Subliminal priming enhances learning in a distant virtual 3D Intelligent Tutoring System

Pierre Chalfoun and Claude Frasson

Abstract—**In this paper we discuss the use of subliminal priming in a novel way in the context of a 3D virtual tutoring system. Subliminal priming is a technique used to project information to a learner outside of his perceptual field. Subliminal projections have been used in various fields but never in the domain of 3D Intelligent Tutoring Systems. We also monitored the physiological reactions of the user while they learn. We will present the virtual environment and the subliminal module used. The results of this study show that learners do feel motivated to learn in a 3D environment and enjoy the experience even if they hardly have any video gaming experience at all. Furthermore, subliminal priming, even though not consciously perceived by a learner, seems to elicit strong physiological reactions as well as positively impacts performance.**

Index Terms— **Intelligent tutoring system, subliminal learning, physiological signals, virtual agents**

I. Introduction

FOR more than twenty years now, the aim of intelligent Tutoring Systems (ITS) has been to properly adapt learning sessions and material to the learner. The systems evolved from Intelligent Computer-Aided Instruction to Intelligent Tutoring. Nowadays, ITS comprise of multiple goal-specific modules to aid the learner. One of these modules, the tutor, can possess and make use of one or more pedagogical strategies during a learning session depending on the learner's needs and evolution. However these strategies were mainly based on classical learning and teaching theories where emotions did not, at first, have an important role to play. Nevertheless, the importance of incorporating emotions into those strategies has been getting a lot of attention in recent years. Indeed, a growing body of work has proven that emotions, especially motivation and engagement, and cognition are widely related in various cognitive tasks [1]. Moreover, the importance of measuring emotions as well as consider them has become the focus of much growing research. The availability, ease of use and affordability of physiological devices helped in their integration into the tutoring systems. This interesting collaboration between ITS and physiological devices supplied the student model with affective data. That data is then used to model the learner's emotional and physiological profile and thus adapt learning accordingly. Another step forward was taken when emotions and physiological signals were combined with virtual reality. Indeed, this new partnership is very important to consider for recent evidence has shown the relevance of using such virtual ITS for affective feedback and adaptation [2].

Nevertheless, the current learning strategies have a limitation when it comes to processing complex information. Indeed, classical learning theories base their intervention on attention to the specified task at hand. Complex information is presented in pieces to gradually enable the learner to concentrate on one small piece of the puzzle at a time. However, a large body of work in neuroscience led us to believe that learning simple to complex information can be done without perception or complete awareness at the task at hand [3]– [6]. The idea that any information projected too fast to be consciously perceived by a learner (called subliminal projection), has been the focus of much research in neuroscience but hardly any attention has been directed to it in the ITS community. Indeed, the existence of perceptual learning without perception has been proven and we believe that a subliminal stimulus, that is stimulus below the threshold of conscious perception, can help and increase learning in various situations if carefully constructed and projected.

The approach of combining emotion detection and subliminal projections aiming at faster and better learning in a virtual learning ITS is unique in our field and has, to our knowledge, never been put forward before. We intend to investigate in this paper the impact of such a novel learning strategy in a 3D virtual system on learning by stating three research questions. First, is solving a problem in a 3D virtual system has a positive emotional impact on learning? Second, is it possible to enhance the transmission of classic information using a subliminal technique? And third, what pertinent correlations can we establish between the physiological signals, thus the emotional state of the learner, and the successive suggestions that we will project subliminally?

The organization of this paper is as follow: In the first section, we explain the grounds upon which this novel research is grounded since this work is the first of its genre in the ITS community. The second section will present and discuss the previous work related to various aspects of our research. The third section describes the experiment setup and depicts the various aspects related to subliminal stimulus in a virtual 3D tutoring system. Section four will present the obtained results

We acknowledge the support for this work from the Fond Québecois pour la Recherche sur la Société et la Culture (FQRSC).

Pierre Chalfoun is a PhD student at the Université De Montréal, Montreal Canada (phone: 1.514.343.5648; e-mail: chalfoun@iro.umontreal.ca)

Claude Frasson is a full professor and director of the HERON and GRITI laboratories at the Université de Montreal (e-mail: frasson@iro.umontreal.ca)

Publisher Identification Number 1558-7908-102008-01

which will be discussed in section five leading to the last section where we conclude and present future work.

II. SUBLIMINAL PRIMING

As mentioned before, this research focuses on subliminal stimulus in a 3D virtual system to enhance learning. Before going further, we need to clearly establish the terminology that will be used in this paper. Indeed, the simple mention of the word subliminal can lead to discord and confusion. We establish a stimulus as being subliminal when it is sent too fast for a user to consciously report its existence. Conscious perception is well established in neuroscience and its properties are well known. One of those properties is the existence of a threshold for conscious access. It is precisely this threshold that we accept as being the "line" between conscious and subconscious perception (a term also referred to as unconscious perception). The technique used to send a given stimulus below this threshold of awareness is what's known as a subliminal stimulus as opposed to a paraliminal stimulus that can be consciously perceived above the threshold [7].

Moreover, subliminal information must therefore be presented for a very short time and can vary in intensity, duration and frequency. It has however been established that subliminally sent information can bias behavior and even yield better results under specific experimental situations [5], [8], [9]. Indeed, simply sending subliminal messages without caring for context nor desired goals and emotions can prove to be inefficient or simply useless [10]–[12]. The cognitive process that takes place when the stimulus, either vocal or visual, is either unattended or subliminally projected is a stage we call subconscious processing. Contrary to popular belief, high-level semantic and even emotional processing has been observed during this stage [13]–[14]. Another fascinating experiment placed forward the long-term effect of subliminal priming on the visual system [5]. In this experiment, subjects learned a task without actually realizing it. Participants were asked to focus their attention on random letters appearing on a computer screen while at the same time imperceptible moving dots in different directions were appearing just outside of their visual field. After a month's training, the participants subconsciously learned to recognize and better identify the dots movements even if their attention was concentrated on the letters appearing in their visual field on the screen.

However, sending subliminal primes in a virtual environment is no easy task. Indeed, one of the main techniques used to subliminally project information is called masked priming. In this method, the system displays, for a very specific time (ex: 200ms), a figure that has nothing to do with any of the information we want to learner to process. It usually takes the form of a random series of cubes, rectangles and squares. Immediately after projecting this mask, the information we wish to subliminally project is sent. It is called the prime. This prime can only be sent during a very short time to elude the conscious perception of the learner (ex: 30 ms). Following the prime, a second mask, identical to the first, is projected at the same speed as the first mask. Since a virtual environment is basically a never ending loop where different processes take place, such as drawing the elements, moving the avatars, processing mouse commands and so forth, we carefully implanted a subliminal module to assure that the stimulus be displayed for the specific task without delaying the system.

Thus, we believe possible, with our carefully designed subliminal stimulus, to enhance learning without consciously alerting the learner. We also believe that this new form of learning can elicit a set of positive emotional conditions, such as motivation and engagement, in the learner and thus enhance learning, problem solving and even decision making.

III. RELATED WORK

Subconscious learning in a virtual 3D tutoring system is a novel approach. Thus, to the best of our knowledge, no existent work related to this specific research has been found neither in the ITS community nor Human Computer Interaction (HCI) community. However, a handful of papers in various fields have claimed the use of subliminal priming as a support for memory in the HCI community.

One of the early works regarding the implementation of subliminal cues for task-supported operation within a software was the text editor program of [15]. In this experiment, Wallace and colleagues investigated the response of subjects when requiring help from a text editor. They found that the frequency at which subjects demanded help was much lower when the required information was presented in subliminal matter. Another very important finding is the fact that all previous studies did not have the intended results because the projected stimulus did not take into account the specifications of the computer such as screen resolution and refresh rate. The Memory Glasses by [3] used wearable glasses that projects subliminal cues as a strategy for just-in time memory support. The objective was to investigate the effect of various subliminal cues (correct and misleading) on retention in a word-face learning paradigm and compare recall performance. Another use of priming for memory support can be found in the thesis of [12] where the author assesses the effects of brief subliminal primes on memory retention during an interference task. The thesis examined in detail multiple parameters of subliminal projections such as duration, relevance and contract. Although the results of these priming seemed very encouraging, the author cautions HCI designers that misusing subliminal priming that can lead to critical disruptions of ongoing tasks. Further work from [16] have hypothesized that recognition performance in a standard item-based forgetting paradigm may be altered by subliminal cues. These authors believe that these cues can automatically activate different mnemonic strategies thus enhancing memory retention and recall. The results have shown that item-based words primed with the word "remember" seem to be better retained than "forgot" by a very slim difference however. Besides seeming to impact memory, subliminal priming can also have an emotional consequence on learners. Very recent work from [8] put forward an interesting effect that subliminal priming can have on the self-attribution of authorship of events. Subjects were asked to compete against a computer in removing non-words such as “gewxs” from a computer screen in the fastest time possible. After a determined amount of time, the computer would remove the word. Subliminal primes of self-associated words like “I” and “me” before an action increased the personal feeling that it was the participant that eliminated the non-word and not the computer, thus increasing the feeling of self-authorship of events.

Since we also use physiological sensors to monitor the emotional reactions of the learner, it would be relevant to sum some of the work related to using physiological sensors either to record and analyze emotions that can occur in either a virtual 3D environment or not. Physiological signals are generally correlated with emotions by associating specific signals, such as skin conductance and heart rate, to valance and/or arousal [17]. Indeed, the Empathic Companion is a good example where multiple physiological sensors, namely galvanic skin response, heart rate and respiration were taken in real-time to analyze and adapt the tutor to the emotional reactions of the learner in a virtual 3D ITS [18]. Further research has analyzed a more detailed and relevant emotional significance of physiological signals, either in complex learning or gaming [19]–[21].

IV. Experiment

Our research incorporated and combines all of the many different aspects of the presented related work. It uses subliminal priming in a 3D intelligent tutoring system while monitoring the physiological reactions on the learner. Moreover, we constructed the subliminal cues in such a way that would accelerate the learning process by triggering and enhancing an already possessed knowledge.

A. *Design of the experiment*

Indeed, the focus of the experiment is to visually teach, in a virtual 3D environment, the construction of an odd magic square of any order with the use of neither a calculator nor one mental arithmetic operation. A magic square of order n is a square containing n^2 distinct integers disposed in a way such as all the n numbers contained in all rows, columns or diagonals sum to the same constant. Fig. 1 depicts such a square.

To construct the following square, one must successively apply three very simple tricks. We decided to show the learners the end result of each trick without explaining how. As an example, the first trick to construction any magic square is to place the next number one square above and two squares to the right of the last one (exactly like a knight’s move in chess). If we look at Fig. 1, we see that the number 10 is placed one square above and two squares to the right of number 9. Same logic applies to numbers 1 and 2, 23 and 24 and so forth. Instead of giving away the answer to the first trick, we ask the subjects to deduce this rule by themselves. This is where the subliminal stimulus comes in play. We will have two groups, one group will take part of the experiment without subliminal stimulus (control group) and the tutor will subliminally send the answer to the other group. We will then compare performances, time to complete and physiological signals. The teaching material is separated into parts, or PowerPoint-like slides, and displayed at a slow rate giving every learner an equal chance at fully reading the “slide”. If the learner wished to restart a lesson, he or she simply has to click on the virtual agent.

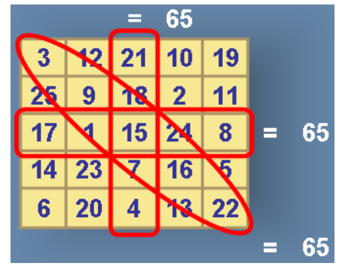

Fig. 1. Magic square of order 5 that sums to 65.

The subliminal stimulus and threshold were carefully chosen following the neural bases of subliminal priming [7]. Each stimulus was preceded by a 271 ms pre-mask of random geometrical figures, a 29 ms prime and a 271 post-mask of other random geometrical figures. The subliminal stimulus that will be presented to one of the two groups will be placed at significant places before and after specific slides. The experiment intends to “boost” learning by priming the answer before showing the corresponding slide. Fig. 2 shows a diagram of the way subliminal priming will take place between slide 1 and slide 2 for example when learning to deduce the way the first trick operates.

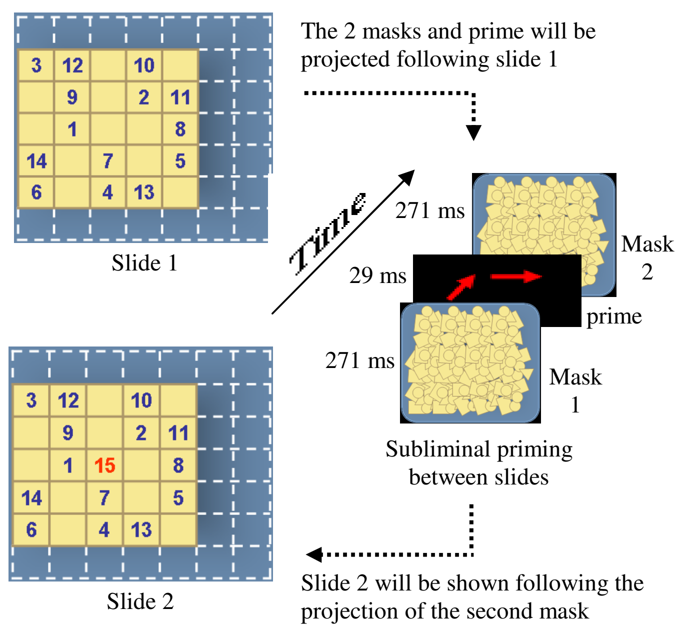

Fig. 2. Subliminal priming of the solution between 2 slides

The learners are instructed to answer questions following each deduced trick to test their knowledge. The learners were instructed to finish the experiment as quickly and efficiently as they could. No time limit was imposed. A base line for the physiological signals preceded all monitored activities. A questionnaire was administered before the start of the experiment aiming at collecting demographical data as well as the gaming experience of the subjects. Another series of questions were asked at the end of the experiment to evaluate the learner's appreciation and more importantly their awareness to the subliminal stimulus.

B. *Mocas and material used*

Learning takes place in a game-like environment called MOCAS [22] as show in Fig. 3. The experiment has 3 rooms like the one illustrated on the left part of the figure. Each room teaches one trick. The lessons and examples are presented in the virtual world. MOCAS takes place in full screen for a more complete immersion and less window distracting events. Furthermore, the system clock is hidden to users don't get stressed by continuously monitoring the time they have spent on each lesson. The interactions between the avatar's learner and the pedagogical are done via a mouse click. One click on the pedagogical avatar starts the lesson.

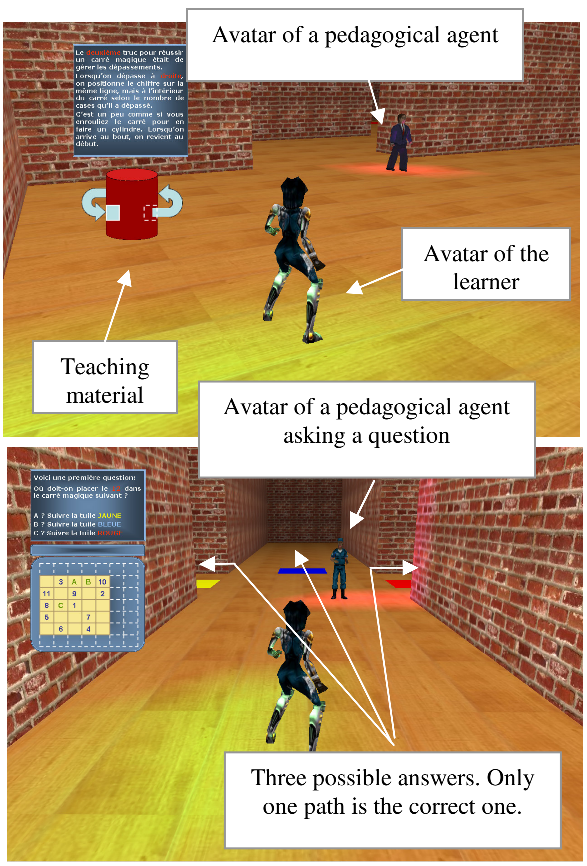

Fig. 3. The 3D virtual learning environment

The learners are instructed to continue once they are convinced they have discovered the workings of each trick. They are then asked to answer a series of questions by another set of visually different pedagogical avatar. Each question is related to the trick previously learned. The agent asks the user to correctly place a number in a magic square. The learner responds by choosing the path that correctly answers the question. In the presented screen shot of Fig. 3, the learner can choose to follow either the yellow, blue or red path. Two of these paths will be dead-ends where he will be instructed to turn back and try again.

Physiological signals of the learners were also monitored in real-time and saved for further analysis. The used signals were heart rate, galvanic skin response, respiration rate and skin temperature. The signals are managed by the ProComp Infinity encoder [23].

V. Learners Tested

A total of 31 healthy volunteers, 16 men and 15 women, took part of the experiment. The sample's mean age was 28 (SD = 4.81). Only two volunteers had extensive video gaming experience. All the others gaming experience ranged anywhere from weak to average high. A repartition of the learners can be found in Table I.

TABLE I
Participants' distribution

	Men	Women
Group A : primed with subliminal stimulus	8	7
Group B : no subliminal stimulus	8	8
	16	*15*
Total	**31**	

VI. Results And Discussion

The first aspect we wanted to investigate in this experiment was the presence, if any, of a positive emotional impact of problem solving in a 3D virtual system. Table II highlights some very interesting results regarding the degree of motivation when using our system. It seems that the learners having the least video game experience are the ones that were actually the most motivated to learn with it.

TABLE II
Motivational level of learners

Video gaming experience	*How motivating was it for you to learn in this 3D environment?*	
	Highly	Moderately
Low	18	
Moderate	6	
Moderate to High	4	
High	2	1
Total	30	1

Measuring the degree of enjoyment was also important because positive emotions are exactly where we want the learner to be for optimal learning. Table II shows that even though the same group of learners who have shown a great deal of motivation seem to have enjoyed the system the most, the 5 learners who showed moderate enjoyment are important to consider. When later asked why they responded with an average score, all five answers converged to the same result: the system was not flexible enough to their needs. They would have loved to be able to manipulate the material taught, to rotate it or spin it in a different direction/angle. The score they gave had nothing to do with the material learned. It had to do with the fact that they expected the environment to be very much like a game, extremely flexible and all components moveable and playable.

The second research question was to wonder if it would be possible to enhance the transmission of classic information using a subliminal technique. The results we obtained are surprising to that regard. Indeed, Fig. 4 clearly shows that overall performance with the presence of the subliminal module was 2.6 times more efficient than without the module (44% less mistakes overall with the presence of the subliminal module).

TABLE III
ENGAGEMENT LEVEL OF LEARNERS

Video gaming experience	*How much was it enjoyable to learn in this 3D environment?*	
	Highly	Moderately
Low	16	
Moderate	6	2
Moderate to high	4	
High		3
Grand Total	26	5

Furthermore, the number of re-clicks is also an important indicator as to the efficiency of the subliminal module. This number represents the number of times learners asked to restart the lesson. A number of 5 re-clicks for the first trick means that this specific lesson was repeated 5 times. We can clearly see on those results that there is a significant difference ($p = 0.03$, $\alpha = 0.05$) in the amount of re-clicks when using the subliminal module, except for the last lesson.

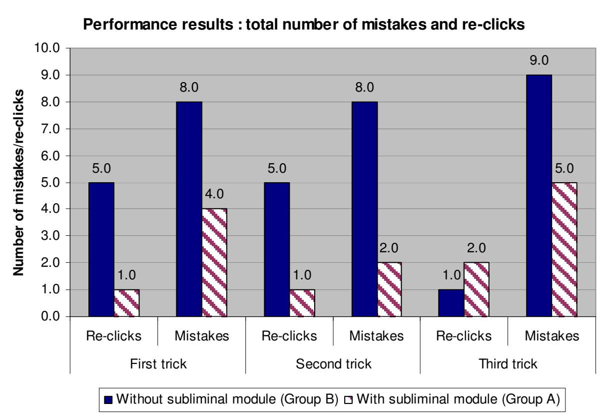

Fig. 4. The overall number of mistakes made for every trick

That tends to show that users tend to repeat every lesson three times less on average. This result is surprising but very encouraging. In our efforts to better understand the reasons behind these results, we decided to analyze the time subliminally primed learners took before answering each question and compare it with the time it took to our control group. Fig. 5 presents the obtained results.

The results tend to confirm what we have been observing all along. Subliminal priming at specific and well timed intervals seem to significantly reduce the time spend on each question. Not only does the performance of primed learners is enhanced but the time they spent on each question is reduced as well by an overall factor of 1.3 (Single factor ANOVA $p = 0.023$, $r = 0.858$, *r-square* = 0.736, $\alpha = 0.05$). It is important to note that NO subliminal priming is done during the questions.

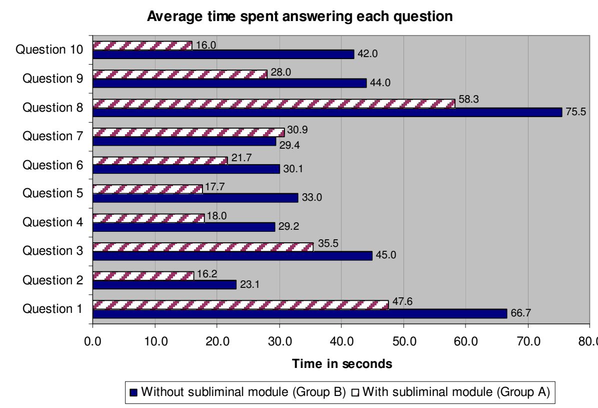

Fig. 5. Average time spent on each question

All the priming is done during the lessons taught. The answer to the questions is not projected subliminally when the question is asked. Two factors in our opinion explain those results. First and foremost, the subliminal priming seems to act as an accelerator on learning because some of the primed learners did not read the entire lessons. Four of them skipped right in the middle and clearly stated that they understood the lesson before its end. None of the learners in the control group interrupted the lessons. Second, the fact that the subliminal priming is goal-relevant to the cognitive task at hand might accelerate already present knowledge to quickly converse to a solution as stated by three previous studies presented here [10].

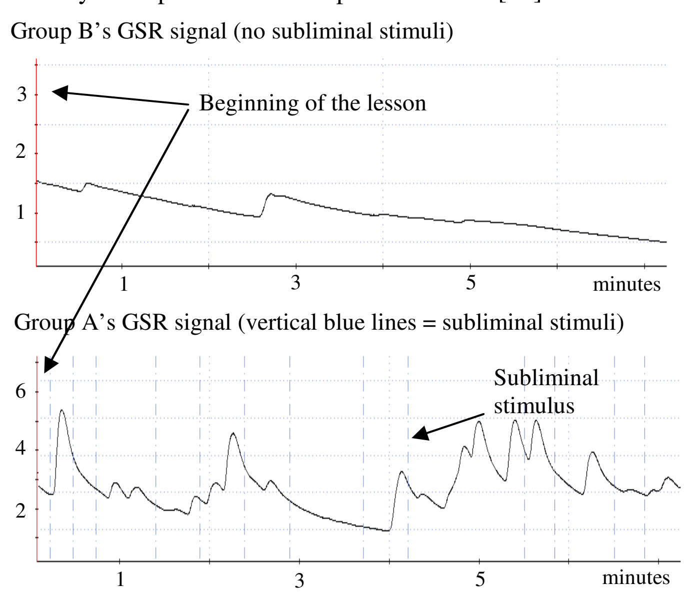

Fig. 6. Mean GSR signals for the subjects while learning the second trick

The last aspect we wanted to investigate was the relevant links between the physiological signals and subliminal primes. We used Matlab to smooth and average the galvanic skin response. Fig. 6 above presents the levels of arousal when learning the second lesson, thus trying to deduce the second trick. The vertical blue dotted lines represent the moment in time when priming is projected on the screen. The GSR signal value is presented in black. The red line denotes the beginning of the lesson.

As we can clearly see, a learner's emotional reaction significantly differs when viewing a lesson without the subliminal primes. The difference seen here represents an increase ranging from 10% to 150% from the averaged baseline. Since there is a positive linear correlation of GSR with arousal [17], we can state with confidence that not only subliminal stimulus is subconsciously perceived but seems to produce significantly high arousal states in the learners.

VII. Conclusion

We presented in this paper the use of subliminal priming in a novel way in the context of a 3D virtual tutoring system. In contrast to the previous work regarding the use of subliminal priming, our work differs in three ways. First, the subliminal priming was used to elicit an already possessed knowledge to get a better and quicker understanding of the problem at hand from the group subjected to subliminal stimulus. We showed that not only the overall performance was enhanced for that group but the time learners took to answering questions was shortened by the presence of the subliminal priming module. Second, the integration of 3D gaming-like environment, physiological sensors and subliminal stimulus is novel in itself and as the results have shown seem to yield very promising results by showing high levels of motivation and enjoyment. Third, we presented physiological evidence supporting the emotional response in terms of valence of subliminal priming in the context of learning in a virtual environment. In the light of the encouraging results, we plan as future work to determine and validate in more details the various links between the subliminal primes and the other physiological signals and try to link them to performance if possible in the hopes of establishing solid correlations. We also would like to examine the pertinence of projecting a more complex series of stimulus in a more elaborate situation where the solution is equal or more important than the problem. We would like to see and test the different kinds of priming that we could use in those specific situations. Finally we would also like to study the various aspects of real-time adaptation and subliminal priming with regards to the emotional state of the learner. Although the preliminary results clearly show that this innovative technique helps learners better answer questions, we believe further research will demonstrate the positive impacts and effectiveness of this novel work on the full learning process.

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