Computers in Human Behavior 42 (2015) 127–137

Contents lists available at ScienceDirect

Computers in Human Behavior

journal homepage: www.elsevier.com/locate/comphumbeh

Utilizing sensor data to model students' creativity in a digital environment

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ARTICLE INFO

Article history:
Available online 8 December 2013

Keywords:
Creativity
Student modeling
Eye tracking
EEG
Skin conductance
Intelligent Tutoring Systems

ABSTRACT

While creativity is essential for developing students' broad expertise in Science, Technology, Engineering, and Math (STEM) fields, many students struggle with various aspects of being creative. Digital technologies have the unique opportunity to support the creative process by (1) recognizing elements of students' creativity, such as when creativity is lacking (*modeling* step), and (2) providing tailored scaffolding based on that information (*intervention* step). However, to date little work exists on either of these aspects. Here, we focus on the modeling step. Specifically, we explore the utility of various sensing devices, including an eye tracker, a skin conductance bracelet, and an EEG sensor, for modeling creativity during an educational activity, namely geometry proof generation. We found reliable differences in sensor features characterizing low vs. high creativity students. We then applied machine learning to build classifiers that achieved good accuracy in distinguishing these two student groups, providing evidence that sensor features are valuable for modeling creativity.

1. Introduction

There is a general consensus that creativity entails a product, idea, or process that is *novel* and *useful* (Amabile, 1996; Mayer, 1999). Given this definition, it is not surprising that creativity is at the core of societal advancement. However, it is important to remember that creativity is present "not only when great historical works are born but also whenever a person imagines, combines, alters, and creates something new, no matter how small" (Vygotsky, 2004). Educational activities therefore afford many opportunities for creativity. Unfortunately, students have become less creative rather than more in recent years, as indicated by a 2011 meta-review published in the *Creativity Research Journal* (Kim, 2011). Certainly, creativity entails many challenges, such as persevering through impasses, attacking a problem from multiple perspectives, maintaining positive affect in the face of failure, dealing with uncertainty in open-ended problem solving, and being flexible in one's approaches (Amabile, Barsade, Mueller, & Staw, 2005; Burleson, 2005; Csikszentmihalyi, 1990; Fasko, 2001; Gough, 1979; Hennessey & Amabile, 2009; Isen, Daubman, & Nowicki, 1987; Mayer, 1989). Therefore, students need personalized, continuous support and training throughout the process of creative endeavors. However, today's classrooms are not equipped to provide such support (McCorkle, Payan, Reardon, & Kling, 2007). In particular, while personalized instruction has tremendous potential to improve student learning (Cohen, Kulik, & Kulik, 1982; Lepper, 1988; VanLehn, 2011), affect (Lepper, 1988; Picard, 1997; Woolf et al., 2010), and metacognitive behaviors (Bielaczyc, Pirolli, & Brown, 1995; Chi & VanLehn, 2010; Muldner & Conati, 2010), providing a human tutor for each student is simply not practical. An alternative approach, which does not suffer from this limitation, corresponds to a class of cyberlearning technologies referred to as Intelligent Tutoring Systems (ITSs).

ITSs rely on Artificial Intelligence techniques to provide instruction that is tailored to a given student's needs, thereby increasing the chances of student learning. Once implemented, ITSs can easily be deployed to provide the benefits of personalized instruction to any student equipped with a computer, a laptop, or a related digital device. ITSs have already successfully improved domain learning by tracking students' problem-solving progress, providing tailored help and feedback, and selecting appropriate problems (Aleven, McLaren, Roll, & Koedinger, 2006; Arroyo, Woolf, Cooper, Burleson, & Muldner, 2011; Koedinger, Anderson, Hadley, & Mark, 1997; Self, 1998; VanLehn et al., 2005). However, ITSs have also been criticized for over-constraining student activities and over-emphasizing shallow procedural knowledge, and therefore not properly addressing 21st century skills such as creativity and critical thinking (Trilling & Fadel, 2009). In particular, to date, very little work exists on using ITSs to support creativity. To fill this gap, our ultimate goal is to extend ITSs with personalized *Intelligent Creativity Support (ICS)* to scaffold creative endeavors in various digital environments.

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http://dx.doi.org/10.1016/j.chb.2013.10.060

To provide personalized support in digital environments through ICS tools, the corresponding system needs information about the student that can then be used to tailor pedagogical interventions. This functionality is realized by a *student model* (also called a user model), which is the ITS component responsible for assessing student traits and behaviors as he or she is working on an instructional task. Typically, student models aim to collect information about students unobtrusively, without disrupting students' work. In our case, a second requirement is that students are given freedom to explore and innovate, i.e., that their interaction with the system is not constrained so that creativity is not hindered. The latter requirement makes the modeling task especially difficult because it is well established that open-ended interaction results in a low-bandwidth situation for the model, as there is little direction information on the target states of interest (VanLehn, 1988a). Further complicating the situation is the fact that there is limited knowledge of how to model creativity in a digital environment.

To address these modeling challenges, one possibility is to provide the model with information about students' physiological data captured by various sensing devices. The use of sensing devices for student modeling has gained a lot of attention lately because these do not require interrupting students or restraining their interaction with a system. Sensing devices are also becoming more ubiquitous and are moving out of the laboratory and into today's classrooms (e.g., Arroyo, Cooper, Burleson, Muldner & Christopherson, 2009). The approach of using sensing devices has already been successfully applied to obtain information on student states like knowledge or affect as students interact with digital learning environments (Kardan & Conati, 2012; Muldner, Burleson, & VanLehn, 2010). However, to date it has not been tested for modeling of individual student creativity.

Here, we present our work exploring the utility of sensing devices for modeling creativity, including an eye tracker, an Electroencephalography (EEG), and a skin conductance (SC) bracelet. Specifically, our work addresses the following question:

Can gaze, SC, and EEG information be used to create a student model that distinguishes between low creativity and high creativity students?

To answer this question, we used the above-mentioned sensors to record data while students engaged in a creative problem solving task in a digital environment. Our analysis revealed reliable differences between *low creativity* and *high creativity* students. We then applied machine learning to generate empirical models of creativity – we present two models that achieved good accuracy in discriminating between the low and high creativity groups.

We begin with an overview of creativity and related work on sensing devices for various modeling tasks. We then describe the study we conducted and our findings, concluding with a discussion of our results and some future work.

2. Related work

Above, we stated that creativity involves the production of "novel" and "useful" ideas or products. In an educational context, novelty may be assessed in several ways. Mayer (1999) notes that creativity should be considered with respect to an individual, and so novel solutions are those that one has not previously produced. Another established novelty metric involves comparing a given student's solutions to other students', for instance to assess how frequent that student's solution is with respect to the pool of solutions produced by all students (Levav-Waynberg & Leikin, 2012). As far as characterizing what is meant by "useful" ideas or solutions, researchers are increasingly recognizing that considering only the correctness of a student's solution is not sufficient, because students learn from "productive failures", impasses, and conflicts (VanLehn, 1988b).

2.1. Factors influencing creativity

Factors that influence creativity can be broadly classified as follows: domain- and creativity-relevant skills, affect, and external factors (Hennessey & Amabile, 2010). Here, we focus on the former two aspects because they are most relevant to our work. As far as domain-related skills, there is not yet agreement on whether being creative requires domain expertise (Baer, 2010). For instance, the well known Torrance Tests of Creativity Thinking aim to predict creativity performance generally, outside of a given domain (for a discussion, see (Plucker, 1998)). In general, however, many researchers agree that creativity requires both domain-independent creativity skills and domain expertise (e.g., Amabile, Conti, Coon, Lazenby, & Herron, 1996), as summarized in (Baer, 2010).

Affect also plays a key role in creative endeavors. The majority of work investigating its impact classifies affect broadly, as positive, negative, and neutral (as, for instance, stated in (Zhou, Shin, Brass, Choi, & Zhang, 2009) and encapsulated in a recent meta review (Davis, 2009)). For instance, Isen et al. (1987) found that participants experiencing positive affect performed better on insight-type creative problem solving tasks than participants in a negative or neutral affective state. In general, Isen and colleagues argue that positive affect fosters creativity and problem solving (Isen, 2008), a finding confirmed by some other work. To illustrate, Murray, Sujan, Hirt, and Sujan (1990) demonstrated that responses of participants in a positive mood were judged as more creative by independent judges than of participants in a neutral mood. Similarly, Amabile et al. (2005) analyzed daily entries written by employees of various companies and found that positive affect increased creativity. The beneficial influence of positive affect on creativity has been recently summarized in several meta reviews (Davis, 2009; Lyubomirsky, King, & Diener, 2005). However, the more recent of these reviews (Davis, 2009) cautions that the relationship between affect and creative performance is likely curvilinear, with moderate intensity of positive affect fostering creativity, but low and high levels interfering with it. Moreover, while in general the meta-reviews highlight that positive affect is better than negative affect for fostering creativity, there are some exceptions. For example, George and Zhou (2002) found that negative affect can help identify when effort is needed to refine and improve creative outcomes.

As far as specific emotions and their impact on creativity, as we pointed out above, there is much less work on fine-grained emotions than on broad emotion categories, but there are some exceptions. One relevant affective state is Flow, which occurs when individuals are fully engaged in a challenge matched to their skill, and which is often present during highly creative endeavors (Csikszentmihalyi, 1996). Another specific construct is motivation and/or interest, which fosters creativity (e.g., Conti, Coon, & Amabile, 1996; Isen & Reeve, 2005). Moreover, short bursts of frustration may be beneficial for creativity (George & Zhou, 2002; Hennessey & Amabile, 2010), because they could help signal a need for refinement and heighten motivation to triumph over the impasse.

2.2. Assessment of creativity

There are many non-automated methods for assessing creativity, for instance using surveys to measure students' inherent creative tendencies or judges to assess creative qualities of products (Gough, 1979; Hennessey, Amabile, & Mueller, 2011; Levav-Waynberg & Leikin, 2012; Torrance, 1974). In this review, we focus on the latter aspect because it is the most relevant to our work, i.e., techniques that measure creative qualities of a product. One technique corresponds to Amabile's consensual assessment (Hennessey