Affective Computing in Intelligent Tutoring Systems

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Learning inevitably involves failure and a host of positive and negative affective states.

“The extent to which emotional upsets can interfere with mental life is no news to teachers. Students who are anxious, angry, or depressed don’t learn; people who are caught in these states do not take in information efficiently or deal with it well.”

- Daniel Goleman, Emotional Intelligence

How do emotions impact learning?
Although the last four decades of research has provided valuable insights into the cognitive and motivational processes that underlie learning, relatively little is known about the influence of affective processes in modulating learning at deeper levels of comprehension.

However, the affective link is critical because affective processes such as appraisal, expression, and regulation are inextricably bound to cognitive and metacognitive processes and have an impact on learning.

The importance of affect is further elevated in problem solving activities because solving problems in mathematics and science is inevitably accompanied by the natural steps of making mistakes and recovering from them.

Failure and success in problem solving are accompanied by corresponding sets of negative and positive emotions depending on the individuals’ affective traits, skills, knowledge, and goals.

Simply put, the importance of emotions during problem solving cannot be underestimated because student affective states can impede or facilitate the problem solving process, as well as engender different modes of thinking.
Student Affective States When Learning


Only the affective states of confusion, happiness, anxious, and frustration occurred at significant levels

<table>
<thead>
<tr>
<th>Affective States</th>
<th>Non-Basic Emotions</th>
<th>Mean</th>
<th>Stdev</th>
<th>Basic Emotions</th>
<th>Mean</th>
<th>Stdev</th>
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</thead>
<tbody>
<tr>
<td>Confusion</td>
<td>0.38</td>
<td>0.19</td>
<td></td>
<td>Anger</td>
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<td>0.01</td>
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<tr>
<td>Frustration</td>
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<td>0.04</td>
<td></td>
<td>Fear</td>
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<td>0.00</td>
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<tr>
<td>Anxious</td>
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<td>Sadness</td>
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<tr>
<td>Contempt</td>
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<td>0.04</td>
<td></td>
<td>Disgust</td>
<td>0.01</td>
<td>0.04</td>
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<tr>
<td>Eureka</td>
<td>0.01</td>
<td>0.03</td>
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<td>Happiness</td>
<td>0.29</td>
<td>0.22</td>
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<tr>
<td>Curiosity</td>
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<td>0.02</td>
<td></td>
<td>Surprise</td>
<td>0.02</td>
<td>0.03</td>
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<td>Sum</td>
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<td></td>
<td></td>
<td>Sum</td>
<td>0.32</td>
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<table>
<thead>
<tr>
<th>Engagement Levels</th>
<th>Mean</th>
<th>Stdev</th>
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<tbody>
<tr>
<td>Disengagement</td>
<td>0.00</td>
<td>0.01</td>
</tr>
<tr>
<td>Socially Attending</td>
<td>0.23</td>
<td>0.18</td>
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<tr>
<td>Actively Attending</td>
<td>0.77</td>
<td>0.18</td>
</tr>
<tr>
<td>Full Engagement</td>
<td>0.00</td>
<td>0.00</td>
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</table>
Possible emotions commonly seen in students learning STEM fields

Tutoring in mathematics and science routinely involves periods of unsupervised problem solving and the inevitable affective responses

<table>
<thead>
<tr>
<th>Axis</th>
<th>-1.0</th>
<th>-0.5</th>
<th>0</th>
<th>+0.5</th>
<th>+1.0</th>
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<tbody>
<tr>
<td>Anxiety-Confidence</td>
<td>Anxiety</td>
<td>Worry</td>
<td>Discomfort</td>
<td>Comfort</td>
<td>Hopeful</td>
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<tr>
<td>Boredom-Fascination</td>
<td>Ennui</td>
<td>Boredom</td>
<td>Indifference</td>
<td>Interest</td>
<td>Curiosity</td>
</tr>
<tr>
<td>Frustration-Euphoria</td>
<td>Frustration</td>
<td>Puzzlement</td>
<td>Confusion</td>
<td>Insight</td>
<td>Enlightenment</td>
</tr>
<tr>
<td>Dispirited-Encouraged</td>
<td>Dispirited</td>
<td>Disappointed</td>
<td>Dissatisfied</td>
<td>Satisfied</td>
<td>Thrilled</td>
</tr>
<tr>
<td>Terror-Enchantment</td>
<td>Terror</td>
<td>Dread</td>
<td>Apprehension</td>
<td>Calm</td>
<td>Anticipatory</td>
</tr>
</tbody>
</table>

**Figure 1 – Emotion sets possibly relevant to learning**

Top half
Student ideally begins in Quadrant I or II. Might be curious (Quadrant I) or puzzled and motivated to reduce confusion (Quadrant II).

E.g. Programming a simulation: student gets idea of solution implementation and builds answer.

But she runs the simulation and it fails… some part of her idea needs to be deconstructed...

Lower half - Quadrant III
Emotions may be negative, cognitive focus changes to eliminating some misconception.

As she consolidates her knowledge with what does and does not work, student may move into Quadrant IV.

Getting a fresh idea propels student back into upper half of the space, most likely Quadrant I.

Thus, a typical learning experience involves a range of emotions, moving the student around the quadrants as she learns.

Third axis could be included – extending out of the plane (z axis) – Knowledge Axis. Dynamics of moving from Quadrant I to II to II to IV as an orbit – third dimension, obtain a spiral with evolving knowledge.

But what adaptations?

Quadrant I: a learner is happily engaged in exploratory learning and/or discovery learning, there needs to be little or no intervention (short of ensuring that all the resources that the learner will need are present and accessible as they are needed).

But what adaptations?

Quadrant II: where a learner is beginning to encounter difficulties arising from a misconception or an incomplete understanding, the intervention must serve the purpose of helping the learner recognize and identify the gaps and errors in his or her mental model.
E.g. subtle to give-away hints, questioning to direct diagnosis. Not let learner be crestfallen.

But what adaptations?

Quadrant III: where the learner has recognized and acknowledged that they had been working from an erroneous or incomplete model, the intervention focuses on providing the emotional support required to survive and emerge from the disappointment, anger, anguish, and self-doubt.

Some learners require more emotional support than others. Quadrant III is the most challenging and uncertain. Need to keep moving. Point at which most students give up.

But what adaptations?

Quadrant IV: learner has ‘gone back to the drawing board’ to construct an improved understanding of subject. Needs inquiry methods, hints, and direct teaching.

Breakthrough back into Quadrant I with fresh insight and idea – may need acknowledgement ritual to celebrate progress or success – to fuel and recharge learner for the next journey around the loop.

But what are the consequences of affective feedback on students?

Negative consequences of poorly selected feedback strategies and contrast these with the positive effects that stand to be gained from appropriate support strategies.

Figure 1. Directed graph representation of significant excitatory transitions. Circular nodes represent affective states. Diamond shaped nodes represent problem solving outcome states (i.e. combination of participant response and system feedback). PP = correct response + positive feedback, NN = incorrect response + negative feedback, PN = correct response + negative feedback, and NP = incorrect response + positive feedback.
On the positive front, affective states such as eureka and happiness are experienced when a correct answer receives the expected positive feedback (PP).
Providing positive feedback to an incorrect answer (NP) is met with the expected surprise. However, in addition to surprise, more visceral negative reactions such as frustration and sadness are evoked when a correct answer received negative feedback (PN).
Affective states that are antecedents to problem solving outcomes:

Boredom and curiosity share antithetical relationships with respect to how they influence problem-solving outcomes.

Boredom inhibits performance while curiosity facilitates performance.

Anxiety causes a form of performance paralysis with a negative impact that is similar to boredom.

Additionally, as could be expected, the eureka experience positively facilitates problem solving.

It is illuminating to note that frustration does not appear to have negative effects like boredom and anxiety, further substantiating the notion that it is boredom and not frustration that is the most detrimental to learning [10].
Confusion

• Confusion is often accompanied by effortful cognitive activities as students try to problem solve and to arrive at a resolution (Confusion → PP link). But confusion also has a less attractive form, where learners are unable to achieve a resolution. This form of unresolved confusion is linked to negative outcomes (Confusion → NN link).
Boredom

It appears that bored students have the potential to get trapped in a vicious cycle of boredom, negative responses, and negative feedback (Cycle 1). Bored students disengage to an extent where any external stimulation is ineffective in alleviating their ennui.
Curiosity

Virtuous cycle spawned by curiosity (Cycle 2). Curiosity is a state that is closely related to interest, and is a form of deliberate exploratory behavior that leads to a correct response and the associated positive feedback and happiness. The happiness further excites curiosity and the positive cycle continues.
Cycles of confusion

Students attempt to alleviate their confusion by deliberation, problem solving, and other effortful cognitive activities. However, the outcome of these cognitive activities is uncertain; confusion can either be resolved or unresolved.
Unresolved confusion leads to incorrect responses, negative feedback, and the inevitable frustration, and since the source of the confusion has not yet been resolved, the frustration eventually leads to more confusion (Cycle 3).
Resolved confusion

This occurs when confusion is followed by a correct response, which receives positive feedback. The students’ confusion temporarily dissipates to neutral but it might recur as the problem solving process continues (Cycle 4).
Interesting theory of confusion

Cycle 5: positive feedback for confused students that submit incorrect responses temporarily alleviates their confusion, and students experience momentary happiness. This happiness has the potential of transitioning to curiosity, where students have the opportunity to enter the virtuous Cycle 2.
Interesting theory of confusion

Cycle 5: However, if the usual negative feedback were provided instead of the contradictory positive feedback, then students’ would be likely to end up in the negative Cycle 3. Although highly suggestive at this point, there might be some merits to temporarily providing contradictory feedback to nudge students towards more positive cycles. Of course, the contradiction needs to be eventually resolved so that learning is not compromised.
Low prior-knowledge students show a dramatic improvement ($p < .05; d = .71$) in learning gains from Session 1 to Session 2 when interacting with the supportive versus the regular AutoTutor. Learning gains between sessions remained approximately consistent for high prior-knowledge students ($p > .05$).

**Figure 4.** Trends in learning gains across sessions

**Possible adaptations**

<table>
<thead>
<tr>
<th>Student Model</th>
<th>Tutor Action</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Current Emotion</strong></td>
<td><strong>Feedback</strong></td>
</tr>
<tr>
<td>boredom, confusion, frustration</td>
<td>positive, neutral, negative</td>
</tr>
<tr>
<td><strong>Classification Confidence</strong></td>
<td>Empathetic and motivational statement</td>
</tr>
<tr>
<td>high or low</td>
<td>Next Dialogue Move</td>
</tr>
<tr>
<td>boredom, confusion, frustration</td>
<td>hint, pump, prompt, splice, assertion</td>
</tr>
<tr>
<td><strong>Previous Emotion</strong></td>
<td><strong>Facial Expression</strong></td>
</tr>
<tr>
<td>boredom, confusion, frustration</td>
<td>surprise, delight, compassion, skeptical</td>
</tr>
<tr>
<td><strong>Global Student Ability</strong></td>
<td><strong>Speech intonation</strong></td>
</tr>
<tr>
<td>high or low</td>
<td>pitch, intensity, speech rate, etc</td>
</tr>
<tr>
<td><strong>Quality of Current Answer</strong></td>
<td></td>
</tr>
<tr>
<td>high or low</td>
<td></td>
</tr>
</tbody>
</table>

*Fig. 2. Production rules to respond to learners’ affective and cognitive States*

Still, so much room for research and application for affective learning systems!