Cognition, Affect\(^1\), and Learning

The Role of Emotions in Learning

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Emotional experiences are ubiquitous in nature and important and perhaps even critical in academic settings, as emotion modulates virtually every aspect of cognition.

– Chai M. Tyng, *The Influences of Emotion on Learning and Memory*

**Emotions in learning 101**

The concept of emotions (affect) in learning is closely related to the pedagogy that an athletic coach employs. A coach recognizes the emotional (affective) state of an athlete, and from that assessment, for example, exhorts that athlete toward increased performance (e.g., raises the emotional (affective) state of the athlete), or, redirects a frustrated athlete to a productive emotional (affective) state (e.g., confidence). A coach recognizes that an athlete’s emotional (affective) state is a critical factor in an athlete’s performance, then, when appropriate, intervenes with a meaningful strategy or tactic. Athletic coaches are very adept at recognizing affective states and dealing with them successfully.

**Educators can have the same impact on a learner** by understanding the learner’s emotional (affective) state and then applying an intervention strategy or tactic.

Compared to an athletic coach’s pedagogy, meaningfully managing a person’s affective state during an academic learning journey is far more complex and exists over a longer period of time. Merely identifying a person’s state during a learning journey is, unto itself, highly problematic, let alone initiating a meaningful intervention. For example, a learner may appear to be in a state of frustration, or, boredom, or cognitive assessment, which all typically present the same outward appearance. However, each state is very different and must be addressed with a different intervention. Frustration and boredom are affective states where an educator would intervene with very different tactics in-order to move the learner to a positive affective state, while a student performing cognitive assessment must be left alone as the learner is attempting to understand what was just ‘taught’.

**What** people learn, the contents of a given body of knowledge, is very well established, but such is not the case for **how** people learn, how they acquire knowledge, make decisions, and develop wisdom. Even though there has been research conducted in a number of fields in regard to various aspects of emotions (affect), still, that research has not addressed the overarching question of **how people learn**, in other words, how affect can meaningfully impact a person’s learning journey. There is a need for a **balanced and comprehensive pedagogical framework** (i.e., a model) from which educators can **learn to accurately observe/recognize affect and apply an intervention**, on-the-spot, to meaningfully aid a person during their learning journey (Picard, 2004; Feidakis, 2016; Tyng, 2017).

We propose to build a **comprehensive pedagogical framework** – a model to address the role of emotions in learning by establishing relevant collaborations and supported by NSF funding.

\(^1\) We use the term 'affect' to subsume the spectrum of emotional states and feelings that one can experience while engaged in the learning process. A sampling is shown in Figure 4 along with nuanced terms for degrees of intensity.
Setting a stake in the ground

The use of the computer as a model, metaphor, and modelling tool has tended to privilege the ‘cognitive’ over the ‘affective’ by engendering theories in which thinking, and learning are viewed as information processing and affect is ignored or marginalized… It is time to redress the imbalance by developing theories and technologies in which affect, and cognition are appropriately integrated with one another.

– Rosalind Picard, et al., Affective Learning – A Manifesto

Affect (emotions) is an important factor in a pedagogical theory of learning; emotions are part of the learning process (Vygotsky, 1978; Damasio, 1994; Picard, 1997; Bransford, 2000; Reeve, 2001; Kasl & Yorks, 2002; Callahan, 2002; Craig, 2004; Goleman, 2004, 2006; Perry, 2006; Dirkx, 2006; Wolfe, 2006; Immordino-Yang & Damasio, 2007; Schutz, 2007; Lashari, 2012; Cabada, 2017; Tyng, 2017). Nevertheless, affect is ignored or marginalized (Llewellen & Cahoon, 1965; Picard, 2004; Miller, 2005; Gano-Phillips, 2009; Cabada, 2017). Furthermore, research informs theory but not practice. The derivative effect is that, in STEM, this critically inhibits the learning process (Picard, 2004; Calvo & D’Mello, 2012).

Benjamin Bloom (1956), the seminal learning/education theorist of our time, remains a strong influence on educational research. Bloom (1956) noted that emotional (affective) states were present throughout a learning journey. However, Bloom and successive researchers failed to recognize the implications of a learner’s various emotional (affective) states during their learning journey. There have been bursts of research in regard to the effect of emotions on the learning process since Bloom (1956). However, there has been a hiatus of such research since the end of the first decade of the 21st Century. This is due to the growth, monetization and/or gamification of digital technology (e.g., educational games, games (in general), intelligent tutors), which has focused research on a limited range of user behaviors that are unique to a given technological artifact. ‘Pedagogical’ research continues to be focused on improving learning resources (e.g., Web-based simulations), addressing specific concepts, or, in support of a meta-concept (e.g., constructivism, behaviorism). However, even those research results are rarely applied to teaching-learning. When they are applied, they are not applied in a manner that will support the evolution of a comprehensive framework (a model) that would develop deep thinking, recursion, reflection, and metacognition (i.e., model-based reasoning).

Guided by experimental tests of theory and practice, science has advanced rapidly in the past 500 years. Guided primarily by tradition and dogma, science education meanwhile has remained largely medieval.

– MIT Professor Carl Wieman, 2001 Nobel Lauriate in Physics

Even leading theorists of the cognitive scientific revolution have called for greater representation and an understanding of affect in learning, as affect-based interventions and strategies have enormous potential in complex knowledge domains (e.g., STEM) (Simon, 1967; Norman, 1981). They can be employed to create a balanced and comprehensive pedagogical framework/model to meaningfully aid a person/educator during a learning journey (Picard, 2004; Feidakis, 2016; Tyng, 2017).

This framework/model would systematically explain how to:

  a.) create and validate functional affective interventions and strategies,
b.) identify and understand meaningful positive and negative affective states that impact learning (e.g., curiosity, ennui, frustration, confusion, anxiety), and

c.) identify the gold standard of affective states.

We propose to return the research agenda to a quest to understand how people learn (and what causes people to learn). We propose a model that is inspired by theory often used to describe complex dynamic interactions in engineering systems. As such, it is not intended to explain how learning works, but rather to provide a framework for thinking and posing questions about the role of emotions in learning. As with any metaphor, the model has its limits. The model does not encompass all aspects of the complex interaction between emotions and learning but begins to describe some of the key phenomena in metacognition.

Our novel model and its supporting theory goes beyond previous research and existing pedagogical models not just in the range of emotions addressed, but it formalizes an analytical model that describes the dynamics of a learner’s emotional states, and, does so in a language that supports metacognitive analysis. We propose:

- organizing a consortium of education researchers, cognitive psychologists, neuroscientists, etc. to investigate/understand the interplay between cognition, motivation, and affect in complex knowledge domains,

- systematizing the processes whereby pedagogical strategies optimally manage affective states, and,

- developing an Affective Intervention Theory, which will meaningfully facilitate a person’s learning journey by interceding, when necessary, with a strategy or tactic to: a.) process a learner’s emotional state, or, b.) initiate a positive or negative emotional state.

To move forward we must recognize that “[t]here is need for new types of studies on the role of affect in learning… to measure, model, study, and support the affective dimension of learning in ways that were not previously possible” (Picard, et al., 2004). The National Science Foundation’s Science of Learning program (NSF, 2018) is designed to address this.

Model-based and rule-based knowledge domains are very different

There are two knowledge domains; model-based domains\(^2\) and, rule-based domains\(^3\). Current theories/models of learning are effective when people are learning material from a rule-based knowledge domain (e.g., spelling, geography, accounting). To a limited extent, delivering model-based domain knowledge (e.g., any science, engineering) as if it were a rule-based knowledge domain is marginally functional, at least it will provide greater success on high-stakes tests, or, if a person is a

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\(^2\) Model-based domains contain knowledge that is built upon scientific theories/laws and the knowledge, when applied, is applied based upon an analysis of varying situations (e.g., physics, engineering).

\(^3\) Rule-based domains contain knowledge that is typically arbitrary and is applied universally (e.g., language, spelling).
contestant on a game show. But to be a successful learner a person must be able to transfer/apply model-based knowledge to various real-world situations.

However, all STEM areas are model-based knowledge domains, which, to be comprehended, necessitates deep learning, recursion, and understanding of the various models and theories in those domains—have the ability to transfer that domain’s knowledge onto new and varying situations. Due to the belief that model-based and rule-based knowledge can be deliver via similar methods, in spite of that belief scientists, engineers, or mathematical thinkers, and systems thinkers are produced; the current educational system does not evolve (or involve) curiosity and does not develop analytical skills in a learner, all of which are critical in any model-based domain.

It is a miracle that curiosity survives formal education.
-Albert Einstein

To facilitate a meaningful change that would assist in **evolving a more comprehensive pedagogical framework** to support delivering model-based knowledge to a person, or a group, three key issues must be agreed upon:

1. identifying and understanding various affective states is critical in facilitating a person’s learning journey regardless of the knowledge domain (i.e., rule-based, or model-based),
2. cognitive researchers spending more time working with teachers, testing, and refining their theories in real classrooms,
3. delivering knowledge from a model-based domain (e.g., physics, engineering) requires **vastly** different methods than delivering knowledge from a rule-based domain (e.g., languages, spelling, geography), nonetheless, current practice fosters and promotes their delivery via the same methods, and,
4. the belief that all STEM disciplines are model-based knowledge domains.

To deliver knowledge effectively and efficiently from a model-based knowledge domain (all STEM knowledge domains), **a more comprehensive pedagogical framework to support a person’s learning journey must include** an understanding of, and the ability to appropriately manage, the:

- Affective states of a learner as he/she proceeds through their learning journey. The affective state of a learner signals a learner’s need for support or intervention, and,
- Teaching/learning in the very early stages of learning in a model-based knowledge domain is probably best delivered as if the domain were rule-based.

**Beyond mere rules: a deeper dive into the gory details**

Rule-based methods are well-known to be problematic at best and dysfunctional at worst. Model-based methods are essential to STEM disciplines. But accepting this is a major paradigm change fraught with intractable politics. We can make the case, but it will take a generation or longer for such a shift to become a reality.

- Barry Kort

What’s the deeper difference between rule-based and model-based? And why do we care about ‘models’ and less about rules? To further explain the difference, a deeper dive may be very helpful.

It’s important to understand the 5-stage sequence between rules and models. After reviewing the 5-stage sequence, it may seem as though this is a manifesto for social interactions across humanity; it
may very well be. However, it is applied here to establish the foundation for our theory for the delivery of knowledge from a model-based domain. It should also clarify the difference between rule-based knowledge domains and model-based knowledge domains; and further clarify why models are needed to deliver knowledge from STEM domains.

1. **Heaps of Rules** are most prevalent for grammar school children or in single-step processes. The difficulty is that if there is a sequence of actions or subsequent steps in a process those ‘next steps’ are unspecified, or, arbitrary, or, capricious. Rule-based systems are mathematically chaotic, while the rules are clear, for example, in a game or a life situation, each person selects the rule to use at a given moment thus the outcome is unpredictable and arbitrary.

2. **Suites of Protocols** are more sophisticated than are rules, or heaps of rules. Unfortunately, this concept is not introduced until a person enters college. The most common examples are diplomatic protocols. Statutory legislation, also known as a heap of rules, cannot deal with evolving application of knowledge/wisdom in a subtle or delicate diplomatic situation. The Internet is a much newer domain which is governed by protocols. Before the advent of the Internet, the term 'protocol' was typically used in contexts such as ‘diplomatic protocol’ (which can be thought of as a carefully choreographed mating dance). With the advent of the Internet, we acquired technical protocols such as TCP/IP (Transmission Control Protocol)/(Internet Protocol), FTP (File Transfer Protocol), SMTP (Simple Mail Transfer Protocol), and HTTP (HyperText Transfer Protocol). These examples are similar to mating dances to set up the technical parameters for exchanging specific kinds of information between otherwise dissimilar systems.

3. **Library of Functions** is a math-based concept and it is difficult to fully appreciate or understand without a math background. Here is an example of a ‘function’: A toddler (thus named as they are unable to gracefully stand erect) learns to stand-up without falling as their brain, over time, hard wires the balance function that allows the toddler to gracefully stand upright. The exact function (how to keep a vertical column from falling over) is a 1st year calculus problem. It’s derived from Newton’s model of gravitational mechanics as applied to a vertical column (e.g. the Inverted Pendulum Problem). This is not rule-based as the person receives timely and continuous input from the real-world, assesses it, and computes a dynamic correction to remain upright—there are no rules for this. The person executes the balance function. A very similar example of a function is balancing an inverted broom in your hand. A person continuously focuses on the top of the broom that provides raw data (the so-called Directional Derivative), which enables the person to reactively move his/her hand to keep the inverted broom balanced. Another example of a function is walking on a balance beam. This is an application of the 1st derivative of Newton’s model of a vertical column as it falls over. The balance beam walker takes-in data and adjusts in a functional manner—no rules, the language of rules is too impoverished and cannot produce the requisite order or stability.

4. **Collections of Models** are built from a library of functions. Manipulating various functions from a person’s library of functions, which means having the faculty of defining/constructing models. Good scientific models have: explanatory, predictive, and, diagnostic powers; heaps of
rules lack these characteristics at a meaningful scientific level. The payoff is explanatory, predictive, and, diagnostic power, which allows an educator/learner to successfully navigate the world and meaningfully and effectively apply their knowledge to reach an imaginable goal safely and efficiently.

5. **Ecology of Systems** is composed of models, which interact to collaboratively establish a world situation where sustainability and progress are key values. All sorts of factors determine the success of the plan—a well-educated person has this capacity—the ability to effectively perform model-based reasoning. We call this visionary insight and wisdom.

**Simplifying the Gory Details**

There is a progression in STEM education that we have barely begun to embrace. The progression began (some 5000 years ago) with Rule-Based Methods (of teaching). Rules are simple Dos and Don'ts, with discrete (typically binary) alternatives.

The next step after Rule-Based is Protocol-Based, where there is an orderly sequence of steps (rather than a Heap of Rules to be applied in no particular order). Recipes and Algorithms are examples of doing the steps in a prescribed order (typically with some feedback along the way to regulate the details).

After Protocol-Based Methods comes Function-Based Methods, where the elements can rely on arbitrary mathematical functions. Another name for Function-Based is Procedure-Based.

After Function-Based Methods come Model-Based Methods, where the Functions and Procedures comprise a Model (e.g. a scientific model or an engineering model or a biological model or a social model or a psychological model). Models can be solved (mathematically) for Functional Best Practices to drive the Model to a desired Goal State.

After Model-Based Methods comes Systems Science -- the art of juggling an EcoSystem comprised of autonomous interacting semi-autonomous models.

We need to discover how to advance from Rule-Based Methods to Protocol-Based, to Function-Based, to Model-Based, and then to Systems Theoretic Methods.

<table>
<thead>
<tr>
<th>Stage</th>
<th>Nominal Academic Level</th>
</tr>
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<tbody>
<tr>
<td>Rule-Based Methods</td>
<td>Grade School</td>
</tr>
<tr>
<td>Protocol-Based</td>
<td>Middle School</td>
</tr>
<tr>
<td>Function-Based</td>
<td>High School</td>
</tr>
<tr>
<td>Model-Based Methods</td>
<td>College Undergraduate</td>
</tr>
<tr>
<td>Systems Thinking</td>
<td>College Graduate Level</td>
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Table 1: Stages for Various Methods
Creating a balanced comprehensive pedagogical framework

[In the 1970s], educators paid little attention to the work of cognitive scientists, and researchers in the nascent field of cognitive science worked far removed from classrooms. [In the early part of the 21st Century], cognitive researchers [began] spending more time working with teachers, testing, and refining their theories in real classrooms

– John Bransford (ed.), How People Learn: Bridging Research and Practice

While cognitive researchers have been “refining their theories in real classrooms” (Bransford, 2000), the impact of affect on learning has been “ignored or marginalized” (Picard, 2004). Current teaching-learning methods continue to focus on a model that provides ‘information’ (or ‘data’) to learners (Figure 1) rather than providing knowledge and wisdom. High-stakes testing, which assesses a person’s ability to only draw out ‘information’, drives this; and those who can extract ‘information’ are judged to be ‘educated’ or ‘intelligent’—but this not knowledge acquisition, which is a person’s ability to organize and appropriately apply information/data. This approach/belief does little to provide learners with needed problem-solving skills. It only develops rule-based learners in an era that must have model-based reasoners also known as systems thinkers.

To understand the need for a novel model, let us first examine the current educational model. The current model, as shown in Figure 1, begins with ‘data,’ which is a collection of answers to questions that the learner has not yet seen fit to ask or needs to ask. Such data becomes ‘information’ when it answers a question that the learner cares to ask or the educator provides. For the most part, an educator must somehow motivate the student to care enough to seek the answers found in the data, in a Socratic approach the ‘teacher’ supplies curiosity-developing questions to encourage the learner to ‘study’ and learn. Studying is like ‘panning for gold’ where the answers are the ‘nuggets’ buried in a ton of otherwise uninteresting gravel. Once we have our ‘nuggets of information’ how do we organize them into a ‘body of knowledge’? We may think of ‘information’ as the pieces of an unassembled jigsaw puzzle, whereas ‘knowledge’ is the assembled jigsaw puzzle. That is, the question-answer (Q&A) pairs are organized into a coherent structure, in the logical and natural order in which new questions arise as soon as old ones are answered.

Figure 1 – Illustration for delivery of knowledge from a rule-based domain.

Elements of learning in conventional classroom pedagogy.

The assembled ‘jigsaw puzzle of knowledge’ reveals a previously hidden picture—a ‘big picture,’ if you will. Or to put it another way, the assembled ‘jigsaw puzzle of knowledge’ is a tapestry into which is woven many otherwise hidden and previously unrevealed stories. The illustration in Figure 1 accommodates rule–based knowledge where only ‘rules’ are involved. The ‘rules’ are applied in every situation (e.g., apple is always spelled the same way). This model does not accommodate model-based...
knowledge where the theories must be understood to the extent that they must be applied appropriately in ever-varying situations.

Our novel model (Figure 2 below) goes beyond the model in Figure 1. The focus of attention shifts to the construction of ‘knowledge’ and to the extraction of meaningful ‘insights’ from the ‘big picture.’ When ‘knowledge’ is coupled with a personal or cultural value system, ‘wisdom’ emerges. In other words, wisdom allows us to harness the power of knowledge for beneficial purposes. ‘Wisdom’ affords us the possibility of extracting the stories woven into the tapestry of knowledge. So, from ‘wisdom’ we craft the bardic arts of story making and storytelling. The ancients created myths and legends. These were the prototypical stories of their cultures, which were intended to impart ‘wisdom.’ A story is thus an anecdote drawn from the culture. A well-crafted anecdote or story has value both as an amusement and as a source of insight into the world from which it is drawn. And the plural of ‘anecdote’ is data—a collection of anecdotal stories or evidence. This observation closes the loop in Figure 2.

Figure 2 suggests a novel model that, on a fundamental level, supports an improved educational pedagogy. This will serve as a foundation for the next part of our model—how a learner’s affective state should be incorporated into this overall model.

![Figure 2 – Model for delivery of knowledge from a model-based domain](image)

While proceeding through a model-based knowledge domain as illustrated in Figure 2, the learner’s journey can be managed by understanding the effects/impact of various emotions (e.g., curiosity, frustration, ennui, anxiety). This knowledge is particularly valuable if an educator understands what emotional states can be employed during a person’s learning journey and understands how various emotional states can provide a meaningful impact to move a learner forward.

**Affective state overview: Emotions in learning**

There is a dynamic process called ‘learning’ that takes place as we build a knowledge base. The rate of learning is generally not steady. We learn in fits and starts and occasionally have to ‘unlearn’ a misconception or two. That is, our ‘learning curve’ does not gracefully ascend but has ‘wiggles’ in it as the learning process advances and retreats.
There are identifiable emotions that appear along the way. Among these we especially note curiosity, fascination, confusion, anxiety, surprise, perplexity, frustration, chagrin, despair, hope, satisfaction, and elation.

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*

To re-engineer the current state of educational pedagogy, educators should first look to expert teachers who are adept at recognizing the emotional state of learners, and, based upon their observations, take some action that scaffolds learning in a positive manner. But what do these expert teachers see and how do they decide upon a course of action? How do students who have strayed from learning (e.g., become frustrated, bored) return to a productive path, such as the one that Csikszentmihalyi (1990) refers to as the “zone of flow”?

The notion that a student’s affective (emotional) state impacts learning and that appropriate intervention based upon that affective state would facilitate learning is the concept that we propose to explore and justify.

In the later 20th and very early 21st Centuries, connections between complex learning and emotions had received significant and increasing attention in the fields of psychology (Carver, 2004; Deci & Ryan, 2002; Dweck, 2002), education (Lepper & Henderlong, 2000; Linnenbrink & Pintrich, 2004; Meyer & Turner, 2002), neuroscience (Damasio, 2003), and computer science (Kort, Reilly, & Picard, 2001a, 2001b; Picard, 1997). But again, this trend has been refocused by the dramatic growth and/or monetization of digital technology (e.g., educational games, games (in general), intelligent tutors).

“Emotions are important in […] learning because they can either impede or motivate learning” (Dirkx, 2001). Serving as motivation to pursue desires, emotion creates purpose and shapes the context of learning experiences (Merriam & Caffarella, 1999; Reeve, 2001). Emotion plays a critical role in the construction of meaning and knowledge of the self in the adult learning process (Dirkx, 2001).

Emotional experiences are ubiquitous in nature and important and perhaps even critical in academic settings, as emotion modulates virtually every aspect of cognition. Tests, examinations, homework, and deadlines are associated with different emotional states that encompass frustration, anxiety, and boredom. Even subject matter influences emotions that affect one’s ability to learn and remember.

– Chai M. Tyng, *The influences of emotion on learning and memory*

The influences of emotions as they impact a person’s learning journey should be carefully considered in the design of educational materials and pedagogy as understanding that the effects that emotions (affect) has on learning maximize a learner’s engagement as well as improve learning and long-term retention of subject matter (Shen et al., 2009). Studies report that the cognitive processes are influenced by emotions, including attention (Vuilleumier, 2005), learning and memory (Phelps, 2004; Um, et al., 2012), reasoning (Jung, et al., 2014), and problem-solving (Isen et al., 1987). “These factors are critical in educational domains because when students face such difficulties, it defeats the purpose of schooling and can potentially render it meaningless” (Tyng, 2017). Additionally,
attentional, and motivational components of emotion have been linked to increased retention (Pekrun, 1992; Seli et al., 2016). Hence, the need for a comprehensive framework that is based on an understanding of the effects/function of emotions should be more deeply explored.

It is also imperative that recent studies into cognitive/affective neuroscience, and educational psychology be conducted to optimize learning and memory outcomes (Carew and Magsamen, 2010; Um, et al., 2012). There must be greater collaboration among the education establishment and the various fields that delve into the brain’s operating system.

Presently, poor engagement with the topic of emotions and learning has resulted in little literature on the topic. For example, “[r]elatively few scholars and practitioners in adult and higher education regard emotion as integral to the meaning-making process” (Dirkx, 2006). But in the early years of the 21st Century, the reality that affect/emotion has a critical impact on the learning process has begun to experience benign neglect (Colby & Sullivan, 2009; Pierre & Oughton, 2007; Shephard, 2008; Gano-Phillips, 2009).

Researchers began to make progress giving computers abilities similar to people in accurately recognize affective expressions (Graesser, 2005; Picard, 2000; Scheirer, 1999), facial expressions (Bartlett, 1999; Chen, 1998; Cohn, 1999; DeSilva, 1997; Donato, 1999; Ekman, 1997; Essa, 1997) and gestural expression (Huang, 1998; Kapoor, 2001). But other factors (e.g., monetization of digital technology) have refocused the progress and development of affective interventions and strategies.

Our own preliminary pilot studies with elementary school children suggest 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 (Kort 2001a, 2001b; Burleson, 2003). 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 she is confused or frustrated before offering to provide coaching or hints). Moreover, successful learning 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. But how can people acquire this same level of proficiency as that of gifted coaches, mentors, and teachers?

Our first step is to offer a model of a learning cycle, which integrates affect. Figure 4 suggests six possible emotion axes that may arise while learning. Figure 3 denotes the herky-jerky nature of a typical learning journey (a non-monotonic process).

Figure 3 reflects the ups and down of the rollicking learning curve. This is 'non-monotonic learning'. It portrays that a learner acquires erroneous beliefs and misconceptions, which are eventually discarded. Superimposed in Figure 4 is 'Frowny Face Scowl' and a 'Happy Face Smile' to illustrate the emotional states are variously negative valenced (unhappy) or positive valenced (happy learning curve).
Our next step is to suggest six possible emotion axes (Figure 4) that may arise while learning. Figure 3 reflects the two aspects to emotions (listed in Figure 4). One aspect is any of these emotions will occur at any moment in a person’s learning journey. Understanding the cause of these occurrences can be addressed by understanding how to move a learner toward a positive affective state (toward an affective state on the right-hand side in Figure 4). The other aspect, is to consciously invoke a negative emotion in-order to motivate a learner (e.g., invoke frustration and incrementally offer hints/clues so that the learner will feel confident and be motivated to move forward). Such manipulations will/can occur during a person’s learning journey as depicted in Figure 2 (and in Figure 1). But it is more complex in Figure 2 (a model-based learning journey).

<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>
</tr>
</thead>
<tbody>
<tr>
<td>Anxiety-Confidence</td>
<td>Anxiety</td>
<td>Worry</td>
<td>Discomfort</td>
<td>Comfort</td>
<td>Hopefulness</td>
</tr>
<tr>
<td>Ennui-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-Enthusiasm</td>
<td>Dispirited</td>
<td>Disappointed</td>
<td>Dissatisfied</td>
<td>Satisfied</td>
<td>Thrilled</td>
</tr>
<tr>
<td>Terror-Excitement</td>
<td>Terror</td>
<td>Dread</td>
<td>Apprehension</td>
<td>Calm</td>
<td>Anticipatory</td>
</tr>
<tr>
<td>Humiliated-Proud</td>
<td>Humiliated</td>
<td>Embarrassed</td>
<td>Self-conscious</td>
<td>Pleased</td>
<td>Satisfied</td>
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In Figure 5, 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.
Students ideally begin in Quadrant I or II: they might be curious or 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 a bright idea how to implement a solution and then builds a simulation. If she runs the simulation and it fails, she sees that her idea has some part that doesn’t work—that needs to be diagnosed and reconstructed. At this point she may move down into the lower half of the diagram (Quadrant III) into the ‘dark teatime of the soul’ while discarding misconceptions and unproductive ideas. As she consolidates her knowledge—what works and what does not—with awareness of a sense of making progress, she advances to Quadrant IV. Getting another fresh idea propels the student back into the upper half of the space (Quadrant I). Thus, a typical learning experience involves a range of emotions, cycling her around the four-quadrant cognitive-emotive space as she learns.

If one visualizes a version of Figure 5 for each axis in Figure 4, 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 cyclic nature is natural in learning science, mathematics, engineering, or technology (SMET), and that when he lands in the negative half, it is an inevitable part of the cycle. Our aim is to help students to keep orbiting the loop, teaching them to propel themselves, especially after a setback.

A third axis (Figure 6) can be envisioned as extending out of the plane of the page—the cumulative 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. 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 wanes. In Quadrant III, as the negative affect runs its course, the learner discards misconceptions and ideas that do not pan out. 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 until completion of the learning exercise. Note that the orbit doesn't close on itself, but gradually spirals around the cumulative knowledge axis.
Briefly stated, each time around the loop in Figure 5, there is a net gain in total cumulative knowledge. Adding the Knowledge Axis, perpendicular to the Phase Plane of Emotions and Learning (Figure 5), the trajectory appears similar to the helix in Figure 6.

**Surface level behaviors -- inferring an affect state**

Affective states in learning, such as different posture patterns, gestures, eye-gaze, and facial expressions accompany the affective states of: interest, boredom, confusion, and excitement. Rich *et al.* (1994) have defined symbolic postures that convey a specific meaning about the actions of a user sitting in an office (e.g., interested, bored, thinking, relaxed, defensive, and confident). Leaning forward towards a computer screen might be a sign of attention—an on-task state—while slumping on the chair or fidgeting suggests frustration or boredom—an off-task state. However, this knowledge has not been aggregated into a central learning mod, or, into existing learning models to the extent that the affective state has been employed in the learning journey—no existing Affective Intervention Theory. The direction of eye gaze is also an important signal to assess the learner’s focus of attention. In an on-task state the focus of attention is mainly directed toward the problem the student is working on, whereas in an off-task state the eye-gaze might wander away from the task. Facial expressions and head nods are also reliable indicators of affective state.

Following Ekman’s (1997) seminal work in facial recognition, an approving head nod (Ekman’s AU 6) or a facial action such as a smile (AU 12), tightening of eyelids while concentrating (AU 7), eyes widening (AU 5), and raising of eyebrows (AU 1+2) suggest interest, surprise, excitement (an on-task state), whereas head shakes, lowering of eyebrows (AU 1+4), nose wrinkling (AU 9) and depressing lower lip corner (AU 15) suggests an off-task state. Also, appropriately directed activity on the mouse and keyboard can be a sign of engagement whereas no activity or sharp repetitive activities may be a sign of disengagement or irritation. These surface level behaviors are loosely summarized in Table 2. Whether all of these are consequential remains to be evaluated. That determination will be made by examining a variety of surface level behaviors related to the inference of a user’s affective state while engaged in natural learning situations.
Validating ideas that lead to deep change

[The standard] method of controlled experimentation that evaluates an idea by implementing it, taking care to keep everything else the same, and measuring the result, may be an appropriate way to evaluate the effects of a small modification. However, it can tell us nothing about ideas that might lead to deep change.

– Seymour Papert, *The Children’s Machine*

How does one go about ‘validating’ ideas, theories, and models that might lead to deep structural change? It is problematic to just implement an idea that will possibly lead to deep change and then expect to validate such deep change in a relatively brief period. Deep change can evolve and, more importantly, be initially validated by supportive appropriate arguments and analyses of those arguments. Then, over a lengthily period of organic evolution in close harmony with social evolution, the models/theory can be validated. Such a process will be guided more by the participant’s intuitive belief than by the outcome of empirical research or other tests and measurements.

Our model for deep change in educational pedagogy falls within Papert’s admonition that the most powerful resource for this process is exactly what is denied by objective psychology and the would-be science of education. Every one of us has built up a stock of intuitive, empathic, commonsense knowledge about learning. This knowledge comes into play when one recognizes something good about a learning experience without knowing the outcome. It seems obvious to me that every good teacher uses this kind of knowledge far more than test scores or other objective measurements in daily decisions about students. Perhaps the most important problem in education research is how to mobilize and strengthen such knowledge (Papert, 1993).

Our Four Quadrant Model (Fig. 5), which espouses theories that may facilitate deep change in the application of affect to learning, will be validated as it is incorporated into

<table>
<thead>
<tr>
<th><strong>Posture</strong></th>
<th><strong>On Task</strong></th>
<th><strong>Off Task</strong></th>
</tr>
</thead>
<tbody>
<tr>
<td>Leaning Forward, Sitting Upright</td>
<td>Slumping on the Chair, fidgeting</td>
<td></td>
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</tbody>
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<table>
<thead>
<tr>
<th><strong>Eye-Gaze</strong></th>
<th><strong>On Task</strong></th>
<th><strong>Off Task</strong></th>
</tr>
</thead>
<tbody>
<tr>
<td>Looking towards the problem</td>
<td>Looking everywhere else</td>
<td></td>
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</table>

<table>
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<tr>
<th><strong>Facial Expressions</strong></th>
<th><strong>On Task</strong></th>
<th><strong>Off Task</strong></th>
</tr>
</thead>
<tbody>
<tr>
<td>Eyes Tightening (AU7), Widening (AU5), Raising Eyebrows (AU 1+2), Smile (AU6+12)</td>
<td>Lowering Eyebrow (AU1+4), Nose Wrinkling (AU9), Depressing lower lip corner (AU15)</td>
<td></td>
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<table>
<thead>
<tr>
<th><strong>Head Nod/Head Shake</strong></th>
<th><strong>On Task</strong></th>
<th><strong>Off Task</strong></th>
</tr>
</thead>
<tbody>
<tr>
<td>Up-Down Head Nod</td>
<td>Sideways Head Shake</td>
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</table>

<table>
<thead>
<tr>
<th><strong>Hand Movement</strong></th>
<th><strong>On Task</strong></th>
<th><strong>Off Task</strong></th>
</tr>
</thead>
<tbody>
<tr>
<td>Typing, clicking mouse</td>
<td>Hands not on mouse/keyboard</td>
<td></td>
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Table 2 – Ekman's Surface Level Behaviors
such artifacts as Intelligent Tutoring Systems, embodied conversational agents, in traditional classroom settings, and other cognitive machines.

**Roadblocks to change**

Deep systemic change, such as we propose, has never come easy as

> [there is a] stubborn refusal to abandon the old ways... [when there is a] challenge to long-established procedures. The problem in education has an additional element. Most honest Schoolers are locked into the assumption that School’s way is the only way because they have never seen or imagined convincing alternatives in the ability to impart certain kinds of knowledge (Papert, 1993).

Another obstacle is defining what ‘affect’ is. The ongoing research in the fields of neuroscience, cognitive science, medicine, and psychology has caused a wide diversity in the definitions of: affect, emotions, attention, etc. We must bring together “theorists and practitioners from different fields in order to refine the language used with respect to affect and learning” (Picard, et al., 2004).

There are many neighborhoods of disciplines customizing delivery of model-based knowledge using different term to describe the same things. These neighborhoods of disciplines use, essentially, the same kind of thinking but different nomenclature (system thinkers, sustainability thinkers, theology thinkers).

The question: “Can you objectively and accurately measure affective states?” remains open. The question that follows is: “How accurately do we need to be able to measure affective states in order to reliably deliver knowledge from a model-based domain?”

Also, teacher preparation institutions typically provide only one or two education psychology courses that address how people learn. These are courses typically entitled: Methods and Materials. They focus-on course ingredients and lesson plans. As a result, while pre-service teachers may receive excellent backgrounds in their chosen knowledge domain and may be familiar with Piaget, Papert, Thorndike, Bloom, etc., they typically lack knowledge and training in the mechanics and techniques involved in how people learn!

In today’s academic world, ‘pedagogy’ is considered to be: lesson plans, presentations, lecture material, homework, and tests in an academic environment. The notion that affective state is a primary factor in learning models/theories is not acknowledged; it is ignored or marginalized. Thus, the focus of research does not assume the role of affect in the learning process.

A significant roadblock is a widespread demand for accountability coupled with the belief that standardized testing can accurately assess the ‘knowledge’ a person possesses in a model-based domain (e.g., engineering, sciences). This belief is true only for a knowledge domain that solely contains rules, no underlying scientific-like theories/models such as: spelling, language, geography, accounting. The belief in the power of standardized testing has led education and government leaders (and the public) to believe that all knowledge domains are similar, thus, should be ‘taught’ using similar methods. However, the sciences and engineering are not rule-based and cannot be effectively taught using the same methods applied in rule-based knowledge domains (e.g., spelling). The sciences
and engineering have underlying theories. In order to measure a person’s skill in those areas, the person’s ability to apply the various theories needs to be measured; not via standardize testing.

Google is a major problem in that it deters deep learning, which is required in STEM domains (model-based domains).

High-stakes testing, which is driving teachers and administrators to ‘teach to the test’ is another impediment. In-order to be successful on the high-stakes tests, a person simply needs to retrieve a matching piece of information. Such a process creates a generation of game show contestants but does not create scientists and engineers—people who are able to apply knowledge in varying situations! The belief that a change is needed is further obfuscated by the explosion of technology-based simulations that support both rule-based and model-based knowledge domains (e.g., Spelling City, theory of elastic collision). While this development has proven to facilitate knowledge from a rule-based domain, it has skewed the definition of pedagogy away from a focus on how people learn and now focuses on what people learn.

While project-based learning (PBL) has gained ascendancy as a new pedagogical approach, it:

has shown itself to be a proven means for setting up the kind of problem-solving challenges that engage students in deeper learning and critical inquiry. It requires students to research, collaborate, decide evidence, accept feedback, design solutions, and present findings in a public space—all factors that create the conditions under which high performance and mastery are most likely to emerge. The rise of PBL, in fact, is a success story for education (Markham, 2018).

Project-based learning is a step in the right direction. However, PBL “continues to be misinterpreted as a single teaching strategy rather than as a set of design principles that allow us to introduce the philosophy of inquiry into education in an intelligent and grounded way” (Markham, 2018). PBL only recognizes that STEM domains must be delivered to learners who are actively engaged in acquiring a deep understanding of how to analyze, synthesize and, transfer the knowledge and information they have acquired onto new or unique situations. PBL’s strength is that there is now a belief that students must be actively engaged. But PBL, does not have a comprehensive pedagogical framework to explain a person’s overall learning journey.

If the notion that model-based knowledge domains need to be in the curriculum then the core mythology in regard to the rule of law will be severely minimized.

Lastly, there have been bursts of research on how emotions impact the overall learning process. However, there has been a hiatus of such research since the end of the first decade of the 21st Century. This is partly due to the growth and monetization of digital technology (e.g., educational games, games (in general), intelligent tutors). Gamification is highly successful in developing games, including educational games, and, in developing non-game technology (e.g., wrist bracelets that notify the wearer of oncoming seizures). While the initial goal of emotions in learning research is intended to evolve a comprehensive theory of emotions in learning that research becomes refocused onto gamification.
Putting it together – the role of emotions in learning

Emotion has a substantial influence on the cognitive processes in humans, including perception, attention, learning, memory, reasoning, and problem solving. Emotion has a particularly strong influence on attention, especially modulating the selectivity of attention as well as motivating action and behavior. This attentional and executive control is intimately linked to learning processes, as intrinsically limited attentional capacities are better focused on relevant information.

– Chai Tyng, The Influences of Emotion on Learning and Memory

Theory inspires our models that are often used to describe complex dynamic interactions in engineering systems. As such, they are not intended to explain how learning works, but rather to provide a framework for thinking and posing questions about the role of emotions in learning. As with any metaphor, the model has its limits. The model does not encompass all aspects of the complex interaction between emotions and learning but begins to describe some of the key phenomena that needs to be considered in metacognition.

These models go beyond previous research studies not just in the range of emotions addressed, but also to formalize an analytical model that describes the dynamics of a learner’s emotional states and does so in a language that supports metacognitive analysis.

Here’s the shtick

New developments in the science of learning raise important questions about the designs of learning environments… [the] general characteristics of learning environments… [that] need to be examined in light of new developments in the science of learning.

– John Bransford, et al. (ed.), How People Learn: Bridging Research and Practice

We propose:

1. Forming an interdisciplinary consortium with an ambitious research agenda. This will be combined with a critical review of existing research in a wide-range of sciences leading to new insights and innovations that incorporate theories of affect into a balanced and comprehensive pedagogical framework from which educators can learn to accurately observe affect and apply this knowledge on-the-spot to meaningfully aid a person during their learning journey.

2. Conducting an ambitious research agenda combined with a critical review of existing research in a wide-range of sciences to evolve a new model for framing a dialogue leading to new insights and innovations that incorporate theories of affect into new or existing pedagogical models/theories.
   a. We hope to attract graduate students who would pursue their thesis and dissertation work in this area,
   b. We would expect to attract faculty members to contribute their expertise to this endeavor,
3. Applying for National Science Foundation funding (and applying to other funding sources).
4. Evolving an Affective Intervention Theory, which will meaningfully facilitate a person’s learning journey by interceding, when necessary, with a strategy or tactic to: a.) process a learner’s emotional state, or, b.) initiate a positive or negative emotional state.
5. Facilitating the creation of a body of knowledge, supported by NSF grant funding, that can be delivered to ‘teachers’ through a series of applied educational pedagogy courses and a
fieldwork experience in recognizing and appropriately applying affective pedagogical interventions to guide a person’s learning journey. That ‘body of knowledge’ will, for example, seek to understand:

a. When to invoke positive or negative emotional states to move a learning episode forward or revitalize it?

b. The brain’s function in regard to various emotions/affective states,

c. What emotional states compose the gold standard?

d. What positive or negative emotional states inhibit or invigorate desired emotional states?

e. How a human teacher (or a teaching-learning object) facilitates a person’s learning journey,
   • How a ‘teacher’ deals with a learner who is, for example, frustrated, or, confused, or, involved in cognitive assessment, or, bored, and,
   • How a person/educator recognizes and manages the emotional states during various stages of learning.

Acknowledgements

We are also grateful to Professor Rosalind W. Picard, MIT Media Lab, and Professor Arthur Graesser, University of Memphis for their continuing support as mentors and colleagues while we performed NSF-funded research. This material is based upon work supported by the National Science Foundation under REC #0325428 Monitoring Emotions While Students Learn with AutoTutor, and, REC #0087768 The Role of Emotion in Propelling the Learning Process. And thanks to Professor Steven Lerman, MIT’s Center for Educational Computer Initiatives, who first gave this project its first home in his laboratory.

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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