have a hard time transitioning the student out of boredom and into a more productive state such as engagement.

A student who is confused is not likely to stay confused. Rather, he is likely to transition into engagement. This finding supports, to some extent, the findings of Craig, Graesser, Sullins, and Gholson (2004), which show a correlation between confusion and achievement. This finding also has implications on the game's ability to help students maintain a state of flow (Csikszentmihalyi, 1990). Flow is a cognitive-affective state characterized by the free investment of psychic energy into chosen goals. Flow is characterized by total immersion in an activity, to the point that the person loses his or her sense of time. For flow to occur, the person must experience an optimal balance of challenge and skill. The balance creates an opportunity to achieve higher levels of performance and contributes to personal growth. If a task is too challenging, the person may experience anxiety or frustration. If a task is too simple, the person may experience boredom. Confusion as experienced by the students in our sample seems to be a positive state because it does not transition to frustration or boredom. Rather, it leads to further engagement with the game.

The fact that engagement was not persistent implies that MATHBLASTER 9-12 does not provide students with a sustained flow experience. It is possible that boredom was persistent because of the lack of challenge as a whole. On occasions when students were challenged, they experienced a form of confusion that we consider to be positive because it helped them transition into engagement. If the level of challenge was inappropriate, observers would have noted more frustration.

## Conclusion

Researchers, educators, and educational game designers are constantly looking for ways to engage students in learning tasks. Games are one of the tools frequently employed to bring students to cognitive-affective states conducive to learning, one of increased motivation, interest, and engagement.

As we examined the dynamics of students' cognitive-affective states as they use the math game MATH BLASTER 9-12, we found that games do still fall into at least one trap that seems to be common among other types of educational software—the persistence of boredom. Transitioning a student out of boredom and into more educationally productive states is a challenge even for game formats. We found that confusion is a positive state. It does not persist, but, rather, it leads to the desirable state of engagement.

This study suffers from several limitations. First, the game was too simple for the target population. If a more challenging game was selected, the cognitive-affective dynamics of the students might be different. Second, out of convenience, we only sampled teenaged boys. A study with girls or adults might yield different results. Third, we used a game specifically for math. A game for other subject areas such as science, history, or language might yield different results. Finally, we relied on human observations for data collection. Although our observers' level of agreement was acceptable, it was still possible that they agreed on an erroneous definition of a cognitive-affective

state. Future studies may adopt more accurate, automated techniques of data collection, such as the use of face recognition software or biometrics such as galvanic skin response devices or brain-computer interfaces.

Despite these limitations, evidence from this study supports the notion that future generations of adaptive educational games should be sensitive to cognitive-affective states and their naturally occurring transitions. Adaptive games can capitalize on this base knowledge, designing interactions that encourage the persistence of desirable states, disrupting undesirable states and leading learners from an undesirable state to one that is more conducive to learning. Additional studies have to be undertaken to determine how exactly games can provide these adaptations and what forms these adaptations will take. Future learning games might vary difficulty levels, help levels, or problem scenarios in response to what they conclude to be the students' cognitive-affective state. Following Orbach's (1979) suggestion, games might also vary character personalities and roles to suit individual preferences better. Embodied agents might also be able to provide empathy or motivational support, taking roles of partners or mentors. In all likelihood, these interventions will vary from game to game, possibly taking into account the cultural differences among educational game users.

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