Published in the Proceedings of Artificial Intelligence in Education Workshops (AI-ED), May 2001, San Antonio, Texas

External Representation of Learning Process and Domain Knowledge: Affective State as a Determinate of its Structure and Function

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ABSTRACT

We present a model of the generic learning process and associated metacognitive processes that aid efficient learning. These models can be used as internal representations of a learner's cognitive-emotive state while engaged in learning. They can also be used to present to the learner a representation of their progress in learning much like a coach or mentor might use to assist a student. These models and associated representations might be displayed alongside the primary external representation of the subject being learned or they might be integrated into it. The assessment of the metacognitive processes which shadow the primary learning process needs to be sensitive to the affective state of the learner. As the student proceeds through the learning journey, their affective state may cycle through a wide spectrum of emotions, which influence how efficiently, effectively, and enjoyably they succeed in the learning task. Based upon an understanding and application of our proposed model, the structure and function of external representations would reflect the learner's cognitive-emotive state. For example, some representations would provide copious hints that would accelerate the learning at the expense of the playfulness of the exercise, while other representations might transform the learning experience into an enthralling game. In particular these models enable the system designer to provide alternative intervention strategies for the learner who is laboring under a misconception, ranging from a no-nonsense remedial intervention to allowing the learner to play out their misconceptions in a free-wheeling simulation model that ultimately reveals the folly of their thinking.

INTRODUCTION

> The question is not whether intelligent machines can have emotions,
> but whether machines can be intelligent without any emotions.
>
> Marvin Minsky, *The Society of Mind*

Given new computational media such as virtual reality, dynamic animation, and wearable devices, the design of innovative learning environments, their structure, their functional features, and the educational pedagogy that underpins them opens challenging questions about their design and human factors.

While it is necessary to explore future directions for research in regard to external representations of knowledge domains and learning processes, our primary interest is to develop an understanding of the requisite educational pedagogy. This is necessary in order to answer such questions as: 'How intrusive should an intervention be and how extensive need a given external representation be,' or 'How do we manage the trade-off between the amount of information and the cognitive load of integrating multiple displays when learning from more than one representation?' It is also necessary to determine the nature of the external representation(s). Too much 'external representation' could distract a learner from the task at-hand if the learner is developing an appropriate understanding of the material, but if the learner is not developing a correct understanding a highly intrusive intervention may be in order to intentionally distract the learner and provide remedial information.

However, current educational pedagogy is lacking in certain areas and must be reengineered before it can serve as a useful foundation for determining the structure and function for external representation(s) of learning process, domain knowledge, and metacognitive aids. In the next section we present a novel theory of emotions and learning that suggests ways to improve the educational experience.

AFFECTIVE STATE: EMOTIONS AND LEARNING

> Do emotions contribute to intelligence, and if so, what are the implications for the development of a technology of affective computing?
>
> Robert Provine, *What Questions Are On Psychologist's Minds Today*?

In an attempt to reengineer the state of educational pedagogy, we should first look to expert teachers who are very adept at recognizing the emotional state of learners and, based upon their observation, taking appropriate action that positively influences learning. But what do these expert teachers *see* and how do they select a course of action? How do students who have strayed from *learning* return to a productive path, such as the one that Csikszentmihalyi [1990] refers to as the "zone of flow"?

Skilled human mentors can assess emotional cues with varying degrees of perception. Researchers are beginning to imbue computers with similar abilities to recognize affective cues [e.g., Picard, 2001; Scheirer, *et al*, 1999; Chen, *et al*, 1998; Donato, 1999; DeSilva, 1997; Ekman, 1997]. Although computers perform as well as or better than people in selected domains, they do not yet rise to human levels of mentoring. We envision that computers will soon become capable of recognizing human behaviors indicative of the user's affective state.

To this end it is necessary for us to rethink what is happening during learning and, based upon our hypothesis, reengineer accordingly. This supposition is based upon our own preliminary pilot studies, with elementary school children, suggesting that a human observer can assess the affective emotional state of a student with reasonable reliability based on observation of facial expressions, gross body language, and the content and tone of speech. If the human observer is also acting in the role of coach or mentor, these assessments can be confirmed or refined by direct conversation (e.g. simply asking the student if they are confused or frustrated before offering to provide coaching or hints). Moreover, successful learning (e.g. solving a difficult puzzle) is frequently marked by an unmistakable elation, often jointly celebrated with "high fives." In some cases, the "Aha!" moment is so dramatic, it verges on the epiphanetic. One of the great joys for an educator is to bring a student to such a moment of triumph.

Our first step is to offer a model of a learning cycle (Figures 1a and 1b) and later to describe a model of emotions (Figure 2) and ultimately to relate them into a single model. Figures 1a and 1b interweave the emotion axes shown in Figure 2 with the cognitive dynamics of the learning process. The horizontal axis in Figures 1a and 1b is an Emotion Axis. It could be one of the specific axes from Figure 2, or it could symbolize the *n*-vector of all relevant emotion axes (thus allowing multi-dimensional combinations of emotions). The positive valence (more pleasurable) emotions are on the right; the negative valence (more unpleasant) emotions are on the left. The vertical axis is what we call the Learning Axis, and symbolizes the construction of knowledge upward, and the discarding of misconceptions downward. Note: we do not see learning as being simply a process of constructing/deconstructing or adding/subtracting information; this terminology is merely a projection of one aspect of how people can think about learning. Other aspects could be similarly included along the Learning Axis.

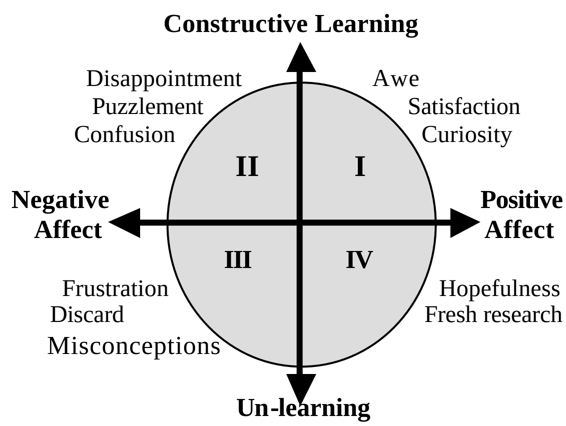

Figure 1a – Proposed model relating phases of learning to emotions in Figure 2

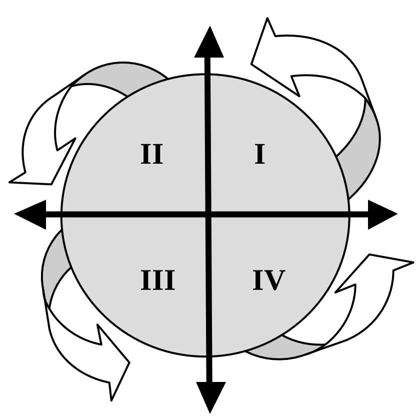

Figure 1b – Circular and helical flow of emotion

Axis -1. 0 -0. 5 0 +0. 5 +1. 0

Anxiety-Confidence	Anxiety	Worry	Discomfort	Comfort	Hopeful	Confident
Boredom-Fascination	Ennui	Boredom	Indifference	Interest	Curiosity	Intrigue
Frustration-Euphoria	Frustration	Puzzlement	Confusion	Insight	Enlightenment	Epiphany
Dispirited-Encouraged	Dispirited	Disappointed	Dissatisfied	Satisfied	Thrilled	Enthusiastic
Terror-Enchantment	Terror	Dread	Apprehension	Calm	Anticipatory	Excited

Figure 2 – Emotion sets possibly relevant to learning

The student ideally begins in Quadrant I or II: they might be curious and fascinated about a new topic of interest (Quadrant I) or they might be puzzled and motivated to reduce confusion (Quadrant II). In either case, they are in the top half of the space, if their focus is on constructing or testing knowledge. Movement happens in this space as learning proceeds. For example, when solving a puzzle in *The Incredible Machine*, a student gets an idea how to implement a solution and then builds its simulation. When she runs the simulation and it fails, she sees that her idea has some part that doesn't work – that needs to be deconstructed. At this point it is not uncommon for the student to move down into the lower half of the diagram (Quadrant III) where emotions may be negative and the cognitive focus changes to eliminating some misconception. As she consolidates her knowledge—what works and what does not—with awareness of a sense of making progress, she may move to Quadrant IV. Getting a fresh idea propels the student back into the upper half of the space, most likely Quadrant I. Thus, a typical learning experience involves a range of emotions, moving the student around the space as they learn.

If one visualizes a version of Figures 1a and 1b for each axis in Figure 2, then at any given instant, the student might be in multiple Quadrants with respect to different axes. They might be in Quadrant II with respect to feeling frustrated; and simultaneously in Quadrant I with respect to interest level. It is important to recognize that a range of emotions occurs naturally in a real learning process, and it is not simply the case that the positive emotions are the good ones. We do not foresee trying to keep the student in Quadrant I, but rather to help him see that the cyclical process is natural in learning, and that when he lands in the negative half, it is only part of the cycle. Our aim is to help them to keep orbiting the loop, teaching them how to propel themselves especially after a setback (metacognition—*learning how to learn* if you will).

A third axis (not shown), can be visualized as extending out of the plane of the page—the Knowledge Axis. If one visualizes the dynamics of moving from Quadrant I to II to III to IV as an orbit, then when this third dimension is added, one obtains an excelsior spiral when evolving/developing knowledge. In this diagram know as a phase plane plot, time is parametric as the orbit is traversed in a counterclockwise direction. In Quadrant I, anticipation and expectation are high, as the learner builds ideas and concepts and tries them out. Emotional mood decays over time either from boredom or from disappointment. In Quadrant II, the rate of construction of working knowledge diminishes, and negative emotions emerge as progress flags. In Quadrant III, the learner discards misconceptions and ideas that didn't succeed, as the negative affect runs its course. In Quadrant IV, the learner recovers hopefulness and positive attitude as the knowledge set is now cleared of unworkable and unproductive concepts, and the cycle begins anew. In building a complete and correct mental model associated with a learning opportunity, the learner may experience multiple cycles around the phase plane until completion of the learning exercise. Each orbit represents the time evolution of the learning cycle. Note that the orbit doesn't close on itself, but gradually moves up the knowledge axis.

Some of our ideas will be fashioned to 'theory,' perhaps beyond a practical level but not beyond a level needed for understanding them. We need to explore the underpinnings of various educational theories and evolve or revise them. For example, we propose a model that describes the range of various emotional states during learning (see Figure 2). We are in the process of performing empirical research on this model to gather data to validate our hypothesis. We are currently conducting several pilot research projects, which appear to support our hypothesis, and we will continue to conduct research in this area over the life of the project. Our initial research to validate the underlying model and to assess the capability of emotion recognition systems is reported in Kort, et al [2001]. Briefly, we are initially experimenting with some new technology in affective computing [Picard, 1997] to automatically track eye gaze and body movements. These are backed up by conventional camcorder recordings which are evaluated and coded by trained human observers. Our research also explores and addresses intervention strategies, not only as a function of the cognitive-emotive state of the learner, but also as a function of a learner's idiosyncratic learning style, as suggested by related research in the theory of learning orientations [Jones and Martinez, 2000; Martinez and Bunderson, 2001].

ADVANCING TECHNOLOGY: DEVELOPING AN 'ER'

> We have only begun to explore what are the appropriate scaffolds for promoting learning.
>
> Eliot Soloway, *Scaffolding Technology Tools to Promote Teaching and Learning in Science*

This model is inspired by theory often used to describe complex interactions in engineering systems, and as such is not intended to explain how learning works, but rather is intended to give us a framework for thinking about and posing questions about the role of emotions in learning. As with any metaphor, the model has limitations to its application. In this case, the model is not intended to fully describe all aspects of the complex interaction between emotions and learning, but rather only to serve as a beginning for describing some of the key phenomena that we think are all too often overlooked in learning pedagogy. This model goes beyond previous research studies not just in the emotions addressed, but also in an attempt to formalize an analytical model that describes the dynamics of emotional states during model-based learning experiences, and to do so in a language that the learner can come to understand and utilize.

External representations can fulfill a number of roles in artificial intelligence systems. One of those roles is to shadow the primary learning process with metacognitive models that aid the learner in diagnosing and remedying misconceptions that may arise in the course of learning. Another role is to transform the learning experience from a relatively dry academic presentation to one that is more engaging or enjoyable (perhaps even game-like). Thus the system representations may need to take into account the affective state of the learner, which varies through the learning journey and influences the efficiency, effectiveness, and enjoyability of the learning experience. Based upon an understanding and application of our proposed model of emotions and learning, the structure and function of external representations would reflect the learner's cognitive-emotive state. Thus some representations might provide copious hints that would accelerate the learning at the expense of reducing the playfulness of the exercise, while other representations might transform the learning experience into an enthralling game. In particular these models enable the system designer to provide alternative intervention strategies for the learner who is laboring under a misconception, ranging from a no-nonsense remedial intervention to allowing the learner to play out their misconceptions in a free-wheeling simulation model that ultimately reveals the folly of their thinking.

This material is based upon work supported by the National Science Foundation under Grant No. 0087768. Any opinions, findings, or conclusions or recommendations expressed in this material are those of the author(s) and does not necessarily reflect the views of the National Science Foundation.

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