Introducing a Challenging Teachable Agent

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Abstract. This paper explores the potentials of a new type of pedagogical agent – a Challenger Teachable Agent. The aim of such a pedagogical agent is to increase engagement and motivation, and challenge students into deeper learning and metacognitive reasoning. It is based on the successful implementation of the Learning by Teaching approach in Teacheable Agents, and in addition it draws on previous work that has shown the potential of resistance or challenge as means to improve learning. In this paper we discuss how these two bases can be combined and realized through new types of behaviours in a Teachable Agent.

Keywords: teachable agents, challenging agents, self-efficacy, educational technology.

1 Introduction

More than 2000 years ago Seneca the Younger wrote dicendo discimus, which is latin for "by teaching, we learn", in a letter to Lucilius. Thus, the idea that one learns by teaching someone else has been around for a long time. In more recent years this idea has been realized in pedagogical approaches in classrooms. Studies have shown many advantages of the Learning by Teaching (LBT) approach, for instance, that people who learn in order to teach others to pass a test learn better than those who learn in order to pass the test themselves (Bargh & Schul, 1980).

There are many aspects of LBT that contribute to improved learning. Leelawong and Biswas (2008) mentions structuring, taking responsibility and reflecting. To be able to present and explain a material to someone else, the teacher needs to be responsible for what material to include and for the structuring of it. Leelawong and Biswas (ibid) showed that doing this leads to a deeper understanding of the material and better organization of ideas. Schneider (2008) also showed that meta-memory functions are supported and trained when the teacher is checking whether s/he has a sufficient understanding of the material to be able to explain it to others. Thus there are many advantages concerning the preparation phase of teaching. When moving on to the phase of actual teaching, other mechanisms come into play, for example what Leelawong and Biswas (ibid) refer to as reflection, that the teacher ponders on how the information presented was understood and used. The teacher has to compare his or her expectations with the actual outcome, to see if there is material that needs to be

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explained in a different or more elaborate way. This may also lead to the teacher reflecting on his or her own understanding of the material and perhaps the teacher must revise his or her own ideas of the domain. Chin et al. (2010) describe how the three phases of teaching, result and repair, are repeated and how that results in a self-regulated learning cycle for the teacher.

In other words, the pedagogy of LBT can be powerful and involve several kinds of benefits. However, to implement fruitful LBT situations is not unproblematic. For example, when students teach other students, some students may find it hard to take a teacher role since they are not so knowledgeable or do not believe sufficiently in their own knowledge and competence. Also, if a student does a poor job as a teacher the students being taught are negatively affected. Moving to the digital arena is a way to keep the benefits of LBT and at the same time avoid the mentioned drawbacks.

The LBT approach can be implemented in virtual learning environments where the real student teaches a digital tutee, often referred to as a Teachable Agent (TA). AI techniques guide the TA's behaviour based on what it is taught (Brophy et al., 1999). This makes it possible for every student to have his or her own tutee to be a teacher for, and if the student fails at teaching no real person comes to harm. It is also possible to match the agent's knowledge to the level of the student to provide a reasonable challenge. The digitalization also adds the possibility to introduce game characteristics and other variables to support learning processes and emotional and motivational aspects. A further advantage with a digital learning environment is that it makes it possible to reach a larger audience.

More details on teachable agents and the benefits of using them are provided in the next section. The reminder on the paper then explores the idea of a new type of teachable agent, a Challenging Teachable Agent (CTA). We present some current ideas of why challenging behaviour of pedagogical agents is desirable, and how this can be integrated with teachable agents. Finally we give some examples from ongoing work with implementation of a challenging teachable agent in a virtual learning environment for history.

2 Teachable Agents

There are many learning environments that make use of pedagogical agents, but most of these are tutors, i.e. the agent is the expert teacher. A teachable agent is the total opposite, an agent that is to be taught by the student. The teachable agent therefore should exhibit a behaviour that invites and motivates the user to teach. In this section we present results from studies that illustrate the positive effects teachable agents can have on motivation and also other aspects of learning, such as metacognition.

2.1 Motivation and Effort

Effort is an essential aspect when aiming for more and deeper learning. Students often prefer pedagogical methods that results in surface learning, since deep learning

requires more effort and it is more hard work (D´Mello et al., 2012). To aid the learning process, the student therefore needs to be motivated to make more effort and to strategically direct that effort.

In the LBT domain a central motivational factor that is often mentioned with respect to TAs is the *protégée effect*; i.e. "students make greater effort to learn for their TAs than they do for themselves" (s. 2). This effect was shown in a study where the alternatives were to either learn a material for a future test or to teach a TA (Chase et al., 2009).

According to Chase et al. (ibid) the protégée effect is attributed to a synergy of different contributing effects: i*) ego-protective buffer*, which means that a possible failure would be assigned to the TA, and not the student directly, thereby reducing failure anxiety in the student. ii) r*esponsibility*, in that the student treat his or her TA as a social entity and shows concern and responsibility for its academic success. By taking that responsibility the student is motivated to revisit learning material, rethink his or her own understanding and try to come up with new and better ways of helping the TA to understand the material. iii) *incrementalist theory*. To world as a teacher, the student appear to accept the idea of incremental knowledge, i.e. that TAs could perform academically better after being taught by the student.

2.2 Metacognitive Reasoning

One way to reach deeper learning is to increase metacognitive reasoning in the student. To stimulate metacognitive reasoning, we need to raise the students' awareness of the causality between learning choices and the results of those choices. This can be illustrated using teachable agents since the choices made during teaching of the agent are reflected in the understanding and knowledge the agent has as a result. In this way the learning process is made more visible. The positive effects do not appear only when the digital learning environment is being used, but also in transfer situations (Schwartz & Martin, 2006).

Letting students work with a TA that expresses its metacognitive reasoning, might stimulate the student to incorporate some of the learning strategies on herself. This was termed metacognition by proxy and was showed to be successful by Chin et al. (2010).

A learning environment could further aid the metacognitive processes by giving the students directions and letting the TA be a model of "productive learning behaviour" (Blair et al., 2007). This could be realized by designing a TA that demonstrates useful learning strategies, in addition to direct instructions from the TA or learning environment. A student that has a higher level of awareness for the causality between learning choices and their result, i.e. metacognition about learning strategies, will have a higher ability to take responsibility and further on direct effort strategically in his or her learning process.

3 The Power of Challenge

It can be tiresome and boring to interact with an agent that is always positive, compliant and cheerful – and such agents are weak in believability (Cassell & Thórisson, 1999). The TAs developed so far does not have much of a personality and usually accept all information provided by their teacher without questioning it. Although one of the seminal papers on TAs, (Brophy et al., 1999), proposed an agent that "may be impetuous, not listen or collaborate well", this has to our knowledge hitherto never been realized nor evaluated. In this section we explore positive aspects of agents that do not collaborate well but rather challenge the user in different ways, and other aspects of challenges during learning.

There have been approaches to experiment with characteristics as impetuousness within related fields with other types of pedagogical agents. Within the area of peer learning, Aïmeur et al (1997) describe a troublemaker agent in a virtual learning environment that also includes a tutor agent. The troublemaker peer may suggest a correct or faulty solution and ask the student if she agrees or not. If the student does not agree, the troublemaker will debate about its solution until the student either agrees or the troublemaker runs out of arguments. If the student agrees, the troublemaker solution will be presented to the tutor for feedback. In a study conducted by Frasson and Aïmeur (1999), it was found that the use of the troublemaker agent "encourages the learner to question his own knowledge" and thereby motivates the learner. However, the troublemaker agent and the teaching strategy "learning by disturbing" implied academic improvement primarily for high achieving students.

The learning by disturbing teaching strategy basically uses the intrinsic motivation that comes from not understanding each other, which sometimes, can be just what is needed. Dissonance theory proposes that when an individual experiences a conflict between her own and someone else's understanding, the individual also experiences a motivational drive to resolve the conflict (Aïmeur et al., 1997). To not understand one another might even be "an ignition to learn together" (Schwartz, 1999). An individual in a state of cognitive dissonance will get motivated to revise or defend his position to solve the mental conflict.

In a LBT condition it could therefore be meaningful for the teachable agent to cause dissonance or small conflicts, by for example introducing errors in the same manner as the troublemaker agent. This can manifest itself in productive learning behaviours if the teacher needs to revise or defend his/her position. This can in turn lead to the teacher having to revisit information material or formulate arguments about why his/her position is more correct.

Another way a teachable agent can challenge the student is in the choice of learning activities and the difficulty level of these activities. To facilitate learning the distance between the task difficulty and the student´s current level of mastery should be such that it creates a challenge. Clifford (2009) points out that a task needs to have a "moderate probability of success", in order to generate intrinsic motivation. She rates a 50% probability of success to be moderate. Clifford also writes about "the privilege of learning by mistakes", by encouraging students to try out task on a higher level than they master. An easy mastered task will not affect the intrinsic motivation since

it is considered under the student's level of performance. A mastered task that was considered too difficult would be considered "out of luck" and would also not affect the intrinsic motivation. (Clifford, 2009). Thus, a teachable agent can push the teacher towards tasks of a challenging difficulty level.

4 Designing a Challenging Teachable Agents

Based on the theories and results from previous studies, which we have presented in the previous sections, we see a considerable potential in the combination of two potent teaching techniques; learning by teaching and troublemaking. We choose the name "challenger" TA (CTA) since we experienced that the word troublemaker in our contacts with schools had negative connotations, a troublemaker would be somebody who wants to make trouble – whereas a CTA would be a TA that wants to challenge the student in a positive way.

We suggest that a CTA should be designed to address two qualitatively different tasks; i) to help the student add effort to the learning process, and ii) to help the student direct his or her effort in the learning process.

4.1 Increase Motivation and Effort

Overrating Own Knowledge. An aspect that can fit an impetuous agent personality is a tendency to misjudge, and overrate its own knowledge. In line with this the CTA may insist on choosing learning and testing activities at a higher level than actually mastered. This would increase the level of challenge and may have positive effects on the level of intrinsic motivation (Clifford, 2009).

Varying Willingness to Learn. True collaborative work is based on the precondition that the individuals enter a relationship with free wills and their own goals/intentions with the collaboration (Schwartz D. 1999). Therefore we choose to simulate that the CTA has its own will and sometimes questions why a certain activities should be done or express reluctance to do some activities. This will accentuate that it has its own agency and strengthen the student's experience of responsibility towards, and also motivation for teaching, the CTA. Being questioned by the CTA about the task relevance can also spark metacognitive reflections within the student, as she has to find good arguments for persuading the CTA.

4.2 Improve Learning Strategies

Debating solutions in Learning Activities. "The desire to understand and be understood -- to share meaning -- is a strong motivator of human behaviour" (Schwartz, 1999, p. 8). The CTA can at times ask for explanations and clarifications before, perhaps, accepting a solution to a task in a learning activity. Designing the CTA not to readily accept everything the student tries to teach, is a possible way of promoting

deep learning. A task oriented dialogue would also give the student an opportunity to train to use the domain specific concepts, relations and facts.

Introducing Errors. This strategy was used by Frasson & Aimeur (1996) for their troublemaking learning companion. The idea is to provoke the student to react and justify his/her answer, and thus become more certain of it and its bases. Training to distinguish between right and wrong solutions is also a mean to achieve higher confidence in the student with respect to the study material (i.e. self-efficacy).

Inducing Confusion. Confusion or cognitive disequilibrium can be induced by e.g. contradicting information and can provide deeper learning in a controlled setting for learning. When conflicting information is perceived, the individual heightens its attention towards the new information and tries to resolve the conflict through e.g. visiting informational material. The purpose is to provoke the student to reflect, deliberate, and decide on what is true, thereby processing the material at a deeper level. (D´Mello et al., 2012).

4.3 Individual Differences and Timing

While we believe a Challenger Teachable Agent can have many positive effects on students learning, we hypothesize that student variables like self-efficacy, goal-orientation and achievement will interact with different types of challenging behaviour and produce different learning outcomes and user experiences for different groups of users. For example, challenging tasks are viewed differently depending on a student's goal orientation, since challenging tasks present the risk of failure, but also offer opportunities for learning (Ames & Archer, 1988). A performance oriented student is more likely than a competence oriented student to try to avoid challenging tasks. Furthermore, students with high self-efficacy, may profit more from a CTA than students with low self-efficacy.

Another important factor to pay attention to is the time-relation between challenging behaviours and student variables. We hypothesize that some challenging behaviours are preferably introduced at a certain progression-level and some others would be a consistent feature. We suspect that the behaviours should be gradually phased in or out. How often the different behaviours should be occurring, and when, may also interact with student variables.

5 Realizing a CTA in a History Learning Environment

The CTA is currently being implemented in a digital learning environment for history where the target users are 10-12 year olds. To our knowledge this is the first TA system outside the STEM area. In the game narrative the old Guardian of History is about to retire and searches for a successor among his helpers. A potential successor

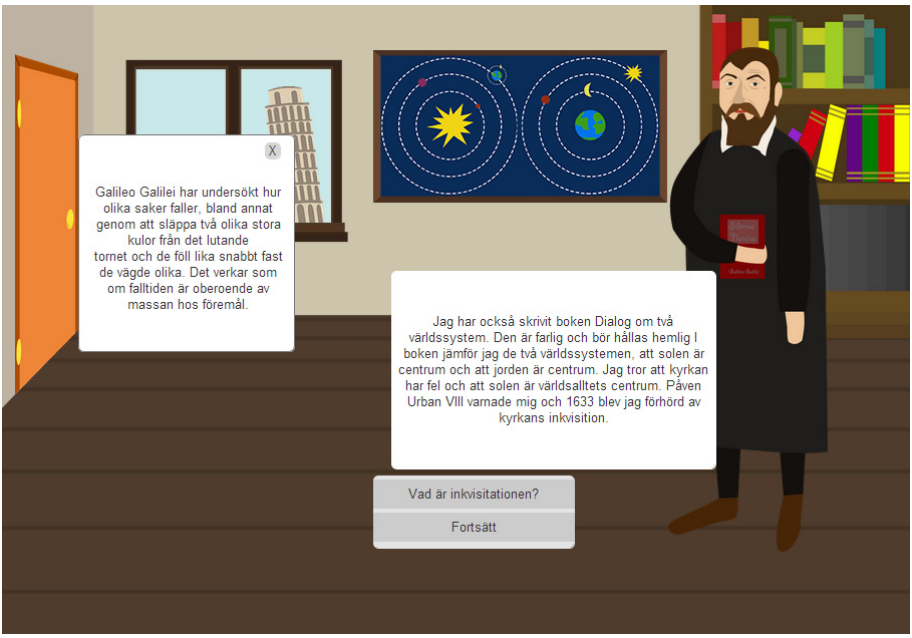

Fig. 1. The picture shows a historical setting with Galileo Galilee

has to show extensive knowledge of history, and in order to gain such knowledge the helpers have a time machine at their disposal. The helper Timy is very eager to learn about history, but unfortunately gets motion sickness in the time machine. Therefore the student is asked to use the time machine to learn about history in order to thereafter teach Timy. Thus the narrative introduces the TA in a natural way that can encourage the protégé effect. The main character Timy is gender neutral, since our earlier studies showed that it decreases negative gender-effects that sometimes appear in interactions with virtual agents (Silvervarg et al 2012, Silvervarg et al 2013).

The information gathering activities are performed with a time machine. During travels to the past the student can visit different historical settings and interact with people, documents and artefacts. Se Fig. 1 for the historical setting where the student is visiting Galileo Galilee in Pisa.

When the student return from the time travels s/he shall try to teach Timy what s/he has learnt. A learning activity is a game-like task which is performed by the student and Timy. Typically the student can choose if Timy should watch when the student plays or if they should play together. The system includes various learning activities, and the activities can be performed at different difficulty levels.

During a learning activity Timy will add new knowledge to his memory or grow more certain or uncertain about previous known facts that are included in the learning activity. Facts can be correct or incorrect, more or less certain, and typically reflect the student's own knowledge of the domain. Different learning activities promote different kinds of facts. For example, the learning activity in Fig. 2 uses a time line to

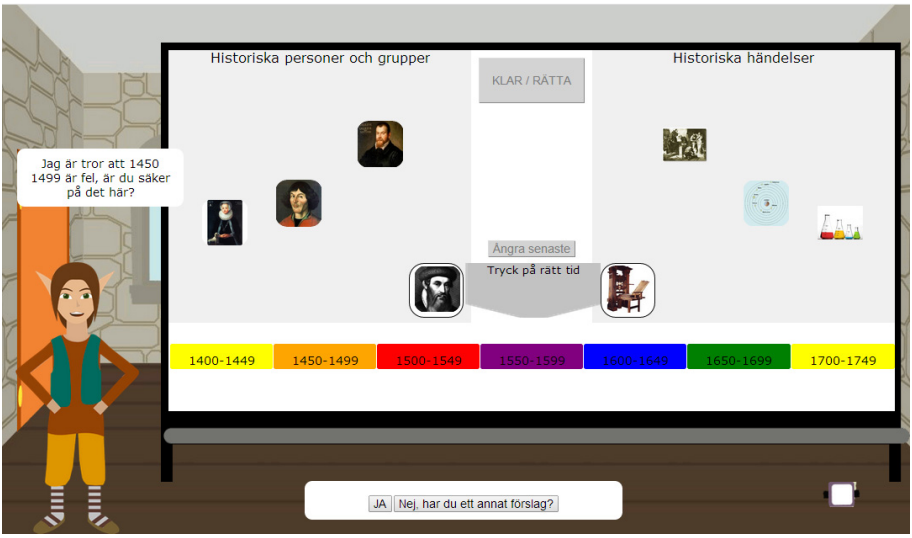

Fig. 2. A learning activity where the user is teaching the digital tutee Timy by doing a Timeline activity together

visualize facts about persons, events and time periods. In this example the student is doing the activity together with Timy. Timy questions that the student's proposed fact is correct, stating that he thinks that the time period is not correct. The student can now insist that he or she is correct or ask Timy what he thinks is correct, and in the next step either accept or reject Timy's suggestion.

A testing activity will be unlocked when a sufficient amount of learning activities has been carried out. Timy will then by himself answer the questions using the knowledge he has been taught by the student teacher. If Timy was taught well, s/he will get a good grade and also grow more certain of the answers s/he provided. The results of the test give the student feedback on how well s/he has taught Timy and hint at information gathering and/or learning activities s/he may have to redo in case of uncertainty or errors.

5.1 Challenging Behaviour during Learning Activities

The challenging behaviours of the CTA are realised in the choice of learning tasks and the performance of the learning activities, where agent will interact with the user through multiple choice dialogue, as illustrated in Fig. 2. This are the first challenging behaviours to be implemented in our CTA:

Varying Willingness to Learn. We implement this by letting the CTA sometimes question the learning activities the student chooses. During an activity the agent might express that the activity is too boring, too hard or that it would be more fun to do some other activity not directly related to learning. At such occasions the student will get a dialogue prompt to answer or motivate the agent to continue the activity.

Overrating Own Knowledge. The CTA knows nothing from the beginning, but learns from the user. A traditional TA learns rather slowly and needs to repeat a fact many times before s/he is confident that s/he "knows" it. The CTA puts much more confidence in what it has learnt, and can suggest that the student teacher moves on to learning activities and tests at higher difficulty level more quickly.

Learning more quickly and overrating own knowledge can also lead to the agent being certain of erroneous facts that has only been presented once, and it can use these to contradict the student teacher when the correct facts are introduced, and resist replacing erroneous with correct facts.

Debating Solutions in Learning Activities. When the student shows the CTA a fact or a solution, it will sometimes debate whether it is correct or not. In the "do together" activity mode, the agent might question the user's choices, e.g. "Are you sure?" or state "I don´t agree" more often than a traditional TA would.

Introducing Errors and Inducing Confusion. Even if the student teacher only teaches the CTA correct facts, the agent may on purpose "misremember" and propose incorrect facts when it is doing a learning activity together with the student teacher. E.g. the agent may substitute Galileo Galilei as the author of the book "Dialogue Concerning the Two Chief World Systems" with Tycho Brahe.

6 Summary and Future Work

Teachable agents have been proven to work well as an implementation of the Learning by teaching approach, providing many advantages such as increasing motivation, depth of learning, effort, etc. Challenge in the learning process has also been shown to have positive effects on learning processes. In this paper we propose the combination of these two in a Challenging Teachable Agent. We believe that the addition of challenging behaviour in a TA can further strengthen the positive effects. However, this need to be further explored with regard to various user groups to make sure we build educational systems that can benefit all students.

We intend to evaluate the proposed CTA and compare it to a traditional TA as well as a system without an agent, with regard to student variables such as self-efficacy and goal-orientation. Based on findings from such a study, a future research goal is to develop and evaluate algorithms for adequate combinations of agent behaviours. When is it advantageous to use them; which of them and in which combinations – and with respect to which student variables?

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