Frontiers of Affect-Aware Learning Technologies

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'Emotions pervade our daily lives'. Most of us would agree with this statement, so it is a bit surprising that it is only in the last two decades that the psychology research community has wholeheartedly embraced the science of emotion (or affect, as it is generally referred to in the technical community). The learning sciences community is no exception to these changing times. Although most learning technologies have traditionally focused on supporting cognitive processes and outcomes, research on the role of emotions during learning is increasing in the fields of educational psychology and learning technologies.

The integration of emotion with learning technologies was triggered by Rosalind's Picard 1997 book *Affective Computing* [1]. There are two basic tenets of affective computing. The first is that it is possible for a computer to sense human emotions and systems that detect and respond to users' emotions can produce more engaging and fulfilling interactions. These systems require affect detection techniques, which are most recently being developed using multimodal signals (facial expressions, postures, gestures, speech, physiology, and text). A second tenet is that intelligent systems that model emotions can make more effective human-like decisions compared to their purely rational counterparts. These systems make use of computational techniques to model how emotions arise from cognitive appraisals of real-world events and sometimes communicate these emotions via embodied conversational agents, robots, and other avatars. A third unspoken tenet, which we could like to add to the first two, is that products of research activities (devices, sensors, insights) that are undertaken to satisfy the goals of the first two tenants can make significant contributions to the scientific study of emotion. In this fashion, affective computing can

do more than merely borrow from decades of research in the affective sciences. It can also contribute to the science of emotion.

Although affective computing has been an active field of research for 15 years, it is more recent that tangible functional applications are coming online. One area that has spawned considerable excitement and research is the field of affect-aware advanced learning technologies such as intelligent tutoring systems and educational games. This line of research, at the intersection of affective computing, learning technologies, learning sciences, and affective sciences, has been featured in a number of journals, most notably *IEEE Transactions on Affective Computing, IEEE Transactions on Learning Technologies*, and the *International Journal of Artificial Intelligence in Education*. Further evidence of this burgeoning research area can be found in a recent compilation of its state of the art [2] and in the 2012 *Intelligent Tutoring Systems* conference, where motivation and affect was the focus of 19% of the papers.

The new momentum towards developing affect aware learning technologies has been driven by a general appreciation for the inextricable link between emotion and cognition and in improved affect detection techniques [3]. Affective states can be automatically detected through a number of signals: the same facial expressions and speech patterns we humans are sensitive to, the words we write or say, the physiological underpinnings of embodied emotions, and the contextual constraints that give rise to particular emotions. New devices and software techniques have the promise to provide high-fidelity affect detection capabilities and are less expensive, less intrusive, and more scalable.

Affect detection and generation (i.e. in animated pedagogical agents) have been integrated into a number of applications that epitomize how affective computing can improve different aspects of learner interactions. Here, we focus on five research themes in order to highlight some of the pertinent research activities of us, the authors, and our colleagues. We begin by describing an affect-sensitive ITS that detects and responds to boredom, confusion, and frustration, as a prototypical example of a *reactive* affect-aware learning technology. Next, we show how affective computing is challenging some of the widely-held norms by describing a technology that promotes learning by strategically inducing confusion in the minds of learners. We then discuss research activities that focus on two affective states intimately

linked to task persistence, uptake, and ultimately student learning: boredom and engagement. The next application aims to support the development of prosocial behaviors, resilience, and positive emotions, all part of the "personal development" curricula that is espoused in schools in the UK, Australia, and is becoming more common in other countries. The fifth theme focuses on a brief overview of research activities that are primarily conducted in classrooms instead of research labs.

Beyond Cold Cognition: Automatically Detecting and Responding to Boredom, Confusion, and Frustration

D'Mello and colleagues have investigated the occurrence of confusion, engagement, curiosity, delight, anxiety, and frustration in the context of several learning environment and activities. Confusion, frustration, engagement, and boredom tend to be the most commonly observed states so we focus on these states. These labels represent a categorical view of emotions, but emotions can also be represented in low-dimensional spaces such as the common valence-arousal space (a.k.a valence-activation). Certain affect detection techniques work better on dimensional models, so we have explored ways to jointly model both categorical and dimensional representations and to use physiological signals as input to classification systems that can automatically detect these emotions after a training period [4].

One distinctive product of this research was the development and evaluation of the first fully automated affect-sensitive dialogue-based ITS for computer literacy (Affective AutoTutor) [5]. The Affective AutoTutor automatically detects students' boredom, confusion, and frustration by monitoring contextual cues and other discourse features, gross body movements, and facial features. The sensed affective states guide the tutor's responses in order to help students regulate their negative emotions. The tutor synthesizes affect via the verbal content of its responses and the facial expressions and speech of an embodied pedagogical agent. A laboratory experiment comparing the affect-sensitive and non-affective tutors indicated that the affective tutor improved learning for low-domain knowledge students (d = .73 sigma), particularly at deeper levels of comprehension after some period of interaction. It was, however, less effective for students with high domain knowledge.

Beyond Uninspired Clarity: Strategically Planting Confusion to Create Learning Opportunities

As the average student will attest, confusion is one of the most common affective states that accompany learning activities that are pitched at deeper levels of comprehension, such as reading a difficult text or understanding the principles of Newtonian physics. Confusion can be caused by anomalies, contradictions and uncertainties in the content being studied or via discrepant events that arise during the learning process. Although the experience of confusion is generally seen as negative, there is some evidence to indicate that confusion can create opportunities for learning, particularly when students engage in effortful cognitive activities to resolve their confusion [6]. D'Mello, Graesser and others have been studying how opportunities for these type of events can be triggered in ITSs. The ITS must be able to create learning situations that *trigger* confusion in students, then *track* and monitor their experiences, finally providing support so that students can productively instead of hopelessly confused.

To test these ideas, D'Mello et al. [7] developed a system that strategically introduces confusion in the minds of the students over the course of learning difficult research methods concepts. Confusion was induced when two animated pedagogical agents provided contradictory opinions and asked the students to decide which of the opinions had more scientific merit. The intriguing finding was that the contradictions had no effect on learning when students were not confused by the manipulations, but performance on multiple-choice posttests and on transfer tests was substantially higher when the contradictions were successful in confusing students.

Beyond Boredom: Strategies to Promote Engagement and Task Persistence
It is widely acknowledged that students are more likely to achieve positive learning outcomes when they
are actively engaged in a learning activity [8]. Certain forms of engagement, require time so the students
can understand the activity and commit to it. Engagement can be studied in a number of learning activities
that provide this time and meaningfulness. Writing activities, for example, provide one useful context to
study this form of engagement. The importance of writing has also been recognized as an essential skill

for students in all disciplines, so improving writing proficiency is a critical challenge for 21st century students.

As part of the efforts by the learning technologies research community, we have been studying how to build systems that are aware of the writer's affective states. It is often believed that one way to engage students in writing is to ask them to express opinions on socially charged topics like abortion and capital punishment. Yet, some initial evidence suggests that writers' emotions depend not just on the topic, but also the alignment between their personal opinions and those they must support in the writing. For example, one recent study [9] tracked writer's emotions when they had to argue both in favor of and against a controversial topic (abortion in this case). As expected, the findings indicated that students were more engaged when their beliefs aligned with the argument they were asked to support, and expressed more boredom when they had to argue against their personal beliefs. Engagement has also been found to predict writing outcomes beyond individual differences in scholastic aptitude, writing apprehension, and exposure to print.

There are also certain environmental conditions are more likely to lead to increased engagement while writing. Calvo has proposed a new type of tool, *Reflective Writing Studios* (RWS), that can be used to study writing phenomena in a comprehensive way, by taking into account the writer's physical and social surroundings, their emotions and other mental states (e.g. motivation) in addition to the cognitive processes that are generally studied. RWS can also be used to scaffold writers' reflections on how these affective and cognitive processes affect their work, and help them identify personalized conditions that are associated with engaged writing. The architecture combines structured information about the activity provided by the writing management system with multimodal sensor data from the writer and the environment (e.g. webcam). Data fusion and user interaction (e.g. visualizations) are performed using affective computing techniques. RWS can support novice writers to reflect on the context, process, and outcomes of writing – these are the aspects that are acknowledged as being instrumental for developing writing skills.

Beyond the Negative Emotions: Wellbeing, Positive Psychology, and Positive Computing

Researchers have recently started exploring design strategies, and new tools to support wellbeing. Calvo and Peters [10], [11], for example, have discussed design guidelines for systems that support the development of wisdom. Strategies for supporting wellbeing have been studied in positive psychology [12] and have had an impact on the educational curricula. Positive schooling, as it is called, highlights the importance of developing wellbeing skills in schools. In the UK, for example, this is included in the Personal, Social and Health Education (PSHE) curricula (called Personal and Social in Australia) that covers topics designed to prevent bullying, racism, drugs and to provide sex education. A common theme for this personal- and social- development curricula is that there are important educational goals that extend beyond the traditional academic domains. The aim is to help students develop attitudes and emotions (e.g. empathy or resilience) that are considered important for life satisfaction. The American Psychological Association has summarized several of these topics in its 10 tips for building resilience in children and teens.¹

Personal development curricula is emerging as new frontier for ITSs that have generally focused on the traditional curriculum (e.g. Science, Technology, Engineering, and Math or STEM). The design of systems to support wellbeing has been called 'positive computing' [10], and 'positive technologies' [13]. One of the few systems in this area is FearNot! (Fun with Empathic Agents Reaching Novel Outcomes in Teaching) [14]. FearNot! is a virtual reality system with a mechanism for generating unscripted narrative (i.e. Virtual Storytelling). Following an anti-bullying curriculum, but in a digital environment, the child is introduced to a scenario were one of the characters is bullied and the agent asks the child for advice on an appropriate course of action. The child must then suggest a coping behavior and can see how the situation evolves when the agent follows his or her advice. After each episode, a questionnaire helps the system assess how well the child can empathize with the character being bullied. The characters are driven by an affective architecture, where the agents perceives the world through sensors and acts on it through

¹ http://www.apa.org/helpcenter/resilience.aspx

effectors, thereby producing dynamic behaviors. The architecture uses a model of the agents' emotional state to select actions using action-tendencies (e.g. a strategy of begging the bully to stop) and coping behaviors (e.g. crying).

Beyond the Lab and Into the Schools

AC researchers have made significant strides in testing their tools and techniques in classrooms. Four notable examples are highlighted below:

- Ryan Baker, Didith Rodrigo, and colleagues [15] have conducted several studies involving online
 observations of student affect while they interact with several advanced learning environments in
 classroom computer labs. They have made great strides in using techniques from the field of
 educational data mining to infer observer-annotated affect from the interaction logs, thereby
 paving the way for scalable context-based affect detectors.
- Cristina Conati [16] has pioneered a research program that integrates bottom-up data from sensors (e.g., an eye tracker) with top-down contextual information to intelligently reason about emotions that 6th and 7th grade students experience while learning with an educational game.
- Beverly Woolf, Ivon Arroyo, Win Burleson, and their teams [17] have collected multimodal
 affect data (facial expressions, body movements, electrodermal response, mouse pressure, and
 contextual cues) while high-school students interacted with an ITS on topics in elementary
 mathematics.
- James Lester, Jennifer Sabourin, Scott McQuiggan, and colleagues [18] have tracked student
 emotions, built models to predict emotions from interactional parameters, contextual cues,
 individual difference measures while students interact with CRYSTAL ISLAND, a narrativecentered learning environment.

Looking Forward

Affective Computing is advancing the fields of learning sciences and learning technologies in a number of ways. First, affect detection and affect generation techniques are progressing to a point where it is feasible for these systems to be integrated in next-generation advanced learning technologies. These systems aim to improve learning outcomes by detecting and responding to affective states which are harmful to learning and/or inducing affect states that might be beneficial to learning.

Second, technological artifacts from the field of AC is also advancing our understanding of learning processes. The new technologies provide a magnifying glass into diverse learning phenomena by affording the moment-to-moment non-intrusive tracking of ephemeral affect-cognitive relationships that are beyond the radar of current self-report measures.

Finally, we envision a new class of learning technologies that are aimed at the personal development curricula, a field yet to be actively explored. The emphasis in ITS research has been on supporting STEM learning, which is perfectly justifiable given the importance of STEM for career development. That being said, it is increasingly recognized in the fields of psychology that personal development skills are important for student's wellbeing and can and should be taught alongside academic skills. Affect-aware systems have the potential to make a significant impact in this application domain.

In summary, the limits of how technologies can support learning and the type of experiences they can afford are constantly been pushed due to progress in affective computing. The *frontiers* of what we know about what should and can be done to promote learning are moving forward in traditional and in new application domains. The future of affect-aware learning technologies is bright indeed.

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