Cultivating Students' Reflective Learning in Metacognitive Activities through an Affective Pedagogical Agent

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ABSTRACT: There is an increasing interest in the ways pedagogical agents can provide cognitive, emotional, and metacognitive support to students. Moreover, several research studies have proposed various approaches for cultivating students' reflective learning. A variety of research has also been conducted into interrelations between metacognition and affective processes. However, very few studies have examined the effect of emotional feedback provided by a virtual Affective Pedagogical Tutor (APT) on students' self-reflection during a metacognitive learning activity. An experimental research design was used in a study aimed at measuring the extent to which an APT's affective feedback managed to enhance students' self-reflection about what and how they had learned. Participants were a sample of 45 fourth-year high school students, who were divided into experimental and control groups (APT vs. human tutor) in a real online learning situation that involved metacognitive activities. A questionnaire was specifically designed to collect data from both groups. Our results showed that experimental group students achieved better scores in the self-reflection process, since the APT's affective feedback significantly enhanced students' conceptual change (what has changed with respect to their initial beliefs), as well as students' personal growth and understanding (what led them to change their initial beliefs). They also indicated the affective competencies that the APT needs to have in order to achieve a conceptual and personal change in students. Finally, the limitations of our study and directions for future research are discussed.

Keywords: Reflective learning, Metacognitive activities, Affective tutor, Pedagogical agent, Affective feedback

1. Introduction

Reflective learning involves students' conscious thinking and analysis about what they have done in a previous learning activity (Henderson, Napan, & Monteiro, 2004). Reflective learning can be triggered and supported by specific metacognitive activities which allow students to become more engaged in their own learning (Carini, Kuh, & Klein, 2006). In particular, metacognitive activities enable students to enhance their awareness about the best practices they followed in order to learn more effectively as well as exercise essential skills such as critical and creative thinking, understanding and learning from failure, adaptability, personal responsibility, and more (Desautel, 2009; Schmitt, 1990). Consequently, we need to provide ways to help students engage in reflective learning in an efficient manner (Silver, 2013).

Several research studies have proposed approaches for cultivating students' reflective learning. One approach is students' explicit training through specific activities that aim to develop their metacognitive abilities (Jackson & Larkin, 2002; Lin, 2001; Parkes & Kajder, 2010). Another approach is based on social learning that encourages collaboration in small groups, which allows students to engage in a reflective practice that lets them comprehend their own learning in relation to others (Chinnery, Appleton, & Marlowe, 2019; Jarvela et al., 2015). Furthermore, a feedback approach can be used by the teacher, who can guide students through specific prompts to contemplate the learning process they have followed (Menz & Xin, 2016; Schoenfeld, 1992).

Emotions also play a very important role in motivation, self-regulated learning and performance (Arguedas, Daradoumis, & Xhafa, 2016a; Feidakis, Daradoumis, Caballé, Conesa, & Gañán, 2013; Pekrun, Goetz, Titz, & Perry, 2002). In metacognitive activities, a teacher's affective and cognitive feedback can make students reflect on the way they learn, the learning strategies they use and the way these strategies have influenced their learning. Moreover, in cases where students have had negative experiences, a teacher's affective feedback should help students progressively attenuate the impact that those negative experiences have had on their motivation for learning (Belland, Kim, & Hannafin, 2013).

In general, affective feedback should be timely, situation-aware and personal, so that it can redirect students' focus of attention and induce a change in the way they think, act and interact with others, while regulating their behavior in a learning situation (Bahreini, Nadolski, & Westera, 2012; Shen, Wang, & Shen, 2009). Moreover, adequate affective feedback depends on the teacher's emotional competencies (Jennings, 2011). The teacher can also provide affective feedback based on mechanisms that provide emotion awareness information, which ensures students' emotional safety and their engagement or persistence in the learning experience (Feidakis, Caballé, Daradoumis, Gañán, & Conesa, 2014).

To assist the human teacher, in past studies animated pedagogical agents have been extensively used to provide customized feedback with the aim of improving both students' emotional states and learning performance (Atkinson, 2002; Elliott, Rickel, & Lester, 1999; Stone & Lester, 1996). However, more recent studies on pedagogical agents, outlined in the literature review work by Heidig and Clarebout (2011), question the efficiency of pedagogical agents, in the sense that feedback provided by these agents does not necessarily motivate, interest, or support students' learning better than other simpler teaching and learning artifacts. Yet, the research question set by Heidig and Clarebout, which explores both the conditions and design issues under which pedagogical agents facilitate learner motivation and learning outcomes and when they are effective, still needs to be investigated further.

Consequently, the aim of this work is to measure the effectiveness of affective feedback types used by a human teacher and a virtual Affective Pedagogical Tutor (APT) in their group of students in activities promoting metacognitive (reflective) learning. We especially explore the effectiveness of the APT's affective feedback to identify what affective competencies the APT needs to have in order to effectuate a positive change on students' affective and cognitive states when performing metacognitive activities.

In order to achieve this goal, we have organized the rest of the paper as follows: First, we review the literature regarding affective pedagogical tutors, metacognition and affective feedback. Then, we set out our research context and questions. Next, we describe the methodology used in this study. Subsequently, we present the results and then discuss and analyze these results with respect to the research questions. Finally, we present the conclusions and future work.

2. Literature review on affective pedagogical tutors, metacognition and affective feedback

The area of pedagogical tutors has generated a significant amount of research, which has also proved to be quite controversial. Heidig and Clarebout's (2011) systematic review of pedagogical agents yielded no difference in learning. However, Schroeder, Adesope, and Gilbert's (2013) meta-analysis evidenced that pedagogical agents may produce a slight positive effect on learning performance. Furthermore, Schroeder, Romine, and Craig (2017) coincided with Heidig and Clarebout in that the issue of whether we can consider a pedagogical agent useful and capable of enhancing learning is too broad, since it depends on a variety of conditions and on specific pedagogical features that agents should have.

As regards affective learning, affective embodied agents (AEA) are specific artifacts designed with the ability of emotional expression with the aim of acting as affective pedagogical tutors in order to help students overcome negative affect, such as boredom or frustration, during a learning process (Kim, Baylor, & Shen, 2007). In another study, Guo and Goh (2016) incorporated an AEA into an information literacy game, finding that it can enhance students' motivation, enjoyment, perceived usefulness and behavioral intention. However, their AEA used minimal artificial intelligence; consequently, its affective expressions and feedback were not always sufficiently believable for the players-students. Other specific studies examined the effect of the emotional feedback created by an AEA on behavioral intention to use computer-based assessment (Terzis, Moridis, & Economides, 2012; van der Kleij, Eggen, Timmers, & Veldkamp, 2012). They concluded that different methods that provide feedback on students' learning outcomes may have different effects, which need further investigation. The design of AEAs is becoming increasingly sophisticated. However, research has focused more on how to deliver efficient information (a cognitive task) rather than on analyzing the metacognitive aspects of their use in educational systems.

Moreover, affective tutoring systems (ATS) combine affective computing techniques with emotional expressions in order to recognize learners' emotions during the learning process. Based on this information, they can provide appropriate emotional feedback in order to improve motivation, usability and interaction (Lin, Wang, Chao, & Chen, 2012; Wu, Huang, & Hwang, 2016). However, evidence about the effectiveness of affective pedagogical

agents is still diverse and inconclusive. Most positive results have been based on experimental research in controlled learning environments. As a consequence, more research is needed in order to explore the behavior, efficiency and usefulness of affective pedagogical agents and affective feedback in authentic, long-term educational settings under different conditions, contexts, and learning situations (Arguedas, Daradoumis, & Xhafa, 2016b).

A considerable amount of research has investigated the role of pedagogical tutors and the metacognitive support they provide to students. In particular, in the field of self-regulated learning, Azevedo and Hadwin (2005) presented some initial challenges to the issue of scaffolding self-regulated learning and metacognition, which had specific implications for the design of computer-based scaffolds. Molenaar, van Boxtel, and Sleegers (2011) showed that using a pedagogical agent to support metacognitive activities resulted in improving students' metacognitive knowledge. Finally, it was seen that students who were provided with metacognitive support through a pedagogical agent developed better self-regulation skills (Karaoglan Yilmaz, Olpak, & Yilmaz, 2018). As a side effect of that study, the pedagogical agent's metacognitive support also had a significant effect on students' self-reflection skills. Boaler (2016) stressed the important role of self-reflection in making learners powerful by engaging them in a metacognitive process of thinking about what they know.

Finally, it is generally accepted that affective feedback can help students enhance self-regulation by informing them of what they did well (Labuhn, Zimmerman, & Hasselhorn, 2010). In this sense, affective feedback acts as metacognitive feedback, letting students know where they need to improve and what steps they can take to improve their work (Hattie & Timperley, 2007). This can help students not only improve their academic achievement (Brookhart, 2011) but also enhance their motivation (Wigfield, Klauda, & Cambria, 2011).

3. Research aims

3.1. Context

We performed a real experiment in a high school classroom setting based on a learning situation that involved specific metacognitive activities (which are described in more detail in the next section).

In this context, the Affective Pedagogical Tutor (APT) is a specifically designed agent that forms part of a larger framework comprising several components (Arguedas, Casillas, Xhafa, Daradoumis, Peña, & Caballé, 2016; Arguedas, Xhafa, Casillas, Daradoumis, Peña, & Caballé, 2018). This framework involves an emotion analysis model, which first analyzes text and conversation (wiki, chats and forum debates) generated by students involved in collaborative learning activities. It then proceeds to identify and represent the students' emotions that take place during these activities in a non-intrusive way.

This information is shown to both the human teacher and the APT, thus providing *emotion awareness* with regard to the way students' emotions emerge and evolve over time. This enables both the teacher and the APT to offer students affective feedback that influences students' motivation, engagement, self-regulation, and learning outcome.

In this study we explored students' self-reflection, referring to *what they learned* (what has changed with respect to their initial ideas and knowledge), *how they learned* (what led them to change their points of view), and which were the biggest difficulties they met. Accordingly, we set the following research questions.

3.2. Research questions

RQ1. In comparison to a human teacher's affective feedback, to what extent has an APT's affective feedback managed to enhance students' self-reflection?
RQ2. Which types of affective feedback proved to be more appropriate and effective for this learning situation?

3.3. Definition of variables for the learning situation

Both independent and dependent variables involved in the study are presented in Table 1. The learning situation contains metacognitive activities aimed at engaging students in a reflective learning process.

Table 1. Dependent and independent variables of the study

Metacognitive activity	
Independent variable:	A = Affective feedback
Dependent variable:	R = Student' self-reflection

4. Method

4.1. Materials

We designed a scenario which involved an authentic learning experience with high school students. The scenario included a main collaborative learning activity, "Design of a website," provided by the human teacher to instruct students in how to design a website following specific design principles. Designing a well-structured and consistent website is not a simple task, especially for inexperienced students, as in our case. Once the main learning activity was concluded, the teacher engaged students in a specific metacognitive learning situation, which is described below.

4.2. Learning situation: Metacognitive activity

Reflection is a learning process in itself that actively engages students to review the tasks they have carried out, to think about how they have performed in them, and ultimately how and what they have learned (Boud, 2001; Dewey, 1933). Indeed, when students reflect, they try to "focus on the cognitive aspects (thinking, problem solving, and so on) that led to particular actions, the outcomes and lessons learned from those actions, and how these inform what they might do in the future" (Mair, 2012, p. 148). Yet, the reflective process is "a complex one in which both feelings and cognition are closely interrelated and interactive" (Boud, Keough, & Walker, 1985, p. 11). There is a variety of research devoted to the study of the interactions and interrelations between metacognition and affective processes; this is evident especially in the area of self-regulated learning (e.g., Efklides, Schwartz, & Brown, 2018; Hudlicka, 2005). However, there are hardly any studies that examine the effect of emotional feedback provided by both the human teacher and a pedagogical agent on students' self-reflection during a metacognitive learning activity.

In this study, the learning situation comprised several online metacognitive activities that were carried out in the computer laboratory after the main class learning activities. Students were divided into small teams and the teacher created a chat space for each team in the Moodle platform and used specific questions and suggestions to encourage students to reflect upon the main learning activities they had performed in the class. The purpose of the online discussions in which students were engaged was threefold: to make students meditate on what they had learned (i.e., what had changed with respect to their initial beliefs), to understand how students learned (i.e., what led them to change their initial points of view), and to reflect on the difficulties they encountered during the realization of their collaborative activity and whether they dealt with them and how.

4.3. Participants and procedure

Participants were a sample of 45 fourth-year high school students attending the "Web Design" course. Within the sample, 11 of the students were girls (24%) and 34 were boys (76%). We randomly divided students into two big groups, a control and an experimental group, with 22 and 23 students respectively. In the control group, four teams were formed: two teams of five members and two teams of six members. In the experimental group, four teams were also formed: two teams of seven members, one team of five members and one team of four members. The teams were formed by the students themselves. Given that the synchronous online discussion lasted a maximum of one hour, we measured the student's emotional state after each student intervention in the chat.

The types of affective feedback provided are described in Table 2(a). They represent generic types of feedback, based on the theoretical model of feedback of Hattie and Timperley (2007). Since both the human tutor and the APT act independently, each provides their own particular feedback in their own wording and expression, that is, feedback articulation differs between the control and experimental groups. However, each particular feedback utterance should adhere to the generic feedback type it refers to. For the sake of illustration, we show some examples of affective feedback provided by either the teacher or the APT in the metacognitive activity.

The human teacher provides the following affective feedback type 8.1: "Do you remember how uncertain you were when you had to choose between different photos to represent the objectives of your page?", whereas the APT provides the following affective feedback type 8.4: "Are you really happy you chose a single-page site approach instead of a blog-like homepage? Don't you think that the latter could have provided your page with much more information?"

Table 2(b) presents the students' conceptual and personal change, while Table 2(c) presents the students' emotional states we considered to answer RQ2, based on Pekrun's learning emotions (Pekrun et al., 2002). To answer RQ1, we considered the PAD (Pleasure-Arousal-Dominance) emotional state model (Mehrabian & O'Reilly, 1980).

Table 2(a). Affective feedback types that correspond to the metacognitive activity

Affective feedback types that support students' self-reflection	
Make students reflect on the critical factors that influenced the realization of their learning activity	8.1
Make students think whether the type of feedback received during the learning activity was really helpful	8.2
Make students think about the information that would have been most appropriate to support their conceptual and personal change better	8.3
Make students meditate on alternative aspects that could have led them to take different decisions	8.4

Table 2 (b). Students' conceptual and personal change

Students' conceptual change (what students learned, i.e., what has changed with respect to their initial beliefs/knowledge)	
Make students think more critically about what they have learned in this course	6.1
Enable students to meditate that certain changes (in their knowledge and skills) evidently occurred with respect to what they initially thought or knew	6.2
Make students remember when these changes occurred	6.3
Make students think about what these changes are due to	6.4
Allow students to consider the aspects they are still confused about	6.5
Make students reflect on what they want to know more about	6.6
Students' personal growth and understanding (how students learned, i.e., what led them to change their initial beliefs)	
Make students reflect on the actions they took to change their initial points of view	7.1
Let students remember what difficulties they have encountered that made it harder for them to achieve the desired changes	7.2
Enable students to meditate on how their perception was finally altered	7.3
Enable students to think about how their comprehension changed	7.4
Let students imagine how they are going to tackle their next work more efficiently	7.5

Table 2 (c). Students' emotional states

E.1	Motivated
E.2	Curious
E.3	Confident
E.4	Pleased
E.5	Optimistic / challenging (stimulated)
E.6	Insecure or Embarrassed
E.7	Bored
E.8	Anxious or Dismayed
E.9	Outraged

It is worth mentioning here that we distinguish between two different ways of inferring emotion. The first is provided by our emotion awareness mechanism, which is used to identify the emotions that students experience during their work in the learning activities and which are retrieved through text (in our case, chat) analysis, as mentioned in the Context section above. The second way of inferring emotion is through the questionnaire, which contains questions related to specific emotional states (Table 2(c)) that students may experience when they receive affective feedback, either from the human teacher (control group) or the APT (experimental group). By responding to these specific questions, students basically evaluate the emotional effect that affective feedback types had on their self-reflection. That is, students' self-reporting of affective states refers only to those affective states resulting from the affective feedback offered by the human teacher or the APT.

4.4. Data collection

This experiment supplied us with rich quantitative data, which enabled us to measure the effectiveness of the affective feedback types that the human teacher and the APT used in their group, as well as to evaluate the learners' emotional state with regard to the metacognitive learning situation.

The questionnaire was composed of:

- questions related to the affective feedback types presented in Table 2(a), that is, feedback types that support students' critical thinking;
- questions related to the students' individual conceptual change as well as students' personal growth and accountability, presented in Table 2(b);
- questions related to the different emotional states of students resulting from the affective feedback offered by the human teacher or the APT, shown in Table 2(c).

For all questions, we used a five-point Likert-type scale ranging from 1 (Almost never) to 5 (Almost always) and requiring a quantitative answer.

4.5. Reliability statistics and multivariate normality

Due to space restrictions, we provide a compact version of reliability statistics and multivariate normality measures rather than presenting them for each subscale. To ensure the reliability of data collection, Cronbach's alpha has been applied to both the control group (CG) and the experimental group (EG). The values of Cronbach's alpha obtained are shown in Table 3 and are higher than .70, thereby reinforcing the reliability of our indicators.

Table 3. Cronbach's alpha for the metacognitive learning activity in CG and EG

CG (N = 22)		EG (N = 23)	
Cronbach's alpha	No. elements	Cronbach's alpha	No. elements
.957	15	.915	15

In addition, the skewness and kurtosis of each variable were examined to check for multivariate normality. The critical values of all test statistics were calculated. The results showed that data were normally distributed as absolute values of skewness and kurtosis did not exceed the allowed maximum (2.0 for univariate skewness and 7.0 for univariate kurtosis).

5. Results

In this section, we present our results for the first research question through descriptive statistic measures.

5.1. The descriptive statistic measures

In this study we provide the most in-depth statistical analysis possible, in a gradual, progressive, and cumulative manner. Accordingly, the purpose of this section is to directly answer our first research question. The answer to the second research question is provided in detail in the Discussion section. To this end, we use descriptive statistic measures for comparing the two groups (control vs. experimental), thus evaluating the effectiveness of the APT's affective feedback with respect to that offered by the human teacher. As a consequence, we focus the analysis on a comparison of the two group's scores to check if there are any statistically significant differences in the effects of the different affective feedback types between the two groups.

5.2. The results with regard to metacognitive activity

With respect to the metacognitive learning activity, the questionnaire was composed of three parts, as seen in Table 4. With regard to *the items of the first part (6.1 – 6.6)*: The mean exceeded the value of three (3.0) in all items in both CG and EG. This indicates that all students (in both CG and EG) managed to carry out a fruitful meditation about what they had learned in this course and find out what has changed with respect to their initial ideas and knowledge. Certainly, EG students achieved better scores in this process. However, it is worth noting

here the lower value of item 6.5 that EG students scored with respect to the CG students. This item refers to the process that students followed in order to think about and consider those aspects of the topic that they were still confused about. Personal interviews with EG students showed that the lower value that they obtained in item 6.5 was due to the fact that they did not consider such aspects since they did not need to. That is, the APT's affective feedback had managed to clarify things for them during the main learning activity.

With regard to *the items of the second part (7.1 –7.5)*: In the CG, the mean exceeded the value of three (3.0) in items 7.1-7.2 and 7.5, obtaining the values 3.53, 3.26, and 3.26 respectively. In EG, all values exceeded the value of three (3.0) in all items. This means that EG students managed to provide clear evidence of personal growth and understanding; that is, they were able to reflect on how they learned and what led them to change their initial points of view. In contrast, CG students demonstrated difficulties in meditating on how their perception and comprehension had eventually changed (items 7.3 and 7.4).

Table 4. The descriptive statistics in metacognitive learning activity

	(CG) ($N = 22$)				(EG) ($N = 23$)			
	Min	Max	Mean	*SD*	Min	Max	Mean	*SD*
6.1	1	6	3.16	1.608	1	6	4.27	1.077
6.2	1	6	3.79	1.475	1	6	4.27	1.241
6.3	1	6	3.11	1.629	2	6	4.00	1.345
6.4	1	5	3.05	1.545	2	6	4.00	1.380
6.5	1	6	3.79	1.653	1	6	3.32	1.644
6.6	1	6	3.37	1.674	2	6	4.32	1.171
7.1	1	6	3.53	1.541	2	6	4.09	1.306
7.2	1	5	3.26	1.727	1	6	3.95	1.253
7.3	1	5	3.00	1.700	2	5	3.82	1.220
7.4	1	5	2.89	1.595	1	6	4.27	1.077
7.5	1	6	3.26	1.790	2	6	4.59	1.436
8.1	1	5	2.95	1.747	1	5	4.00	1.414
8.2	1	6	3.58	1.575	1	6	3.95	1.463
8.3	1	6	3.11	1.912	1	6	4.00	1.690
8.4	1	6	3.47	1.744	1	6	4.36	1.529

Note. In all the tables, gray values indicate the best score obtained when we compare equivalent values in CG and EG.

With regard to *the items of the third part (8.1 –8.4)*: In the CG, the mean exceeded the value of three (3.0) in items 8.2-8.4, obtaining the values 3.58, 3.11 and 3.47 respectively. In EG, all values exceeded the value of three (3.0) in all items. Here again, EG students achieved high values of critical thinking skills in group work. CG students also showed quite acceptable similar skills with an exception in item 8.1 (they did not reflect so much on the critical factors that influenced the realization of the main learning activity).

Finally, in the last table, Table 5, it can be observed that all students (in both CG and EG) showed very similar feelings of pleasure, arousal, and dominance after the end of the learning scenario, with EG students being slightly more expressive about their personal satisfaction.

Table 5. Students' emotional states: The values obtained for pleasure, arousal and dominance in CG and EG

	CG ($N = 22$)				EG ($N = 23$)			
	Min	Max	Mean	SD	Min	Max	Mean	SD
Pleasure	5	6	5.49	.129	5.6	5.7	5.64	.0405
Arousal	5	5	4.99	.040	5.1	5.1	5.10	.0092
Dominance	5	5	5.05	.051	5.0	5.1	5.07	.0252

Note. In all the tables, gray values indicate the best score obtained when we compare equivalent values in CG and EG.

6. Discussion

In the previous section, the presentation of questionnaire results based on descriptive statistics provided us with insights about the effects of affective feedback types provided by both the human teacher and our virtual Affective Pedagogical Tutor (APT).

The purpose of this discussion is to focus on the experimental group and explore the types of affective feedback —used by our virtual Affective Pedagogical Tutor (APT) — which were more effective for improving students' self-reflection. As a side effect of this, we also draw some initial conclusions about the affective competencies the APT needs to have in order to achieve a positive change in students' conceptual, personal and affective aspects.

It is worth mentioning here that besides the importance of the feedback type itself, each feedback is a combination of gestural signals (emotional expressions), voice and/or text. Yet, the effectiveness of a feedback type is due mainly to the verbal power of the feedback rather than the non-verbal features of it.

Previous research on pedagogical agents yielded no difference (Heidig & Clarebout, 2011) or a small positive effect on cultivating student learning accountability (Schroeder, Adesope, & Gilbert, 2013). More recent research coincides in that the issue of whether we can consider a pedagogical agent useful and capable of enhancing learning is too broad, since it depends on a variety of conditions and on the specific pedagogical features that agents should have (Schroeder, Romine, & Craig, 2017). This also depends on the specific type of learning situation in which pedagogical agents try to be influential on learners' motivation or learning development (Dinçer & Doganay, 2017).

Taking previous research on pedagogical agents into account, we proceed to discuss and provide a response to the second research question of our metacognitive learning activity. We also take the opportunity to revisit and look at the first research question from the APT's point of view. To that end, we calculated the Pearson correlations of the different variables we defined (Tables 6 and 7) in order to identify the strong positive or negative linear relationships that exist among these variables. For the sake of convenience, we repeat each question below.

Table 6. Pearson correlations between APT's affective feedback and students' conceptual and personal change in experimental group (EG, $N = 23$)

	6.1	6.2	6.3	6.4	6.5	6.6	7.1	7.2	7.3	7.4	7.5
8.1	.517*	.211	.100	.022	.054	.387	-.154	.281	.412	.397	.538*
8.2	.291	.103	.711**	.535*	-.378	.210	.440	.309	.249	.446	.199
8.3	.555*	.402	.674**	.638**	.324	.508*	.546*	.227	.530*	.587**	.430
8.4	.665**	.603**	.353	.361	-.060	.622**	.336	.823**	.319	.438	.474*

Note. *Correlation is significant at the 0.05 level (2-tailed); **correlation is significant at the 0.01 level (2-tailed).

Table 7. Pearson correlations between APT's affective feedback and students' emotional states in experimental group (EG, $N = 23$)

	E.1	E.2	E.3	E.4	E.5	E.6	E.7	E.8	E.9
8.1	.478*	.515*	.374	.629**	.134	-.254	-.068	-.140	-.057
8.2	474*	.322	.305	.479*	.503*	-.287	-.380	-.143	-.415
8.3	.224	.329	.420	.520*	.363	.116	-.294	.278	-.106
8.4	.320	.298	.536*	.202	.585**	-.026	-.531*	-.070	-.343

Note. *Correlation is significant at the 0.05 level (2-tailed); **correlation is significant at the 0.01 level (2-tailed).

6.1. RQ1 and RQ2 regarding the metacognitive learning activity

RQ1. To what extent has an APT's affective feedback managed to enhance students' self-reflection?
RQ2. Which types of affective feedback proved to be more appropriate and effective for this learning situation?

In the experimental group (EG), the APT's affective feedback seems to have a positive effect on students' behavior. Indeed, the results in Table 6 indicate several strong positive relationships between all feedback types and students' conceptual and personal change to a greater or lesser extent. This finding is consistent with research indicating that that using a pedagogical agent to support metacognitive activities results in developing better metacognitive knowledge and self-regulation skills (Dignath & Büttner, 2008; Karaoglan Yilmaz, Olpak, & Yilmaz, 2018; Molenaar, van Boxtel, & Sleegers, 2011).

Unique to this study was the provision of different affective feedback types that focus on improving students' self-reflection on what and how they learned as well as the differentiation between the effectiveness of the different affective feedback types used. To the best of our knowledge, the effects of different types of affective feedback of a pedagogical agent in a real learning situation that involves metacognitive activities have not yet been investigated in a systematic study.

In our study, the affective feedback types with a major effect were 8.3 and 8.4; we therefore focus our discussion on these two. Indeed, APT feedback types 8.3 and 8.4 gave students the chance to think critically about the appropriateness of the information they received during the main activities. They also enabled students to provide insights about alternative aspects that, if they were supplied to them, would have led them to take different decisions.

The combination of feedback types 8.3 and 8.4 managed to make students think more critically about almost all elements we considered as basic influential factors for their conceptual and personal change (items 6.1, 6.2, 6.3, 6.4, 6.6, 7.1, 7.2, 7.3, 7.4 and 7.5 in Table 6, and described in Table 2(b)): what students learned, that is, what had changed with respect to their initial beliefs/knowledge; how students learned, that is, what led them to change their initial beliefs.

This trend echoes findings from other studies indicating that using different types of reflection prompts students to feel more engaged in metacognition by exhibiting different categories of metacognitive knowledge, such as planning learning tasks, monitoring comprehension, or evaluating progress (Menekse, 2020; Menz & Xin, 2016). Furthermore, our results are broadly consistent with previous research that has suggested that pedagogical agents can strengthen learners' reflection on what they have done or engaged in (Daumiller & Dresel, 2018) as well as improve the reasoning and decision-making abilities of their users (Le & Wartschinski, 2018). The research also underlines that the type of verbal feedback they provide really matters (Lin, Atkinson, Christopherson, Joseph, & Harrison, 2013).

In our study, there was only one element that had a non-influential relationship (and this occurred with all four APT affective feedback types): item 6.5 (*allow students to consider the aspects they were still confused about*). This is certainly not an easy matter to assess based only on quantitative data. As mentioned in the Results section, personal communication with EG students showed that these students simply did not consider the need to deal with such aspects, since at the end of all the main learning activities, they had completed the course goals successfully. They were also very happy at the end, as we can see in Table 7 (E.4). Yet, prompting students to reflect on confusing concepts lets them engage in a process for identifying the confusing concepts, while stimulating self-monitoring activities, such as comprehension reviews and searches for related knowledge (Menekse, 2020).
Based on the above, the answer to RQ1 is positive.

Regarding RQ2, as seen above, the types of affective feedback which proved to be more appropriate and effective for this learning situation were feedback types 8.3 and 8.4. As regards the other two APT affective feedback types (8.1 and 8.2), Table 6 shows that, though they offered some help to the students' critical thinking process, they certainly need to be further elaborated and improved.

Finally, Table 7 shows that the APT's affective feedback increased students' positive emotional states (E1 to E.5) at the end of the activity. However, this feedback did not have any significant relationship with students' negative emotional states (E6 to E.9), except feedback 8.4, which contributed to reducing students' boredom (E.7). We therefore need to further explore the reasons for this occurrence. That is, we need to examine why the APT's affective feedback did not have any influence on students' feelings of insecurity, anxiety, and anger during the metacognitive activity.

All in all, we are conscious that this study is the beginning of a complex and challenging endeavor and that more work still needs to be done in order to improve the APT design and ensure a truly worthwhile learning experience for students.

7. Conclusion

The study presented in this paper constitutes a real online educational experience involving secondary level students, a study which was missing in the fields of affective pedagogical tutors (APT) and metacognition and learning. So far, many agent-based studies have been laboratory-based and the participants were often university

students. Unique to this study was the opportunity to examine different types of affective feedback used by the APT and determine which proved to be more appropriate and effective for cultivating reflective learning. The successful types of affective feedback employed by the APT in this work give an insight into the affective competencies the virtual APT needs to have in order to achieve a conceptual change in students as well as personal growth and understanding. Certainly, more research is needed to establish a more consolidated APT design with well-grounded and influencing affective competencies that could identify and tackle problems in different ways.

7.1. Limitations of the study and directions for future research

First, our Affective Pedagogical Tutor (APT) should be capable of dealing with more profound reflective and metacognitive learning issues. This requires a more intelligent pedagogical, emotional and technological design, endowed with further artificial intelligence techniques for emotion recognition and dialogue facilities for generating smooth affective feedbacks. In addition, our study with the APT could be extended to make use of more profound reflective and metacognitive learning theories and metacognitive self-regulation scales (Ku & Ho, 2010; Schellings & Van Hout-Wolters, 2011; Tock & Moxley, 2017).

Second, the results of our experiments on APTs' effectiveness are drawn from the users' perceptions. This is done post-experimentally by means of questionnaires. However, further real-time user signals should be captured by other techniques, such as sensors, and analyzed. This information can be fed into the APT to make its behavior more adaptive. It can also be used to cross-check the questionnaires.

Third, since a metacognitive learning activity constitutes an important part of a complete educational scenario, it is very important from an emotional point of view to foster a relationship of trust between the APT and the students, establishing a relationship of complicity between them. The APT should also nurture students' sense of cohesion and belonging to the class. This is related with the important issue of the affective competencies that the APT needs to have in order to achieve students' conceptual and personal enhancement. To that end, further research should focus on analyzing the most effective types of actions a human teacher carries out, adapting each task to the individual progress of each student while sustaining and managing their emotional states to favor their particular learning. Our aim is to endow our APT with these human affective competencies.

Finally, during the metacognitive activities, the APT should also be able to comment on the results obtained and contribute to a reflection and improvement process. The purpose of this is to make students both meditate on how new knowledge has been acquired and analyze which new cognitive and emotional skills were revealed and used to manage their emotions, and thus enhance their holistic development.

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