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

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Abstract

External representations can fulfill a number of roles in artificial intelligence systems. But the external representations need to be sensitive to the affective state of the learner, which varies through the learning journey, and, in large measure, impacts how efficiently and effective a learner acquires and processes information/knowledge. Based upon an understanding of this model, the structure and function of external representations would vary according to a learner's affective state as opposed to the assumption that one-size-fits-all. For example, some representations would provide ubiquitous hints that would not interrupt the focus of a learner who is acquiring an accurate understanding, or, at the other end of the continuum, would provide distracting external representations designed to intentionally redirect the focus of a learner who is constructing incorrect knowledge.

1. Introduction

> 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*

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 open 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 correct information.

However current day 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 and domain knowledge.

But reengineering educational pedagogy is a non-trivial task. To justify change, it must be shown that past research or legacy research, which was based upon earlier technology or pencil and paper based tasks, is obsolete or irrelevant. For general educational pedagogy this is not a difficult task. We need only briefly review the metagoals of education/learning in our previous history.

In Colonial days schools were based upon ‘recitation literacy’ and from the World War I era forward schools were based upon ‘extraction literacy’ [Wolf, 1988]. However a major shift in the intellectual abilities has recently heightened the need for students of the new millennium to understand their state of their knowledge, to build upon it, to improve it, and to apply it appropriately. In short “[s]ociety envisions graduates of school systems who can identify and solve problems and make contributions to society through their lifetime—who display the qualities of ‘adaptive expertise’” [Bransford, 1999; also see Talbert and McLaughlin, 1993]. Thus contemporary theories view learning as a person’s ability to construct new knowledge based upon what they already know or believe to be true (e.g., Cobb, 1994; Piaget 1952, 1973a, b, 1977, 1978; Vygotsky 1962, 1978). In short, the ability to perform model-based reasoning, recursion, and cognitive assessment (metacognition) are critical elements in contemporary educational pedagogy.

Schools seem to be functioning as well as they ever have, however the challenges and expectations have dramatically changed [e.g., Bruer, 1995; Resnick, 1987]. This educational shift is critical when considering the need to redesign the delivery of education to a learner. These new goals require changes in the design of learning environments. However current learning theory “does not provide a simple recipe for designing effective learning environments” given these changing expectations [Branford, 1999]. “New developments in the science of learning raise important questions about the design of learning environments…[the] general characteristics of learning environments…need to be examined in light of new developments in the science of learning” [Bransford, 1999]. The basis of a model that will serve as a foundation for external representations should be embodied from such a mind-set—developing insightful model-based thinkers. It should recognize the affective and cognitive state of the learner and respond in an appropriate manner (e.g., modulate the pace, direction or complexity of the presentation).

2. 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 humans can assess emotional signals with varying degrees of accuracy, and researchers are beginning to make progress giving computers similar abilities at recognizing affective expressions [e.g., Picard, 2000; Scheirer, et.al., 1999] and from facial expressions [e.g., Donato, 1999; DeSilva, 1997; Ekman, 1997]. Although computers only perform as well as people in highly restricted domains, we believe that accurately identifying a learner’s cognitive-emotive state is a critical indicator that will determine how to assist the learner in appreciating an understanding of the efficiency and pleasure of the learning process. We also assume that computers will, much sooner than later, be more capable of recognizing human behaviors that afford strong inferences about affective state.

To this end it is necessary for us to rethink our perspective of 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 this model of emotions (Figure 2). 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.)

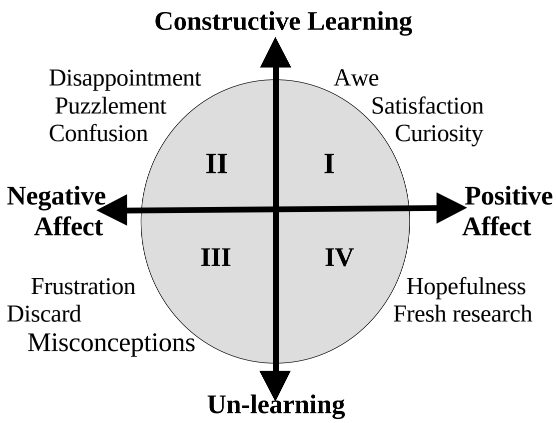

Figure 1a – Proposed model relating phases of learning to emotions in Figure 2

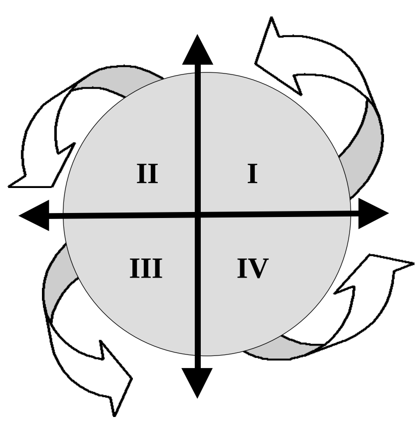

Figure 1b – Circular and helical flow of emotion

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	Ephipany
Dispirited-Encouraged	Dispirited	Disappointed	Dissatisfied	Satisfied	Thrilled	Enthusiastic
Terror-Enchantment	Terror	Dread	Apprehension	Calm	Anticipatory	Excited

-1. 0 **-0. 5** **0** **+0. 5** **+1. 0**

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 science, mathematics, engineering or technology (SMET), 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.

A third axis (not shown), can be visualized as extending out of the plane of the page—the Knowledge Axis. If one visualizes the above 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 the 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 pan out, as the negative affect runs its course ("good grief!"). 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 justify our hypothesis. We have conducted several pilot research projects, which appear to support our hypothesis, and we will continue to conduct research in this area.

3. Advancing Technology—Developing External Representations

> We have only begun to explore what are the appropriate scaffolds for promoting learning. We have also much to learn on how computational and communication technologies can support teacher collaboration and professional development .
>
> - Eliot Soloway, *Scaffolding Technology Tools to Promote Teaching and Learning in Science*

The above 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 SMET learner can come to understand and utilize.

External representations can fulfill a number of roles in artificial intelligence systems. But the external representations need to be sensitive to the affective state of the learner, which varies through the learning journey, and, in large measure, influences how efficiently and effective a learner acquires and processes information/knowledge. Based upon an understanding of this model, the structure and function of external representations would vary according to a learner's affective state as opposed to the assumption that one-size-fits-all.

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