Unveiling the Power of Affect during Learning

ELIZABETH B. CLOUDE

PENN CENTER FOR LEARNING ANALYTICS, UNIVERSITY OF PENN
TAMPERE UNIVERSITY (FALL 2023)
What is affect?
Affect

- Feeling, mood, or emotion
- Affect encompasses multiple systems at multiple levels and at multiple time scales
- Signaling functions (Schwarz, 2012), pointing out gaps in knowledge (confusion)
  - Appraising events in terms of their value, goal relevance, and goal congruence (Izard, 2010)
Component process model

Emotion episode

- **interrelated, synchronized changes** in all or most components

- in response to evaluation of an external or internal stimulus

- relevant to major concerns of the individual

<table>
<thead>
<tr>
<th>Emotion function</th>
<th>Organismic subsystem and major substrata</th>
<th>Emotion component</th>
</tr>
</thead>
<tbody>
<tr>
<td>Evaluation of objects and events</td>
<td>Information processing (CNS)</td>
<td>Cognitive component (appraisal)</td>
</tr>
<tr>
<td>System regulation</td>
<td>Support (CNS, NES, ANS)</td>
<td>Neurophysiological component (bodily symptoms)</td>
</tr>
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<td>Preparation and direction of action</td>
<td>Executive (CNS)</td>
<td>Motivational component (action tendencies)</td>
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<td>Communication of reaction and behavioral intention</td>
<td>Action (SNS)</td>
<td>Motor expression component (facial and vocal expression)</td>
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<td>Monitoring of internal state and organism–environment interaction</td>
<td>Monitor (CNS)</td>
<td>Subjective feeling component (emotional experience)</td>
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*Note: CNS = central nervous system; NES = neuro-endocrine system; ANS = autonomic nervous system; SNS = somatic nervous system.*
Component process model

The **process** consists of the coordinated changes over time.
Valence

UNIDIMENSIONAL

positive

negative
Model of Affective Dynamics

(D'Mello & Graesser, 2012)

Model of Affective Dynamics

- Valence
- Temporal dimension

(D'Mello & Graesser, 2012)

<table>
<thead>
<tr>
<th>Affect sequence</th>
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<tr>
<td>Engagement → confusion → delight → engagement</td>
<td>The student has fully resolved the source of confusion and returned to working on the task</td>
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<td>Confusion → delight</td>
<td>The student recently resolved the source of confusion, but has not yet returned to engagement with the task</td>
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<td>Confusion → frustration</td>
<td>The student became frustrated after not resolving the source of confusion, but has not disengaged</td>
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<td>Engagement → confusion → frustration → boredom</td>
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Empirical does not match theoretical

- Lee et al (2011)
- D'Mello et al. (2014)
- Andres et al. (2019)
- Karumbiah et al. (2022)
Challenges

• Methodological
  ○ Typically rely on interval data
  ○ Need for fine-grain and continuous data on multiple affective dimensions

• Analytical
  ○ Model dynamically
Leading Questions

How to measure affect as a dynamic process?

How to model affect as a dynamic process?
Affective Dynamics and Cognition with Crystal Island

Game-based learning environments foster emotional engagement via mechanics to enhance learning (Clark & Tanner-Smith, 2016; Plass et al., 2020)

RQ: Are there dynamic relationships between time expressing frustration, confusion, and neutral states and time engaging in scientifically reasoning?

Methods

Sample of 78 Undergraduates (67% females)
- Age: 20 years
- 69% White
- 71% played 0-2 hrs of video games/week

Random assignment to the full (n=62), restricted (n=16), no agency
- Restricted agency: 78 mins
- Full agency: 81 mins
Scientific reasoning:

- Time engaging in scientific reasoning = overlap in
  - Eye gaze fixations using Areas of Interest
  - Log file interaction with game elements (Cloude et al., 2020)

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<tr>
<th>Variables</th>
<th>Data channels</th>
<th>Game elements</th>
</tr>
</thead>
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<tr>
<td>Action 1: gathering information</td>
<td>Timestamped log files and eye fixations</td>
<td>Reading books, research articles, and posters; talking to NPCs.</td>
</tr>
<tr>
<td>Action 2: hypothesis generation</td>
<td>Timestamped log files and eye fixations</td>
<td>Backpack, food items, first field in the diagnosis worksheet.</td>
</tr>
<tr>
<td>Action 3: experimental testing</td>
<td>Timestamped log files and eye fixations</td>
<td>Final diagnosis field on the worksheet, concept matrix, and scanner.</td>
</tr>
</tbody>
</table>

Data Coding and Scoring (2)

Emotions:
- Time expressing confused, frustrated or neutral states
  - AUs via iMotions
  - Facial landmarks deviated from baseline (neutral)
- Confused
- Frustrated
- Neutral
Statistical Analysis

Multi-level Growth Model
- Fixed term - between-subject variability
- Random term - within-subject variability

Two-level growth models:
- Level 1: within-individuals (15,882)
- Level 2: between-individuals (78)
  - Pre-test scores
  - Agency condition
  - Action

Unconditional Models:
\[ Y_{ij} = \lambda_{00} + \lambda_{01} (Time)_{ij} + \sigma_{0j} + \sigma_{1j} (Time)_{ij} e_{ij} \]  

where \( Y_{ij} \) describes the outcome variable (e.g., time scientific reasoning), \( \lambda_{00} \) and \( \lambda_{01} \) are, respectively, mean initial status and average growth rate. The symbols \( \sigma_{0j}, \sigma_{1j}, \) and \( e \) represent, respectively, residual variance in initial status, residual variance in growth rate, and within-person residual variance.

Condition Models:
\[ Y_{ij} = \lambda_{00} + \lambda_{01} (Time) + \lambda_{02} (Action) + \ldots \]  

where \( Y_{ij} \) represents the outcome variable (e.g., time scientifically reasoning). \( \lambda_{00} \) and \( \lambda_{1j} \), respectively, represent the average initial status and average growth rate for predictors. Symbols \( \sigma_{0j}, \sigma_{1j}, \) and \( e_{ij} \), represent, respectively, residual variance at initial status, residual variance in growth rate, as well as within-individual residual variance.
Are there dynamic relationships between time expressing frustrated, confused, and neutral states and scientifical reasoning?

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<tr>
<th>Variable</th>
<th>Frustration</th>
<th>Confusion</th>
<th>Neutral</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Fixed effects</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mean initial status</td>
<td>114.07 (27.13)</td>
<td>140.38 (21.11)</td>
<td>92.59 (29.43)</td>
</tr>
<tr>
<td>Mean growth rate</td>
<td>-0.05* (0.01)</td>
<td>-0.05* (0.01)</td>
<td>-0.05* (0.01)</td>
</tr>
<tr>
<td><strong>Emotion duration</strong></td>
<td>0.32* (0.05)</td>
<td>0.26* (0.03)</td>
<td>0.40* (0.05)</td>
</tr>
<tr>
<td>Action(_1)</td>
<td>-115.30 (4.54)</td>
<td>-116.37 (3.77)</td>
<td>-114.38 (1.93)</td>
</tr>
<tr>
<td>Action(_2)</td>
<td>-84.19 (2.93)</td>
<td>-84.78 (4.11)</td>
<td>-83.57 (2.25)</td>
</tr>
<tr>
<td>Action(_3)</td>
<td>-116.41 (12.58)</td>
<td>-117.03 (7.03)</td>
<td>-114.84 (5.35)</td>
</tr>
<tr>
<td>Pre-test scores [Level 2]</td>
<td>-65.89 (50.04)</td>
<td>-93.00 (38.86)</td>
<td>-53.84 (53.39)</td>
</tr>
<tr>
<td>Experimental condition(_1)</td>
<td>-50.31 (15.76)</td>
<td>33.03 (12.63)</td>
<td>-4.94 (16.28)</td>
</tr>
</tbody>
</table>

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<tr>
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<tr>
<td><strong>Random effects</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Within-individual</td>
<td>53.41</td>
<td>53.55</td>
<td>53.31</td>
</tr>
<tr>
<td>Initial status</td>
<td>82.31</td>
<td>62.89</td>
<td>97.66</td>
</tr>
<tr>
<td>Growth rate</td>
<td>0.05*</td>
<td>0.04</td>
<td>0.05*</td>
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<td>0.40*</td>
</tr>
<tr>
<td>Action(_1)</td>
<td>37.55</td>
<td>30.18</td>
<td>10.51</td>
</tr>
<tr>
<td>Action(_2)</td>
<td>22.10</td>
<td>33.67*</td>
<td>14.53</td>
</tr>
<tr>
<td>Action(_3)</td>
<td>110.29</td>
<td>60.68*</td>
<td>45.35</td>
</tr>
<tr>
<td>Deviance</td>
<td>172787</td>
<td>172672</td>
<td>172757</td>
</tr>
<tr>
<td>ICC</td>
<td>0.70</td>
<td>0.58</td>
<td>0.77</td>
</tr>
<tr>
<td><strong>Pseudo-R^2 (fixed effects)</strong></td>
<td>0.25</td>
<td>0.30</td>
<td>0.35</td>
</tr>
<tr>
<td><strong>Pseudo-R^2 (total effects)</strong></td>
<td>0.90</td>
<td>0.85</td>
<td>0.91</td>
</tr>
</tbody>
</table>

Note. *p < 0.05; Action\(_1\)=Information gathering, Action\(_2\)=Hypothesis generation, Action\(_3\)=Experimental testing
Key Takeaways

• More frustrated and confused predicted more engagement in scientific reasoning

• Within-subject variability explained large portion of outcome variable
  ○ Individual differences (e.g., values, goals)

• More prior knowledge predicted less engagement in scientific reasoning
  ○ May be moderated by confusion
Case Study: Modeling Confusion as a Non-linear Dynamical System
Adaptive Complex Systems theory
Nonlinear dynamical systems theory

Recurrence quantification analysis is a nonlinear time series analysis
- Sequential organization in a time-series

Embedding Parameters:
- Time delay = high-dimensional phase-space trajectory reconstruction (Takens, 1981)
- Radius = defines the window of recurrence plots
Sample

Sample of 80 participants
• Age = 20.12 (SD=1.57)
• 66% female

• Experimental design:
  ○ Random assignment: Full (n=51), Restricted (n=29)
  ○ Pre-test
  ○ Calibrated to Sensors
  ○ Gameplay
  ○ Post-test
Research Questions

- Do repetitive instances of confused facial expressions differ between full and partial agency conditions during game-based learning?

- Do repetitive instances of confused facial expressions relate to post-test scores while controlling for agency and pre-test scores?
Do repetitive instances of confused facial expressions differ between full and restricted agency conditions during game-based learning?

- Radius of .01 = smallest window

- A t-test revealed no significant differences in the rate of repetitive confused facial expressions between restricted ($M=1.46$) and full ($M=1.50$) agency conditions, $p=.3106$.

This suggests that learners expressed similar repetitive rates of confused facial expressions during game-based learning regardless of agency.
Do repetitive instances of confused facial expressions differ between full and restricted agency conditions during game-based learning?

Lowest RR%

Highest RR%
Do repetitive instances of confused facial expressions during scientific-reasoning actions relate to post-test scores while controlling for agency and pre-test scores?

Multiple linear regression

<table>
<thead>
<tr>
<th>Regression estimates of associations with post-test scores.</th>
<th>Beta</th>
<th>Std. Error</th>
</tr>
</thead>
<tbody>
<tr>
<td>Intercept</td>
<td>1.096*</td>
<td>0.244</td>
</tr>
<tr>
<td>Condition&lt;sub&gt;1&lt;/sub&gt;</td>
<td>-1.10*</td>
<td>0.335</td>
</tr>
<tr>
<td>Experimental Testing (Action 1)</td>
<td>0.558</td>
<td>0.299</td>
</tr>
<tr>
<td>Hypothesis Generation (Action 2)</td>
<td>0.622*</td>
<td>0.269</td>
</tr>
<tr>
<td>Information Gathering (Action 3)</td>
<td>0.347</td>
<td>0.296</td>
</tr>
<tr>
<td>Duration</td>
<td>0.002</td>
<td>0.001</td>
</tr>
<tr>
<td>Recurrence Rate of Confusion</td>
<td>-0.816*</td>
<td>0.165</td>
</tr>
<tr>
<td>Pre-test Scores</td>
<td>-0.551</td>
<td>0.430</td>
</tr>
<tr>
<td>Recurrence rate*Condition&lt;sub&gt;1&lt;/sub&gt;</td>
<td>1.228*</td>
<td>0.234</td>
</tr>
</tbody>
</table>

\[F = 68.91^*\]

\[Df = 31,48\]

Adjusted \(R^2 = 0.342\)

*Note.* *p < 0.05.*
Key Takeaways

- More recurring time expressing confusion was detrimental to post-test scores
- Positive interaction between restricted agency and confusion on post-test scores
- How to best determine the parameters of RQA
  - 2-5% for human systems (Webber & Zbilut, 2005)
  - Increase radius
- Multiple signals of confusion
Future Work

- Measure and model multiple dimensions of an emotion episode
Future Work

- Measure and model multiple dimensions of an emotion episode
Microlevel ← Neurophysiological | Cognitive Appraisal | Subjective Perceptions | Expression → Motivation → Confusion → Macrolevel

a) Single emotion component

Data: A time series of one system element.
Analysis: time series analysis, auto-recurrence quantification
Microlevel \hspace{2cm} \rightarrow \hspace{2cm} \text{Macrolevel}

- Neurophysiological
- Cognitive Appraisal
- Motivation
- Subjective
- Facial Expression
- Confusion

(a) Single emotion component

\textbf{Data}: A time series of one system element.
\textbf{Analysis}: time series analysis, auto-recurrence quantification

(b) Two emotion components

\textbf{Data}: Two time series of different system elements.
\textbf{Analysis}: co-occurrence network analysis; cross-recurrence quantification
a) Single emotion component

**Data:** A time series of one system element.
**Analysis:** time series analysis, auto-recurrence quantification

b) Two emotion components

**Data:** Two time series of different system elements.
**Analysis:** co-occurrence network analysis; cross-recurrence quantification

Facial expression

```
1 0 0 1 0 0
```

Heart Rate

```
1 0 0 1 0 1
```
a) Single emotion component

Data: A time series of one system element.
Analysis: time series analysis, auto-recurrence quantification

b) Two emotion components

Data: Two time series of different system elements.
Analysis: co-occurrence network analysis; cross-recurrence quantification

c) Several emotion components

Data: multiple time series of different system elements.
Analysis: dynamical modelling (e.g., fractal, wavelet, multidimensional recurrence quantification, multilevel growth model)
a) Single emotion component

*Data:* A time series of one system element.  
*Analysis:* time series analysis, auto-recurrence quantification

b) Two emotion components

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c) Several emotion components

*Data:* multiple time series of different system elements.  
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Thanks for your time!

ecloude@upenn.edu

Scan here for references!

gr.link/4JwMhz