A Study of subjective emotions, self-regulatory processes, and learning gains: are pedagogical agents effective in fostering learning?

Nicholas Mudrick, Roger Azevedo, Michelle Taub, Reza Feyzi-Behnagh, François Bouchet

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Nicholas Mudrick, North Carolina State University, Raleigh, North Carolina, nvmudric@ncsu.edu
Roger Azevedo, North Carolina State University, Raleigh, North Carolina, razeved@ncsu.edu
Michelle Taub, North Carolina State University, Raleigh, North Carolina, mtaub@ncsu.edu
Reza Feyzi Begnagh, McGill University, Montreal, QC, reza.feyzibegnagh@mail mcgill.ca
François Bouchet, Université Pierre et Marie Curie – LIP6, Paris, France, francois.bouchet@lip6 fr

Abstract: Though some research has focused on agent-direct affective processes, none has examined its impact on multi-agent learning environments and on the detection, modeling and fostering of self-regulated learning processes. 38 participants interacted with MetaTutor, an intelligent, multi-agent hypermedia-learning environment, to learn about the human circulatory system. The log files, containing information about their overall performance, and self-report measures, assessing emotions and impressions towards agents obtained from their interactions with MetaTutor were used to assess the relationship between subjective agent-directed emotions, SRL processes and overall learning gains. Results indicate that agent-directed emotions were not significantly related to SRL strategy use, negative agent-directed emotions were significantly related to negative learning gains and negative agent-directed emotions for two specific agents (representative of two SRL pillars) were related to negative learning gains. Implications for the design of multi-agent systems and the role of emotions during human-agent interactions and their relation to learning are discussed.

Introduction

While some researchers have focused on agent-directed affective processes, none have examined the impact that multi-agent systems have on the detection, tracking, modeling and ultimately fostering of different self-regulated learning processes. Within the literature, there is an implicit assumption that the use of pedagogical agents (PAs) is effective for learning and beneficial in fostering cognitive, affective, metacognitive and motivational (CAMM) processes (Azevedo et al., 2013). However, none have asked the fundamental question of whether or not PAs actually do facilitate the use of self-regulated learning (SRL) processes and impact overall learning about complex topics. Because of the paucity of current research regarding this topic, this study aims to address these issues through an examination of the associations between subjective emotions towards agents, SRL processes, and overall learning gains.

A recent review of the literature on PAs (Veletsianos & Russell, 2014) has revealed that research on PAs has been predominantly couched within socio-cognitive and cognitive-load theories, following the paradigm of computers as social actors (Kim & Baylor, 2006). A prevalent assertion within this paradigm is the view that PAs are able to aid learning with adaptive, supportive scaffolding and guidance of cognitive and metacognitive skills (Biswas, Leelawong, Shwartz, Vye & the Teachable Agents Group at Vanderbilt, 2005). Researchers within this area purport the possibility that agents can provide adaptive, individualized scaffolding and feedback to students and the basis for this idea rests in the success of one-to-one human-human tutoring (VanLehn, 2011). Another claim noted in the literature is the perceived ability of agents being able to emulate human behavior through realistic simulations (Sklar & Richards, 2010; Veletsianos & Russell, 2014). The employment of this strategy intends to facilitate natural communication between the PAs and the learners, and some research evidence indicates that when agents are highly realistic, an overall emotional connection is increased (Gulz, 2005; Woo, 2008). Furthermore, research has indicated that a sense of social interaction with the agents can help with collaboration in social learning (Gulz, 2005; Kim & Baylor, 2006; Sklar & Richards, 2010; Woo, 2008). Some studies indicate that engaging in unconstrained interaction with agents, learners treat the agents as conversational partners (Graesser & McNamara, 2010) while other research indicates that they could also lead to frustration and disappointment (De Angeli & Brahnam, 2008).

Contemporary research also operates on the expectation that the presence of agents increases students' motivation (Kim & Baylor, 2006; Kim & Wei, 2011; Kramer & Bente, 2010; Lusk & Atkinson, 2007). Agents are presumed to impact learners' interest, attention, and provide students a medium between humans and computers through the provision of motivational and affective instructions (Baylor, 2011; Lusk & Atkinson, 2007). Some have situated their examination into these processes within the persona effect, which claims learners perceive their learning experience positively as a result of understanding computers to be social actors (Choi & Clark, 2006).

A universal assumption within the research exists that PAs improve learning and performance through the combination of the aforementioned factors. Agents can provide various affordances that lead to a deeper understanding of the presented material (Veletsianos & Russel, 2014). Most importantly, empirical research "has shown that simply adding pedagogical agents in a digital environment does not lead to better learning outcomes," (Veletsianos & Russel, 2014, p. 764). Much of the literature has shown no significant differences between the presence and absence of agents on learning outcomes within an intelligent tutoring system (ITS) (Choi & Clark, 2006; Louwerse, Graesser, Lu, & Mitchell, 2005). While research that has found significance of agent presence has been predominantly focused on the design of the agents themselves (Jackson & Graesser, 2007; Veletsianos, 2007, 2010). All of the claims and assumptions about the effects of agents within ITSs are predicated on the students' interpretations of the agents themselves. However, the effects of these claims have yet to be addressed in a comprehensive manner.

We have begun to address some of these issues using an intelligent, hypermedia multi-agent learning environment called MetaTutor (Azevedo et al., 2009, 2010, 2012, 2013) that attempts to facilitate SRL in students as they learn about complex science topics. SRL rests on the assumption that successful learning is based in a learner's ability to accurately monitor and regulate their cognitive, affective, metacognitive, and motivational processes during learning (Zimmerman & Schunk, 2011). As such, it is a fundamental education construct that has been shown to be effective in students' ability to learn and study about various concepts (Azevedo, 2007; Winne & Perry, 2000; Zimmerman & Schunk, 2011). Research has shown that when students engage in SRL in the context of learning in computer based learning environments (CBLEs), they achieve high learning gains (Azevedo et al., 2013; Greene & Azevedo, 2010).

The impact of agent-directed self-regulation on learning gains with the MetaTutor environment has also been discussed. Within the learning environment, there are four PAs present who act to assist the student in learning through the provision of appropriate scaffolding for each participant. Each of the three agents specializes in one of the three pillars of self-regulated learning; Sam the Strategizer facilitates the use of learning strategies, Pam the Planner supports setting sub-goals and planning learning, and Mary the Monitor assists the learner monitor their overall learning. An additional agent, Gavin the Guide, functions to guide the participants through the learning environment as well as to prompt the self-report measures meant to assess the CAMM states of each participant. Several studies with the MetaTutor have revealed that these agents have a somewhat beneficial influence on learning and self-regulated learning processes (Azevedo et al., 2012, 2013).

However, we also have not examined the extent of the impact of PAs on SRL and learning gains, especially within the context of affect and SRL processes. It is of fundamental importance to look at the students' perceptions of the agents in relation to their performance. Their affective connotation towards the agents is a potential mediator of the agents' effectiveness in the promotion of self-regulated learning processes and overall learning. As such, the present study assesses the following research questions; (1) Are students' feelings towards agents associated with the frequency of their use of SRL processes; (2) What is the extent of the association between feelings towards the agent and the students' learning gains; (3) Are feelings towards the specific agents of MetaTutor (who are representative of specific SRL processes and the environment itself) related to learning gains?

Methods

Participants

A subset of 38 (68% female) undergraduate participants was sampled from a large multi-site research project. The sample included undergraduate students from two Canadian universities in Montreal, Canada, and one from Chicago, USA. The participants' ages ranged from 18 to 31 years old (M = 21.13, SD = 2.84) and were paid up to $40 dollars for completing the study.

Research Design

The data used in this paper comes from a larger database that involved an experimental study that examined the effectiveness of pedagogical agent facilitation of SRL in STEM education. There were two conditions in this study; a *control condition* and a *prompt and feedback condition*. In the control condition, participants were free to navigate the system, read content pages, and deploy SRL processes without any scaffolding or feedback from any of the pedagogical agents. In the prompt and feedback condition, participants were provided with prompts for use of SRL processes, scaffolding from the PAs, and received adaptive feedback and content from the PAs. A t-test was conducted to determine if there existed a significant difference between conditions on proportional learning gain. Results indicated the participants in the feedback condition (M = 31.09, SD = 30.14) did not significantly differ from those in the control condition (M = 40.24, SD = 35.92) in terms of proportional learning gain ($t(78) = 1.22$, $p = .225$). Because of this lack of statistical significant difference, only the members of the prompt and feedback condition were examined, as this was where the participants had the most interactions with the agents.

MetaTutor: An intelligent, Hypermedia Multi-Agent System

MetaTutor is an intelligent, multi-agent, hypermedia learning environment, which engages students in learning about a complex science topic, the human circulatory system (Azevedo et al., 2012, 2013). In MetaTutor, there are 38 pages of text and diagrams, all of which address different topics pertaining to the circulatory system. MetaTutor allows for the collection of a wide array of data, including log-file, eye-tracking, think-aloud data, electro-dermal activity (EDA), screen recordings of learner-system interactions, and facial expressions of participants' emotions. These multi-channel data were collected from students while they navigated the system and learned about the circulatory system. This aim of this analysis is to discuss the impact of agent-directed emotions and on self-regulated learning and overall learning gains.

Figure 1. The four pedagogical agents in MetaTutor

Figure 2. A Screenshot of MetaTutor

Experimental Set Up

Students were asked to participate in two sessions (the first, for one hour and the second, for three hours total) and were required to complete both sessions within three days of each other. During the first session, participants completed a consent form and were given an explanation of the study. Then participants began interacting with the environment, but only completing a series of self-report questionnaires that measured demographic information and their emotions. Participants then completed a 25-item multiple choice pre-test to assess prior knowledge of the human circulatory system and were paid $5 for completing this session.

In the second session, participants began interacting with the environment by first creating two out of the seven pre-determined sub-goals based on different aspects of the circulatory systems, which the pedagogical agent, Pam the Planner was programmed to recognize and lead the participants to set. Once the two sub-goals were established, Gavin the Guide presented multiple videos, which introduced the system, including all of the interface elements and how to engage in self-regulated learning strategies. Pam the Planner was presented again and prompted students to provide anything they knew about the given sub-goal they were working on. Finally, students began to learn by using the system freely and were able to use self-regulated learning strategies (e.g., taking notes, summarizing, etc.) and metacognitive monitoring and judgments (e.g., monitor their emerging understanding of the content, coordinate informational sources, etc.) at any point during the session by selecting which strategy they wished to from the SRL palette presented on the right of the screen. During learning with MetaTutor, a variety of different multi-channel data were collected, which included log-files, concurrent think-aloud protocols, EDA, facial expressions, eye-tracking, and audio-recordings, about each participants' self-regulated learning. Furthermore, the participants were also asked to provide responses to self-report measures like the Agent Persona Inventory (API), which was presented at the end of the session after the post-test, and the Emotions, Interests, and Values Questionnaire (EIV) that was administered every 14 minutes until a total of 5 EIVs were completed. At the end of the learning session, the participants were required to take a 25-item multi-choice post-test over the content presented during the session. The participant was then paid up to $40 for their completion of the study.

Data Sources: Learning Outcomes, Self-Report Measures, and SRL Behaviors

Two equivalent 25-item multiple choice pretests and posttests developed by Azevedo and colleagues (Azevedo et al., 2010) were used to assess participants' learning during the one-hour learning session with MetaTutor. A sample item was: "What is the effect of the clotting process?" Each item was scored as 0 or 1 depending on the accuracy of the answer (range for pretest and posttest was 0-25, respectively). Proportional learning gains were calculated using Witherspoon, D'Mello, and Azevedo's (2008) formula determine the amount of learning from pretest to posttest.

Two self-report measures were administered during the second session with MetaTutor, including the EIV and the API. The EIV consists of 20 questions that measure students' emotions, interests and values at a given time and is based Pekrun's (2011) model of academic achievement emotions. The responses are set on a Likert scale ranging from 1-5, where 1 is strongly disagree and 5 is strongly agree. A sample item was "Right now I feel happiness". The range of scores for the EIV is 20-100.

The objective of the API is to get the student to think about his or her interaction as a whole with each of the four agents. There are 22 questions that assess emotional states, with the 23rd a free response question asking what the agents could do differently to help. The student is asked to indicate the frequency with which each agent made them feel the state expressed in the question on a Likert scale of 1 to 5, where 1 indicated never and 5 indicated always. A sample item was "Sam made me feel angry", and this was repeated across the other three agents. The range of scores for the API is 88-440.

Data about learners' frequency of use of SRL processes during learning were extracted from the log-files, which captured the students' interactions with the MetaTutor environment. The extracted data consisted of the SRL strategies students engaged in, as well as their frequency of occurrence throughout the entire learning session. This was based on students' clicking on an SRL palette that was part of the system's interface. A sample button on the SRL palette was "Evaluate how well I already know this content".

Data Analysis

For this study, the data from API and EIV measures were combined into three categories, positive emotions, negative emotions and neutral. For the EIV, the positive emotions category included questions that asked "Right now I feel": happy, enjoyment, hope, pride, curiosity, eureka and surprise. The negative emotions category included a combination of "Right now I feel": anger, frustration, anxiety, fear, shame, hopelessness, boredom, contempt, disgust, confusion and sadness. The neutral category was the data collected from the question "Right now I feel neutral." Because the EIV was prompted a total of 5 times throughout the learning session, ratings data from each EIV administration for each respective student was combined to create a composite measure for overall affect when engaging in the MetaTutor learning environment.

The data collected from the API were combined in a similar manner to the EIV. Participants were asked, for each agent, how the agents made the participants feel. For example, "Sam made me feel happy." A positive emotions score for each agent was then combined, for the same emotions as combined for the EIV. Then, the negative emotions composite for each agent was created. The neutral composite was data from the measure assessing the extent to which all four agents "made me feel neutral." Finally, a compound measure was created for each emotion category. The positive emotions from each agent were combined into a total positive emotions score. The same process was done for the negative and neutral emotion categories.

Finally, the frequencies of cognitive and metacognitive processes for each participant were created into a total SRL category, which was a combination of measures that assessed the frequencies of judgments of learning, content evaluations, feelings of knowing, monitoring progress towards goals, prior knowledge activation, planning, taking notes, summarizing and inferring.

Results

Research Question 1: Are Students' Feelings towards Agents Associated with the Frequency of Their Use of SRL Processes?

Correlations were conducted to measure the association between proportional learning gains and the SRL composite scores. Table 1 demonstrates that the total composite score for SRL (r = .10, p = .536) was not significantly associated with proportional learning gain. The results tend to reveal that proportional learning and SRL strategy frequency were not significantly associated within this analysis. To further explain this association, the relation between the SRL composite and agent-directed emotions was then examined. Results indicated that positive agent-directed emotions (r = .29, p = .150), negative agent-directed emotions (r = .18, p = .377) and the neutral agent-directed emotion (r = .27, p = .096) were not significantly related to the SRL composite scores (see Table 2). Overall, this suggests that learners' agent-directed emotions were not significantly related to SRL frequency.

Table 1: Correlations between frequencies of SRL strategies and proportional learning gain

	Proportional Learning Gain	SRL Frequencies
Proportional Learning Gain	---	.104
SRL Frequencies	.104	---

Table 2: Correlations between frequencies of SRL processes and agent-directed emotions

	SRL Frequencies	Agent-Directed Positive Emotions	Agent-Directed Negative Emotions	Agent-Directed Neutral Emotion
SRL Frequencies	---			
Agent-Directed Positive Emotions	.238	---		
Agent-Directed Negative Emotions	.147	-.025	---	-.221
Agent-Directed Neutral Emotion	.274	.012	-.221	---

Research Question 2: What is the Extent of the Association between Feelings towards the Agent and the Students' Learning Gains?

Then, associations between agent-directed emotions and proportional learning gain were examined (see Table 3). The correlations revealed a significant, negative relationship between proportional learning gain and negative agent-directed emotions (r = -.38, p = .023), while the associations between positive and neutral agent-directed emotions (r = -.08, p = .624; r = .07, p = .640) remained non-significant. The more negative emotions learners experienced directed towards the agents, the worse their overall performance from pretest to posttest.

Table 3: Correlations between agent-directed emotions and proportional learning gain

	Proportional Learning Gain	Agent-Directed Positive Emotions	Agent-Directed Negative Emotions	Agent-Directed Neutral Emotion
Proportional Learning Gain	---			
Agent-Directed Positive Emotions	-.082	---		
Agent-Directed Negative Emotions	-.367*	-.025	---	
Agent-Directed Neutral Emotion	.078	.012	-.221	---

* $p < .05$ level.

Research Question 3: Are Feelings towards the Specific Agents of MetaTutor (Who Are Representative of Specific SRL Processes and the Environment Itself) Related to Learning Gains?

Because the relationship between negative agent-directed emotions was statistically significant, specific agent-directed negative emotions were then examined to determine whether or not any specific agent contributed to the negative relationship found. Within the four agents, the emotions towards two were found to be significantly and negatively associated with proportional learning gains. More specifically, results revealed negative directed emotions were found to be significant and negatively related to proportional learning gain for the male agents, Gavin (r = -.34, p = .036) and Sam (r = -.38, p = .018). While negative directed emotions towards the female agents, Pam and Mary (r = -.24, p = .15; r = -.27, p = .12) were not significantly related to proportional learning gains. These results suggest that negative emotions directed towards Gavin and Sam were associated with negative proportional learning gains.

Table 4: Correlations between specific agents directed emotions and proportional learning gain

	Proportional Learning Gain	Sam-Directed Negative Emotions	Pam-Directed Negative Emotions	Gavin-Directed Negative Emotions	Mary-Directed Negative Emotions
Proportional Learning Gain	---				
Sam-Directed Negative Emotions	-.383*	---			
Pam-Directed Negative Emotions	-.240	.721**	---		
Gavin-Directed Negative	-.342*	.623**	.597**	---	.

Emotions					
Mary-Directed Negative Emotions	-.256	.519**	.526*	.593**	---

** $p < .01$ level.
* $p < .05$ level.

Discussion

This study examined the often-neglected area of PAs, the emotions they induce in learners and their impact on SRL strategy use during complex learning with intelligent, multi-agent adaptive hypermedia systems. The results obtained from this study illustrate the potential impact that subjective feelings towards PAs have on students' learning gains within a multi-agent, adaptive hypermedia-learning environment. The analyses revealed that students' agent-directed emotions, at least negative ones, are associated with performance of SRL strategies and learning gains on macro, all agents considered, and micro, accounting for specific agents, levels.

The initial research question assessed the extent of the relationship between students' subjective feelings towards the PAs of the MetaTutor learning environment and SRL strategy frequency throughout their interaction within the environment. The correlation between SRL frequency and proportional learning gain indicated that, within this analysis, the two were unrelated. An examination was then conducted to assess whether an association between agent-directed emotions and SRL strategy frequency existed. No significant relationship was obtained. This result has tremendous implications for the incorporation of agents within CBLEs. One of the fundamental assumptions behind the inclusion of agents within CBLEs is that the PAs are helpful in fostering student SRL processes. However, results obtained from this analysis indicate this assumption more ambiguous than previously considered. This finding is bothersome since pedagogical agents are designed and embedded in technology systems based on the fundamental premise that learners' positive feelings towards them should be engaging, which should have led to a significant correlation between their feeling and the use of SRL processes and learning gains.

A second correlation analysis was conducted to determine whether a relationship existed between the students' emotions towards the agents were related to their proportional learning gains. The analysis indicated a significant, negative association between proportional learning gains and agent-directed emotions; the more negative the students' emotions towards the agents, the worse their proportional learning gain. This is understandable considering the agents' purpose themselves. As each agent is responsible for specific SRL strategies (i.e., planning, metacognitive monitoring, learning strategies), and negative emotions towards them could possibly interfere with learners inclination and compliance to enact the SRL strategies they are trying to promote the student to employ. If the students ignore the agents' SRL strategy suggestions, their performance and overall learning would be negatively affected. Furthermore, the presence of the agents themselves could account for this negative relationship between learning gain and negative, agent-directed emotions. Students' negative subjective feelings towards the agents could reflect their disdain for the agents' presence themselves, and this disdain could possibly impact their overall performance both through SRL strategy use and learning gain.

The results from third research question indicated similar results from those presented above. Negative emotions directed towards specific agents were examined in relation to proportional learning gain to determine if feelings towards any specific agent could account for this effect. Results indicated that negative emotions directed towards two of the agents, Gavin the Guide and Sam the Strategizer were negatively related to proportional learning gains. Contextualizing this finding within the framework of the MetaTutor learning environment explains these associations. Gavin is responsible for the provision of the self-report measures throughout the learning session. His presence is abrupt and the self-report measures he presents the students to fill-out during the session may detract from their attention to the ongoing learning about the human circulatory system. As such, specific negative feelings towards Gavin himself could be indicative of the student perceiving his presence as ultimately distracting, potentially negatively impacting performance and learning gain. Specific negative feelings towards Sam the Strategizer could be interpreted in line with his intended purpose within MetaTutor as well. Sam instructs students to perform specific SRL strategies, such as taking notes and summarizing. Once prompted by Sam, the student is required to use the strategies immediately prior to continuing to read and inspect additional hypermedia content about the body system. Due to learners' potential inability to comprehend or enact the effective learning strategy, they can go through many iterations of summarization before being allowed to resume interacting with the hypermedia material. As such, negative emotions directed at Sam could reflect a level of frustration and anger towards Sam that could divert students' attention from the task at hand and spiral into a cycle of negative emotions that require emotion regulation in order to deal with Sam's expectation of learner compliance. Furthermore, the negative feelings could also be indicative of the student not wanting to perform these SRL strategies, which, by not performing would ultimately negatively impact their overall learning gain. It is of interest to note that only the male agents were of

significance within the relationship between subjective feelings towards agents and learning gain. This suggests the operation of a potential gender bias on students' perceptions towards the agents as a whole.

Overall, this study provides several questions for future research. Theoretically, this study calls for an amalgamation of current models of self-regulated learning (e.g., Winne & Hadwin, 1998; Schunk & Zimmerman, 2011) and emerging models of externally-regulated learning (e.g., Hadwin et al., 2011) to incorporate social, cognitive, metacognitive, and affective mechanisms to account for the complex human-artificial agents' interactions during complex learning with pedagogical agents. Understanding the complex interactions between multiple pedagogical agents and learners is key to designing effective agents that are not only sensitive to students learning needs but also monitor and regulate their own behaviors (e.g., Sam recognizes a student's frustration when it asks the learner to makes inference and therefore does not repeatedly ask the learner to make inferences) so as to not negatively impact students' ability to monitor and regulate their learning and overall performance.

Methodologically, this study raises several questions about the measurement of self-regulatory processes and analytical approaches used to study complex agent-learner interactions. First, this study calls for the temporal alignment and convergence of multi-channel data (Azevedo et al., 2013). For example, eye-tracking data could be employed to determine the extent to which engaging with one of the four PAs results in specific emotions (e.g., frustration vs. confusion vs. neutral) and measure a tri-state affective cluster for each agent. More specifically, micro-level analyses can be conducted to determine affective transition state before interaction with an agent, during an interaction with an agent, and following the interaction with the agent. This type of data is key to understand the dynamics of emotion generation and regulation and provide fine-grained data on the impact of agents on learners' emotions and learning. Similarly, EDA data could augment eye-tracking data to determine physiological-emotional correspondents while interacting with agents.

In terms of analytical approaches, this study used molar-level aggregation of learning outcomes and self-report measures. A major challenge for the interdisciplinary field of learning sciences remains the development and testing of more sophisticated analytical methods that can be used to describe the underlying phenomena (e.g., impact of agents' presence on the fluctuation of students' affective states during contextually-bound episodes of learning). In addition, the overreliance on self-report measures as the dominant measure of affective and motivational processes must be augmented with processes-oriented measures of emotions. Also, clusters across self-report scales or a trifurcation of positive, negative and neutral emotions could be explored in addition to specific learning centered emotions themselves.

The implications for these findings are staggering and have been left largely unexplained by contemporary research. Assessing whether PAs within CBLEs are effective in what they are designed to do, on a larger scale within different learning environments, has yet to be asked. Contemporary research rests on the assumption that PAs are effective in facilitating the use of SRL strategies, yet the results presented here are in direct conflict with that expectation. Furthermore, the inclusion of PAs is presumed to increase performance and overall learning, while the outcomes of this paper indicate a negative relationship. As these results suggest, including agents for the sake of including agents could potentially be deleterious to students' overall learning.

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