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Adding Challenge to a Teachable Agent in a Virtual Learning Environment

by

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Abstract

The topic of this thesis concerns what happens when challenging behavior is added to a teachable agent in a virtual learning environment. The aim of adding challenging behavior to teachable agents is to encourage students to engage in learning behaviors, improve their motivation and engagement, which may result in a deeper level of comprehension and an improved learning experience. We conducted an explorative user study, using Guardian of History, a teachable agent learning environment in history. We analyzed data from 146 students, 11-12 years old, from a Swedish school. The students were assigned to two different agent conditions: traditional teachable agent (TA) or a challenging TA (CTA). The conditions were also balanced with respect to the students' level of self-efficacy. The CTA exhibited the following challenging behaviors: 1) introduction of error, 2) rejection of correct facts, and 3) proposal of a higher level of difficulty. Students who used the challenging TA and also had a high level of self-efficacy performed better in the CTA condition and students with a low level of self-efficacy reached better academic achievement in the traditional TA condition. Students did not experience the learning-by-teaching effects different by the introduced challenging TA behaviors. Students within the CTA condition got better at responding to challenging TA behavior, than students in the TA condition. The CTA behavior "rejection of correct facts" was better received than the "rejection of correct", this suggests that a challenging TA may benefit to a larger degree by questioning rather than by introducing errors.

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Chapter 1

INTRODUCTION

The need for technological integration in schools has been extensively discussed, both concerning making students technology literate and as a mean of instruction. Davies and West (2014) stress that it is not enough to equip students with hardware and standard programs, such as programs for information access and communication since this does not dramatically improve students' performance. More effort needs to be focused on adaptive instructions and pedagogically sound training, and on improving the effectiveness of technology use to facilitate learning (Davies & West, 2014). "This next generation of technology could enhance learning by such means as supporting deeper conceptual learning and providing more useful, individualized formative assessment to guide instruction." (Darling, Elliott, Wulf, Pea, et al., 2003, p. 6).

This thesis examines the possibility of offering added value to digital software. The focus will be on next generation educational software, based on established theories of learning that are well tested and associated with established learning effects.

1.1 Educational technology and educational software

Educational technology is "the study and ethical practice of facilitating learning and improving performance by creating, using, and managing appropriate technological processes and resources" (Association for Educational Communications and Technology, 2008). Educational technology covers software, equipment, processes and procedures, which support learning and teaching. This broad field studies the design and use of, for example, abacuses, blackboards, the use of pen and paper, educational use of YouTube and Skype, and how to individualize tutoring systems that support learning processes.

We will narrow our scope of our discussion here to the section of educational technology that concerns educational software, where students can follow a curriculum at their individual speed and based on their level of skills. Teaching a full class of students forces students to use similar learning styles since a lecture cannot adapt to each individual (Sjödén, 2015). The adaptive educational software can offer a more individualized learning and also added value, by providing new learning situations.

The student can, for example, "visit" historical persons, have a "chat" with them or try out different roles without the fear of failure in front of their peers. Adding such benefits to an educational software may assist teachers in daily tasks. Educational software should not, and cannot, replace teaching but can be regarded as an additional resource to provide variety and adaptiveness in learning activities.

The more options teachers have for improving lesson quality, the greater the demands for organizing or 'orchestrating' many diverse instructional activities" (Ross, Morrison, & Lowther, 2010, p. 20). Students could use the educational software as an additional educational tool, along with books, lectures, classroom debates, etc. It is, however, important that such software only treat topics or topic aspects well suited for the format of the specific software, and it should be well tested before used on a large scale. Teachers also need to get educated in how to choose, evaluate, and use educational software (Sjödén, 2015).

1.2 Pedagogical agents

Some educational software includes embodied pedagogical agents, that are "visually represented, computer generated characters in pedagogical roles, such as virtual instructors, mentors and learning companions" (Haake & Gulz, 2009, p. 136). The major part of the educational agent-based software is still under development within research projects.

Educational software technologies, using pedagogical agents, can be divided into categories based on the roles the agent and student are given. Most current software using computer agents is tutoring software, where the agent is the expert that teaches the student. Peer learning software contains a learning *peer*, a "learning companion", and the student learns *together* with his or her agent peer. Some educational software does quite the opposite and uses the *learning by teaching* (LBT) paradigm. Here the student is given the role of a teacher's, and the agent is given the role of the tutee. Such an agent is called a *teachable agent* (TA)[1] and will be the focus of this thesis.

1.3 Teachable agents

Learning by teaching is a learning technique that is often used, although not always reflected on as such. When someone prepares to teach, he or she is also getting a supporting context for learning the topic and teacher often learn as much, or more, than his or her students (Brophy & Biswas, 1999).

When implementing the LBT learning strategy into a digital learning environment, "the student teaches the TA, so the TA is dependent on the student. At the same time, the TA contains intelligence that allows it to behave independently" (Chase, Chin, Oppezzo, & Schwartz, 2009, p. 3). Teachable agent learning environments (TALEs) have shown some impressing effects on learning processes both regarding scaffolding good learning behavior (Biswas & Roscoe, 2009) and in motivating students to

[1] TA in this context should not be confused with a common use of TA referring to *teaching assistant*.

spend additional time and effort on learning (Pareto, Haake, Lindström, Sjödén, & Gulz, 2012).

However, there is more educational value to be drawn from LBT pedagogics and the development of educational software invokes an opportunity to offer students new ways of improving motivation to engage in learning activities. Another effect of the TA paradigm is the possibility to foster successful learning behaviors since the students are made aware of what results their learning activity choices have on the TA's performance.

1.4 A new teachable agent

To this day, embodied agents have been rather compliant and cheerful, Cassell and Thórisson (1999) argue that traditional agents are weak in believability and (Gulz, Haake, Silvervarg, Sjödén, & Veletsianos, 2011) found that students during a focus group interviews expressed that the TA should not be too polite, but express some *attitude*"(Gulz et al., 2011, p. 144). Aïmeur, Dufort, Leibu, and Frasson conducted a study that involved peer agents and experimented with different agent behaviors. Their *troublemaker* peer agent exhibited impetuous behavior and questioned what it had been taught. By encouraging learners to question the knowledge of a troublemaker peer agent, motivation for learning activities increased (Aïmeur et al., 1997, p. 4).

It is possible that an agent with challenging behavior better invites and motivates students to engage in teaching, as well as learning activities. A TA that questions what it is taught will hopefully force the student to reflect on the material and thereby reach a deeper level of understanding. Teachable agents that exhibit more challenging, not always collaborative, behavior towards the students is, therefore, a new TALE area to explore. We are speculating that a new type of TA that offers more challenge will stimulate cognitive mechanisms resulting in more and deeper knowledge. An important factor to consider is that not all students learn in the same manner and can react differently to the TA and its behaviors.

Self-efficacy refers to a person's belief in her own capabilities to perform in a specific domain (Bandura, 2006) and we will take the level of self-efficacy into account since it was suggested by Aïmeur et al. (1997) in the neighbour domain of peer agents, that students' level of self-efficacy correlated with the impact on learning when using a challenging agent strategy.

The aim of the research presented in this thesis is to use the current research about TAs and to explore further how different challenging TA behaviors may improve learning and learning strategies. This thesis presents work that has taken the first steps in this direction, aiming to improve an already promising educational technology tool in the form on TAs.

1.5 Research questions

How will a TA that provides challenge in learning situations, in comparison with a traditional TA, affect how students:

Question no.1 experience their learning and what they learn?

Question no.2 experience and react to their TA's behavior?

Question no.3 experience the protégé-effect?

Chapter 2

THEORETICAL BACKGROUND

Many of us have experienced that to teach a topic to others is a fruitful and motivating way to gain a deeper insight into the subject, but it takes time and effort to set up. Using teachable agents in a digital learning environment is a way to deal with such drawbacks and still be able to gain benefits from the learning from teaching strategy. Another factor that can be used to improve learning quality is to introduce learning challenges when students are learning a topic. Students' reactions to a challenge can result in fruitful learning behaviors.

2.1 Learning by teaching (LBT)

A way of challenging a person to take responsibility for his or her learning is to ask that person to teach someone else. The teaching framing contributes to a self-directed strategic learning behavior. Learning by Teaching (LBT) corresponds to the Latin expression *docendo discimus* – by teaching we learn. The procedure of preparing, teaching and reflecting provides the teacher with a particular kind of learning experience (Biswas & Jeong, 2010). Studies have shown that using LBT as a learning paradigm offers opportunities to scaffold and train learning behavior for the individual that takes the role of a teacher (Blair, Schwartz, Biswas, & Leelawong, 2007). Further, studies show an increase in the use of techniques as memorizing, organizing and reflecting, as well as the teacher reaching a deeper understanding of the topic (Leelawong & Biswas, 2008; Graesser, Chipman, Leeming, & Biedenbach, 2009). Bargh and Schul (1980) found that students with the objective to teach learned topics better, compared with students who learned with the objective of passing a test. Metacognitive abilities like checking one's understanding and learning progress used in learning activities are also trained in teaching activities (Schneider, 2008).

Teachers are providers of information, engagers, and role models. They may feel a responsibility to ensure that their students leave their classroom with all the tools they need to continue their learning on their own (Haake & Gulz, 2009), and such a feeling of responsibility for their students is called a protégé-effect (Chase et al., 2009).

Early in the teaching process, teachers start to prepare the material. Here they

reflect on the topic, extract relevant parts, compare central aspects, and prepare to present the material in a coherent way and logical order. In this process, teachers will also revise their understanding repeatedly and try to imagine how the material will be understood by someone that has different prior knowledge (i.e. their students' prior knowledge) (Schneider, 2008). Teachers may at some point imagine themselves not knowing the material and then proceed to build the knowledge base, from this imagined state of knowledge, with the help of their own teaching material. The teacher may try to anticipate students' questions and prepare answers to them when reflecting on the other person's understanding; they are in fact also reflecting on their understanding by proxy (Kim & Baylor, 2006).

After that comes the actual part of teaching, the demonstration. Here teachers confront their students, they try out the learning activities that they composed and face students' reactions. Teachers have to deal with real-time explanations. Perhaps some part of the lecture went into too much detail too early, or maybe the teacher finds students losing focus. Perhaps students posed unexpected questions on a part that the teachers thought would be easy to comprehend. Teachers would then reflect on the material once more and revise their teaching strategy for the next occasion.

Beyond preparing to teach, actual teaching can tap into the three critical aspects of learning interactions: structuring, taking responsibility and reflecting" (Leelawong & Biswas, 2008). This entire teaching procedure, which includes preparation, teaching and reflection are a productive learning behavior for a student to engage in, and it is what lies behind the notion of learning by teaching.

Drawbacks with LBT in school settings

There are, however, some difficulties in creating good LBT classroom scenarios. Firstly, creating good LBT scenarios in classroom settings, which pay off in regards to academic achievement and transferable learning behavior, takes time and effort. Secondly, a potential problem with teaching may be to find matching peers. The peer may be on a too high or low competence, or experience, level compared to the student-teacher which reduces the possibility of knowledge exchange (Rensing, de Freitas, Ley, & Muñoz-Merino, 2014). In addition, a conjecture based on the similarity attract hypothesis is that there may be attitudinal preferences between students and teachers. For example, a student with high self-efficacy may prefer a teacher that exhibit similar characteristics (Reeves & Nass, 1996). Thirdly, students may experience a mental block due to performance anxiety. There are plenty of examples of students who simply cannot perform well during exams regardless of how well they understand the topic. The anxiety of failing a demonstration in front of one's peers may decrease the capacity of performing in teaching and learning activities (Chase et al., 2009). Moreover, the amount of time and number of occasions the student get the opportunity to spend on teaching activities are crucial. Students train to perform such self-regulated learning behaviors each time they get the teacher role.

A solution to the drawbacks with LBT in school settings is to create a virtual learning environment with a pedagogical agent that take the role as a tutee. The TA should exhibit behavior that invites and motivates the user to teach. TALEs are currently being developed and evaluated, with an intention to offer students the chance of trying

the role of a teacher and also reduce some of the extra time and efforts required to develop LBT learning scenarios in classrooms. In addition, no real person comes to harm if the student would fail the assignment to teach (Kirkegaard, Gulz, & Silvervarg, 2014).

2.2 TA learning environments (TALEs)

The notion of something being an *agent* suggests that it exhibits a detectable pattern of responsive actions to events outside the agent, something we commonly interpret as behaviors (Linn, Segedy, Jeong, Podgursky, & Biswas, 2009). Schwartz and Arena (2009), add to the definition that an agent should also be experienced as someone with intentions or an agenda. A TA extends the agent criteria by being able to build its knowledge base when being taught. The act of teaching is implicit or explicit to the user (Leelawong & Biswas, 2008), and if the agents have been taught properly by the students they can solve the problems they confront, or they need to be further educated (Brophy & Biswas, 1999). The simulation of TA behavior is guided by artificial intelligence techniques and is based on what it is taught (Brophy & Biswas, 1999). In this thesis, we will from now on refer to agent-tutees as *he* or *him*, and student-teachers will be referred to as *she* or *her*.

A student who is using a TALE will take the role of a teacher and the TA present in the environment, will act as her tutee. The TA and TALE are embedded in a narrative that justifies why the student should engage in learning activities or what particular problems the TA should be able to solve. The narratives are easily accepted, motivates and helps students to organize learning tasks (Blair et al., 2007). In coming sections an example TALE will be described.

A TALE example: Betty's Brain

We will use *Betty's Brain*[1] as the example of TALEs being developed. This TALE has been extensively described in the literature and has had a profound influence on the domain of TALEs. Betty's Brain is a digital learning environment developed at Vanderbilt University by the Teachable Agents Group (Leelawong & Biswas, 2008).

The TALE includes a TA called Betty, who asks the student to become her mentor. The environment "combines learning by teaching with self-regulated learning feedback to promote deep learning and understanding in the science domain" (Leelawong & Biswas, 2008). The Betty's Brain TALE treats science topics, and currently: ecosystems, climate change, and thermoregulation. The learning environment is targeted at primary school students.

The learning activities of Betty's Brain are embedded in a narrative built around Betty. Students using the TALE are building Betty's causal reasoning. Students can monitor Betty's learning process with the help of a concept map which represents Betty's current state of knowledge concerning relations between cause and effect (see Figure 2.1). Furthermore, the students are expected to gather relevant information from a course book included in the learning environment to teach Betty.

[1] For more information about Betty's Brain, see www.teachableagents.org/research/bettysbrain.

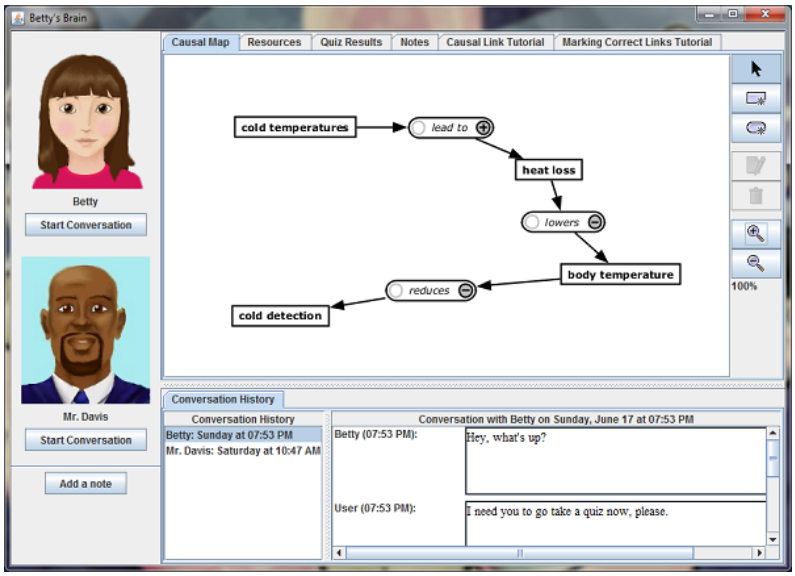


Figure 2.1: Betty's Brain
The Betty's Brain TALE in its teaching mode. Betty is in the upper left corner, and Mr. Davis is below.

At any time, the student can ask Betty a question on the form "If the *temperature rises*, what will happen to the *ozone layer*?". Betty deduces the answer using the concept map constructed by her student-teacher. There is an additional character in the learning environment, Mr. Davis, who is Betty's teacher. Mr. Davis grades Betty's answers and sometimes points at what topic details Betty needs to know better or gives the student advice on how to improve their learning behavior. In addition to the self-study mode where the student reads the book and the teaching mode where the student teaches Betty, there is also a *quiz mode*. In the quiz mode, Betty is asked a set of pre-set questions, and the student gets feedback on the status of Betty's knowledge (i.e. the concept map seen in Figure 2.1).

2.2.1 TALE characteristics

This section provides a short overview of typical TALE characteristics and TALEs that exemplify them.

Choice of curricula

Most educational technologies today are developed to fit into the STEM[2] area, which may be because these fields rest on theories based on causality and that causal relations are relatively easy to model and visualize using computers.

[2] STEM: Science, Technology, Engineering and Mathematics

Agent-student relationship

Existing learning environments use different agent models. In Betty's Brain, the agent and the student have a mentor-tutee relationship where the student instructs Betty. In virtue of being Betty's teacher, Mr. Davis has the authority to correct and scaffold the student. The *teacher* character is not an obligatory part and thus not present in all TALEs.

Knowledge structure

TAs traditionally has either no prior knowledge, or they pretend to learn from the students but have full internal knowledge (Leelawong & Biswas, 2008). The TAs that has full internal knowledge (e.g. Betty's Brain) has the advantage that it through the posing of questions or strategically reasoning can guide the student towards the correct solution. The kind of TA with no initial knowledge is more conceptually sound since the behavior of such agent will reflect only on what it has been taught by the student and, indirectly, on the knowledge of the student. A problem with the latter TA is that the environment cannot register if and when a student diverges from her learning goals and it cannot scaffold the student into the more goal-oriented learning behavior in the same explicit way as a TA that has full internal knowledge.

Knowledge representation

Another common characteristic in TAs is *shared knowledge representation*. Shared knowledge representation means that both the student (teacher) and the TA (tutee) can monitor the agent's current knowledge. The knowledge needs to be organized in a structured, logical way to allow for sufficient monitoring. For example, in Betty's Brain shared representation is promoted. This means "a representation scheme and corresponding data structure keep track of what the student-teacher has taught the agent" (Leelawong & Biswas, 2008, p. 183). The authors found that without shared representation, the actions of the agent were sometimes hard to understand since the student could not follow the reasoning of their agent (Leelawong & Biswas, 2008). Other ways that the student-teacher can get feedback from her TA is by observing how well he manages the learning activities, solves assignments or performs on tests, although these observations are not as explicit as a visual data structure.

2.2.2 Effects of TALE

In the TA domain, a central incentive for TAs is the protégé-effect: students make a greater effort to teach their TA than they do to teach themselves. This effect was shown in a study by Chase et al. (2009) where students were presented with the alternative to either learn material for a future test or to teach a TA. The authors attribute the protégé-effect to a synergy between different contributing effects: 1) *ego-protective buffer*: which means a possible failure would be assigned to the TA, and not the student directly, thereby reducing failure anxiety in the student; 2) *responsibility*: the student treats her TA as a social entity and shows concern and accountability for

her TAs academic success. By taking responsibility, the student is motivated to revisit learning material, rethink her understanding, and try to come up with new and better ways of helping the TA to understand the material; and 3) *incrementalist theory*: To work as a teacher, the student appears to accept the idea of incremental knowledge, believing that their TA could perform academically better after being taught (Chase et al., 2009). Leelawong and Biswas (2008) showed that students using a TALE performed better than students that used a learning environment where they were to teach themselves, but they also showed that this effect persisted into new learning assignments where no TALE was used. This suggests that the trained learning behaviors were transferred to new learning situations.

In the domain of digital tutors, Aïmeur et al. (1997) proposed that different tutoring strategies are needed depending on what topic is taught, and that different strategies train different skills in the learner. They also pointed out that it is important to alternate between several tutoring strategies to maintain the attention of the learner. Furthermore, it has been suggested that TAs may exhibit various types of personalities including varying degrees of self-efficacy and ability to collaborate (Brophy & Biswas, 1999).

We want to explore the possibilities of combining the proven learning by teaching effects on learning behaviors with a challenge in the learning proces. This has to our knowledge hitherto never been realized nor evaluated in the TALE domain. Instead, current TAs plays a compliant role in the learning activities. In comparison to real-world teaching situations, such a compliant tutee is rather rare, although easy to manage.

2.3 Challenged when learning

In general, when developing educational software, instructions are aimed to be adapted to the student to avoid, or rapidly resolve, uncertainty and confusion. To engage in learning in a comfortable learning environment without challenges is to a lower degree, associated with a deep learning than challenging or confusing learning situations (Aïmeur et al., 1997). However students often prefer pedagogical methods that result in shallow learning quality, since it requires less effort (D'Mello, Lehman, Pekrun, & Graesser, 2012).

However, there are mental states that are triggered by the confusion which may be beneficial in a learning context. If confusion is used strategically, it may, for example, promote learning at deeper levels of comprehension (D'Mello et al., 2012). Kirkegaard et al. (2014) suggest some possible approaches to challenge a student that engages in a TALE, example: 1) to introduce errors, 2) to induce confusion, 3) to lower the probability of success, and 4) to debate answers.

2.3.1 Cognitive dissonance

When learners experience a divergence between their beliefs, and what is suggested to them, they will experience a cognitive dissonance and become confused. The person will increase her attention and get motivated to resolve, or avoid, the dissonance

to relieve the discomforting psychological situation she is experiencing (Festinger, 1962). In a study by D'Mello et al. (2012), confusion was the only emotion that significantly predicted learning, and they called confusion a *knowledge emotion* since it arises when the learner is presented with new, for example contradicting, information and she may experience a need to revise her existing mental models and beliefs accordingly (D'Mello et al., 2012). Aïmeur et al. (1997) used the term *learning by disturbing* to denote the learning strategy.

In comparison with shallow learning tasks, complex learning tasks that require comprehension on a high level, often involves confusion as a part of the learning process. Hence, the learner is, for example, required to diagnose and solve problems, make conceptual comparisons, generate explanations and transfer the new knowledge and skills to other domains (D'Mello et al., 2012). Interventions that successfully induce confusion in learners might be what is needed for a student to become more active in their learning processes, but it is important that the conflicts are meaningful and aligned with learning goals. In addition, the learner needs to have the required skills or sufficient knowledge to be able to resolve the confusion or to master the challenges. Also, the student's individual learning approach is a factor to take into account. Students who want to be challenged, risk failure and can manage negative emotions, respond better to the learning by disturbing strategy (D'Mello et al., 2012).

Dissonance qualities

Depending on how the confusion was induced, how the learner reacts on such a provocation and how large the confusion was, there is a shift in attention and engagement in the learner that might benefit educational interventions (D'Mello et al., 2012). So, it is not enough to just to induce confusion; there are also different kinds of confusion to take into account.

Sources of cognitive dissonance are here exemplified by: "obstacles to goals, interruptions of organized action sequences, impasses, contradictions, anomalous events, dissonance, unexpected feedback, exposure of misconceptions, and general deviations from norms and expectations"(D'Mello et al., 2012, p. 5).

Also, the context in which the confusion is experienced is important since different contexts are not expected to have the same effects on learning, the context must be coupled with learning activities that are experienced to be important by the learner. Lastly, the cognitive dissonance needs to get, partly or fully, resolved to result in a *productive confusion*, that can affect learning in a positive way (D'Mello et al., 2012).

2.3.2 A non-compliant TA

TAs developed so far do not have much of a personality, and usually, they accept all information provided by their teacher without questioning it. Cassell and Thórisson (1999) means that it can be tiresome and boring to interact with an agent that is always positive, compliant and cheerful, and that such agents are less believable.

By adding challenging behaviors to the agent, we are also increasing the level of experienced agent agency. Schwartz (1999) means that a teachable agent that exhibit

more agency may increase the student's interest in collaboration with the agent, and Kim (2004) showed that altering the agents persona and responsiveness can affect learning, interest and self-efficacy in the learner.

The learning by disturbing teaching strategy uses the intrinsic motivation coming from not understanding each other, which sometimes, can be just what is needed to improve motivation. In one of the seminal papers on TAs, Brophy and Biswas (1999) proposed an agent that "may be impetuous, not listen or collaborate well"(p. 1), and Aïmeur et al. (1997) proposed that a troublemaker peer agent would spark learning effects in the students. 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 argue for his solution until the student agrees or the troublemaker runs out of arguments. If the student agrees, the troublemaker solution will be presented to the tutor for feedback, and in one of their conducted studies the authors found that the learner was motivated by the troublemaker agent that "encourages the learner to question his own knowledge"(Aïmeur et al., 1997, p. 12).

2.3.3 Risk of making failures

Another way a teachable agent can challenge the student is in the choice of learning activities and the difficulty level of these activities. Clifford (1990) wrote about challenges in learning situations and suggested that students need the risk to make failures to increase emotional engagement. 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. She points out that to generate intrinsic motivation a task needs to have a *moderate probability of success*, which she suggests would be a 50% chance of success. An easily mastered task will not affect the intrinsic motivation since it is considered below the student's level of performance, and a mastered task considered too difficult would be considered to be *out of luck*, and would not affect the intrinsic motivation. By encouraging the students to try out tasks on a higher level than they master, students will get the "the privilege of learning by mistakes" (Clifford, 1990, p. 2).

2.4 A challenging teachable agent (CTA)

A TA that uses a learning-by-disturbing strategy could force the learner to become more self-confident about distinguishing between correct or incorrect facts, improve the learners learning strategies and to try out her newly acquired skills together with her TA (Aïmeur et al., 1997). Their suggestions for a troublemaker peer agent were: 1) The CTA will be the source of dissonance, and challenge. 2) The CTA will at the time be the only available source of information. 3) The TALE and a booklet with instructions will contain means to resolve the dissonance, i.e. including information and possibility to interact with the agent. 4) In the dialogue with the TA, the student can either agree or disagree (Aïmeur et al., 1997). The authors performed a user study where they tried out the troublemaker strategy and showed that the strategy had a greater

impact on learning for students that had higher self-efficacy. Self-efficacy is also according to Bandura (1994) an important factor when it comes to handling challenging situations. A person with high self-efficacy sees difficult tasks rather as challenging than something that ought to be avoided. High self-efficacy is also connected to the attribution of failure to lack of effort, whereas those with a low self-efficacy would attribute failures to personal flaws. In line with these results and theories, we will also include the students' level of self-efficacy in the experimental design.

The next chapter will describe how to realize the challenging teachable agent that exhibit challenging behavior regarding producing dissonance, confusion and pushing students towards a risk of making failures.

Chapter 3

THE GUARDIAN OF HISTORY (GoH)

3.1 TALE Background

Guardian of History (GoH), is web-based self-explicatory TALE that includes learning activities that correspond to the Swedish national curriculum for history in 5-6th grade (Swedish name: *Historiens Väktare*). The primary purpose of Guardian of History is a research tool for studying learning processes in a way that is experienced as nonintrusive by the student. GoH has been used to study how students handle challenges in relation to, for example, visou-spatial memory capacity (Palmqvist, 2013) or level of self-efficacy (Kirkegaard et al., 2014). GoH is designed to offer learning related choices and challenges for students with different academic performance levels.

The secondary purpose with GoH is to study how to best design pedagogical tools for practical use in schools (Kling, 2015). The TALE, GoH, is being developed by the Educational Technology Group, and by students' course projects (e.g. Master's theses) from Lund and Linköping Universities in Sweden. The research group develops "educational technology systems and prototypes with two purposes: (1) exploiting them as research instruments to explore learning processes, and (2) coming up with pedagogical software with a real-world value as pedagogical tools"[1].

GoH is also a first attempt to develop a TALE within social science. The previous TALEs have, to our knowledge, all been developed in the STEM area. GoH has been refined iteratively based on user studies and test sessions conducted during a period of four years. The main study in this study used GoH version: "hWorld, Django, 2016-02-08".

[1]More information about the Educational Technology Group can be found at: http://www.lucs.lu.se/etg/

3.1.1 Narrative

Guardian of History is based on the learning by teaching technique, featuring a teachable agent (TA), "Timy", as the pupil and the *Guardian of history*. The narrative is a central part of the learning environment.

GoH starts out with the guardian of history introducing himself as Chronos, who lives in the *Castle of time* together with his many *time elves*. The time elves work to assist Chronos to watch over history and document it. Chronos has now reached a quite respectable age of 3000 years and is about to retire. Therefore, he now needs to choose a successor amongst his time elves.

Timy, who is one of the time elves, starts to talk with the student and explains that he wants to become the successor of Chronos, but unfortunately, Timy has motion sickness and gets very sick if traveling with the time machine to learn about various events in the past, which is required for becoming the successor to the guardian of time. However, then Timy gets a brilliant idea: the student may help him out and travel to historical persons and historical eras in his place! After the time travels, the student can then get back to teach him about the things that she has learned from her travels.

3.1.2 GoH versions

There are two different versions of GoH: one with a traditional TA and one with a more challenging TA, a CTA. The CTA is designed to be more argumentative and questioning towards the student to challenge her in the learning activities. GoH contains these different types of activities:

Time travels used to gather information.

Learning activities used to teach the TA.

Test activity used to have the TA take tests.

Pause activity used to offer the student an off-task activity.

The historical persons that can be visited in the present version of GoH are Leonardo da Vinci, Johan Gutenberg, Galileo Galilei, Nicolaus Copernicus, Sofia Brahe, Margaret Cavendish, Maria Kirsch, and Emelie Chatelet. In Table 3.1, the assignments used in the study are presented.

3.2 Time travels

The student starts out by gathering knowledge, an aspect of preparing to teach. She enters the time traveling room where the time machine is located. In the time machine, the student can choose what historical person or historical era she wants to visit. The student travels through time and is taken to the historical environment associated with the chosen person or era. In this environment, the student encounters an historical person. A scripted dialogue with information about the person triggered

Table 3.1: Assignment in TALE

Assignment	Activity	Mode
	Theme: Galilei and da Vinci	
1	Time travel	two travels
2	Timeline	1 – *alone, observe, together*
3	Concept map	1 – *alone, observe, together*
	Theme: Worldview	
4	Time travel	two travels
5	Timeline	2 – *alone, observe, together*
6	Concept map	2 – *alone, observe, together*
7	Test	1
	Theme: Female scientists	
8	Time travel	four travels
9	Timeline	3 – *alone, observe, together*
10	Concept map	3 – *alone, observe, together*
11	Test	2
	Time buffer: Play Othello with agent	

either by the student or automatically. In the visited setting, there are also clickable artifacts on walls and tables. When the student clicks on an artifact, information about that item is shown. When the student is finished researching the historical environment, she clicks on the time machine and returns to the Castle of Time. Now she has gathered information that she can use to teach Timy.

3.3 Learning activities

The learning activities in use were *timeline* and *concept map* that both uses with board-game like designs and consists of three difficulty levels and three learning modes, see Figure 3.1.

3.3.1 Timeline

The timeline is a learning activity targeted at a rather shallow knowledge of historical facts. The student should match historical persons with events or artifacts and then place the person-event pairs on a timeline showing 50-year long time slots for the period 1300 – 1900, (see Figure 3.2). When the student wanted to finish the learning activity she clicks "correct now". Chronos appears and gives the student and Timy feedback on whether or not they succeeded with the learning activity, see Figure 3.5.

3.3.2 Concept map

The concept map is a learning activity that requires an understanding of how different historical content in the TALE relates to each other. The learning activity uses a

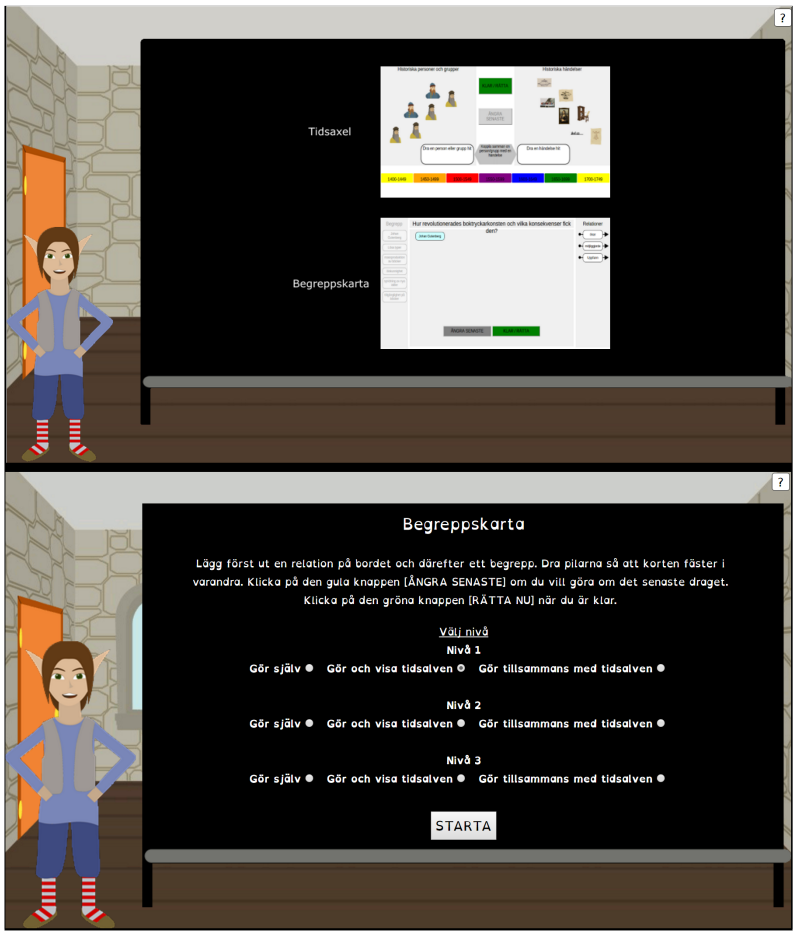


Figure 3.1: Learning activity selection
Note: Choose timeline or concept map, mode [alone, observe, together] and difficulty level [1-3].

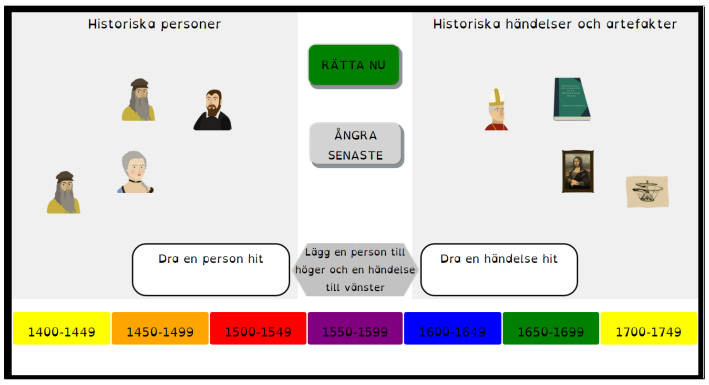


Figure 3.2: Timeline learning activity

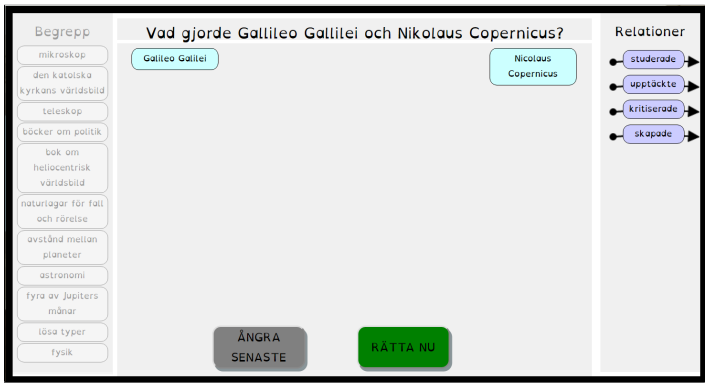


Figure 3.3: Learning activity, concept map

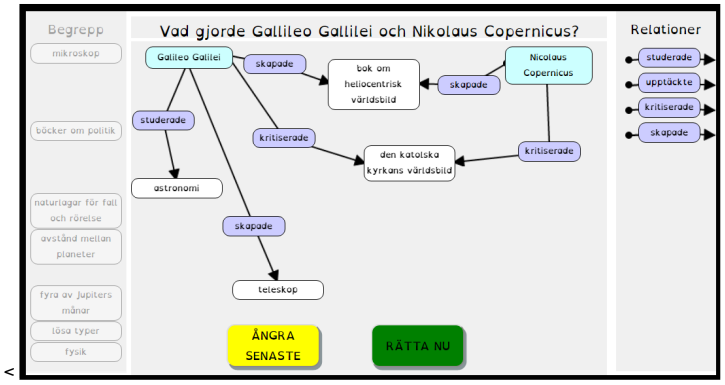
traditional concept map approach where the concepts are presented to the left and the types of relations to the right (see Figure 3.3). In the middle of the game board, the concepts and relations are linked together, see Figure 3.4.

3.3.3 Knowledge representation and reasoning

The TA knows nothing initially, which implies that the student can teach him correct or incorrect facts, as she pleases. If the student teaches her TA only incorrect facts, he will know only incorrect facts. The agent reflects the student's current state of knowledge.

To model a simplified learning process of a tutee, we associated each fact with a certainty value, reflecting the degree to which the TA is certain that the fact is correct. The slowest learning rate, *certainty point* for a fact, is earned by the TA when he passively observes the student as she plays a fact (for data format, see Table 3.2).

When the agent places a fact on the game board that is accepted by the student, the fact's certainty increase with two certainty points. Each fact can reach maximally



Note: Concept map with concepts and relations connected.

Figure 3.4: Concept map example

Figure 3.5: Guardian of history gives feedback

Note: Guardian of History pop-up gives feedback after learning activity: *5 facts were placed out, more are required to be placed out to pass this level.*

Table 3.2: Example of internal fact representation

Person	Event	From	To	Corr.	Cert.
Sofia Brahe	Studied anatomy	1600	1649	0	1
Margareta Kirsh	Painted the last supper	1700	1749	0	1
Leonardo da Vinci	Studied anatomy	1450	1499	1	5
Leonardo da Vinci	Painted the last supper	1450	1499	0	4
Leonardo da Vinci	Painted Mona Lisa	1500	1549	1	1
Leonardo da Vinci	Discovered a comet	1450	1499	0	2
Johannes Gutenberg	Invented the printing press	1450	1499	1	1
Galileo Galilei	Invented the telescope	1600	1650	0	1

Note: Historical person, historical event, from year, to year, correctness and certainty.

ten certainty points. If the agent proposes a fact to the student that is rejected, then that fact's certainty will *decrease* with one certainty point. In cases where the TA's fact suggestion is repeatedly rejected and the fact gets a certainty of zero or below, it gets deleted from the agents list of "known facts". A fact with a negative certainty score would imply that Timy knew that the fact was incorrect.

However, the certainty score of a fact has nothing to do with whether the fact is correct or incorrect. The TA can possess any ratio of correct and incorrect facts, and each with an individual certainty from one and ten.

3.4 Learning activities modes

There are three learning modes: *alone* mode where the student was doing the learning activity without the TA, the *observe* mode included the TA as a passive observer and the *together* mode where the student and the TA took turns playing the learning activities.

3.4.1 The alone mode – preparing to teach

After the information gathering, it is time for the student to try out her acquired knowledge in the learning activities. Before she can teach Timy, she needs to become certain herself. Therefore, the learning activities start with the alone mode, which serves as a preparation for the student to teach her agent.

In the alone mode, the student will engage in the learning activities without Timy present in the learning room. This is to ensure that the student has sufficient knowledge before she starts to teach, to be able to cope with questions from her tutee. Timy will not learn or unlearn anything during these sessions. If the student did not gather sufficient knowledge to pass the alone mode, the Guardian of Time will suggest that she will do additional time travels to gather more information.

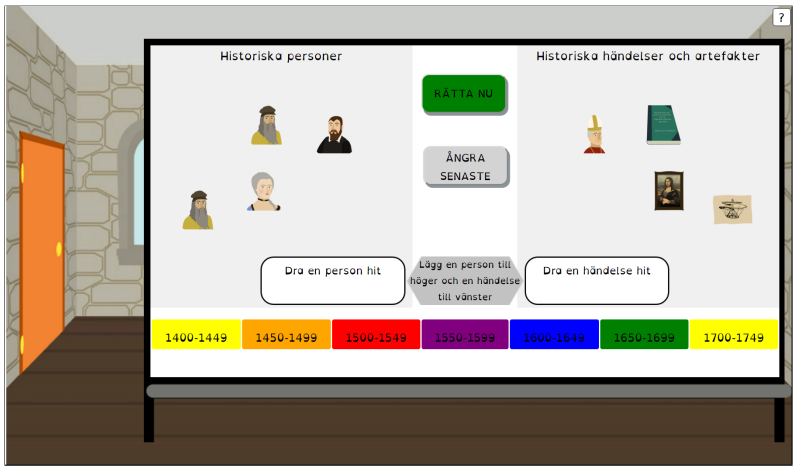


Figure 3.6: Learning activity timeline in the alone mode

Interaction example: timeline in the alone mode for level 1

The first interaction example is taken from the learning activity timeline, the alone mode, and level 1 (out of 3).

- The student drags the icon representing `Leonardo da Vinci` into the person box.
- The student drags the icon representing `invented the helicopter` into the artifact box.
- The student clicks on the time slot `1450-1500`.
- `Leonardo da Vinci` is paired together with `invented the helicopter` and placed on the timeline slot: `1450-1500`.
- Then this procedure is repeated until the student chose to end the activity, either because there are no more matching facts on the table or that the student wants to abort the session.

3.4.2 The observe mode – teaching by demonstrating

When the student passes the first level of the learning activity, it is time to start the teaching of Timy. The mode observe is identical to the previous alone mode, except for that Timy is now being visible to the left of the game board. In this mode, the TA learns from observing the student's actions and responses in the activity.

3.4.3 The together mode – teaching by taking turn

When the student chooses the mode together, Timy is sufficiently confident to take part of the learning activity. Here the student and Timy take turns in proposing facts

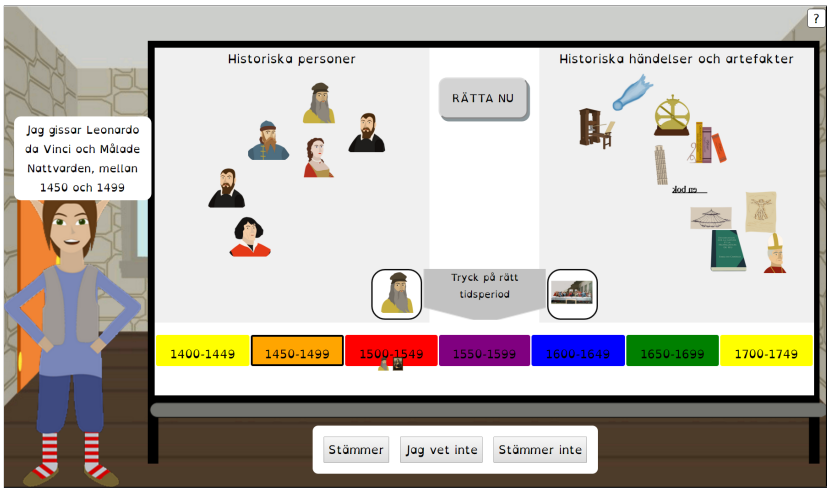


Figure 3.7: Agent proposes a fact
Note: TA proposes: "I am guessing that `Leonardo da Vinci` and `painted the last supper`, between `1450 and 1499`". The student can choose between agreeing or rejecting.

in the learning activities. If the agent rejects the proposed fact (see Figure 3.8), the student can decide whether to insist on, or to withdraw, the fact. When it is Timy's turn to propose a fact, the student needs to reject or accept the proposed fact on the game board. The student, in the role of teacher, always has the last say if she disagrees. In this mode, the agent is learning facts more actively and at a higher learning rate (two certainty points per fact).

Interaction example: timeline in together mode for level 3

The second interaction example uses the learning activity timeline, together mode, level 3 (out of 3). In the example, we use the described events from the previous alone mode interaction to highlight where the interaction differs in the together mode.

This first part of the interaction part is identical to the alone and the observe mode.

- The student drags the icon representing `Leonardo da Vinci` into the person box.
- The student drags the icon representing `invented the helicopter` into the event (or artifact) box.
- The student clicks on the time slot `1450-1500`.
- `Leonardo da Vinci` is paired together with `Invented the helicopter` and is placed on the timeline slot: `1450-1500`.

The following part of the interaction is specific for the together mode

- The TA comments: "You told me something different before, are you sure about Leonardo da Vinci and Invented the helicopter?
- The student chose to click "No, what is your suggestion?"
- The facts are now moved back to the game board, and new ones are picked by the TA.
- TA says: "I think: `Galileo Galilei` and `Invented the telescope` at `1600-1650`."
- The student chooses the alternative: "Yes, that is correct"
- The fact pair is placed on the timeline at the chosen time.
- It is now the student's turn, as the last fact was proposed by the TA.

Reasoning

When the student makes a suggestion about a fact, her agent can either accept the student's suggestion by giving an "OK" response, or he can reject the student's suggestion by stating that he is not so sure about that fact, an example is given in Figure 3.8. The algorithm for rejecting or accepting is:

NEW If the proposed fact is new, then accept it and state "that was new to me".

ACCEPT If the proposed fact exists in the knowledge database and does not contradict any other fact within the database (that has a higher certainty score), then accept the suggestion by replying "OK".

REJECT If the proposed fact contradicts an existing fact in the knowledge database (that has a higher certainty score), then reject the suggestion by replying: "I am not sure, I think it was *in another time/another event/another person*".

3.5 Test activity

Timy may be well taught by the student, or he could just as well be filled with a lot of incorrect beliefs. The test activity was, therefore, to offer the student an objective evaluation of Timy's current knowledge. In the user study, we had set up that the test activity got unlocked when Timy and the student had completed the first two levels of timeline and concept map, which corresponds to completing assignment six out of eleven. After that it was possible for Timy to retake the test after each completed learning activity or time travel.

The Guardian of History tests his successor candidates in his office top floor. When the test is being taken, a simulation of Timy answering the questions in real-time is shown, letting the student monitor Timy's performance. There are two levels of the test and the questions used were randomized, thus, different for each test occassion.

If Timy passed the test at level one, the test at level two was unlocked. The test at first level consisted of four questions and was about information gathered during the

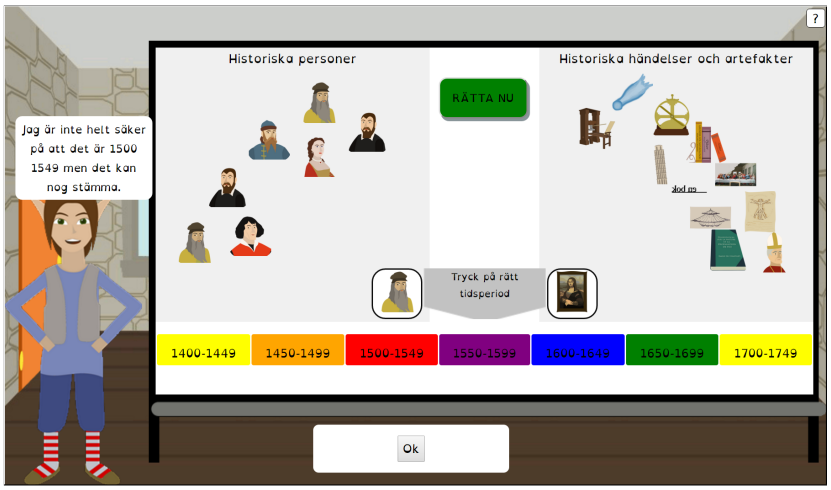


Figure 3.8: Agent questions the student's fact
Note: TA questions: "I am not that sure that it was between `1500` and `1549`, but it might be correct".

first five time travels. The second level of the test consists of seven questions and is about information gathered at all time travels, see Figure 3.10.

The tests were corrected by showing rights and wrongs in the margin, see Figure 3.9, and if Timy got all correct, he achieved the maximum score of three stars. One error resulted in two stars, two errors resulted in one star, and more than tree errors did not result in any stars at all.

3.6 Pause activity

To provide an off-task activity, we implemented the possibility for the student (and Timy) to take a break and play some Othello together in the living room, see Figure 3.11 and 3.12. The Othello game was unlocked after the test at level two was completed with, at most, one error. The student could at this point continue to engage in any activities in GoH since all activities were unlocked.

The Othello game also constituted a way to make the slower progressing students less visible in the classroom, as the students who completed all assignments would still be engaged in the TALE, in the Othello game.

3.7 Challenging agent behaviors in GoH

The two agent conditions are identical with the exception that the CTA condition has a higher frequency of two certain agent behaviors in the learning activities and it also has a third agent behavior when the student is about to choose a learning activity level. The CTA behaviors are based on chapter 2.4 at Page 12.

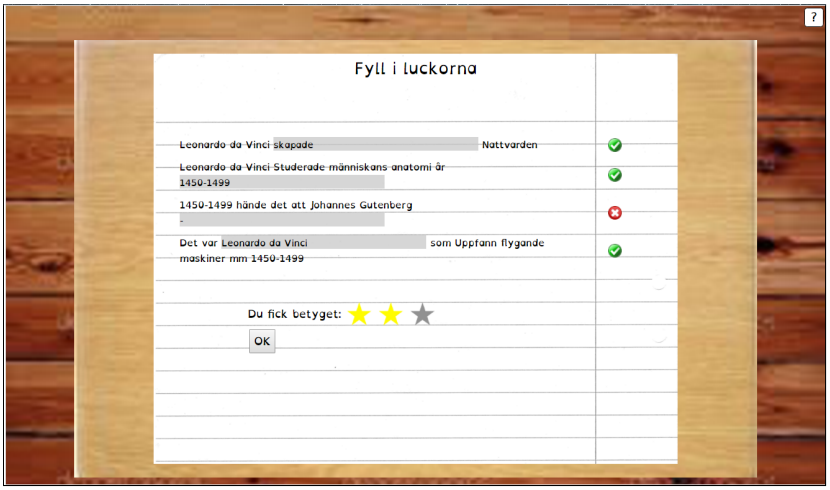


Figure 3.9: Test activity at first level
It is shown four questions completed and corrected with green "correct" symbols and red "incorrect" symbols, and one error resulted in a score of two stars.

Figure 3.10: Test activity at second level
The seven questions were answered in real-time by Timy.

Figure 3.11: Living room

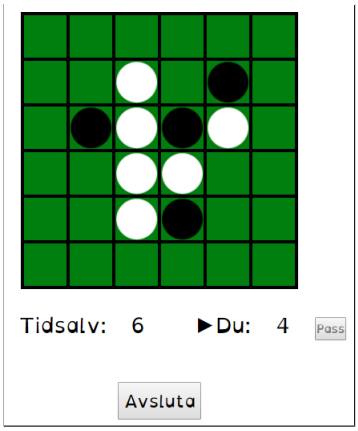


Figure 3.12: Paus activity, Othello
Note: Othello game with score of agent: 6p and you: 4p.

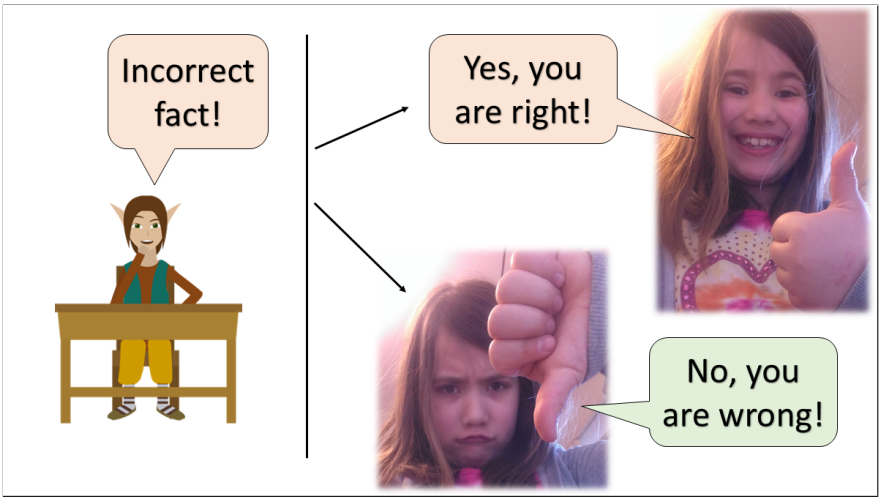


Figure 3.13: Introduction of errors
Note: Conceptual design of the *introduction of error*. The agent proposes an incorrect fact, and the student can accept or reject the proposition.

The first two behaviors are the introduction of error and the rejection of correct facts. These behaviors also occur in the (non-challenging) TA mode when a student previously taught her agent wrong facts and the agent after that would suggest back the same fact to the student. The difference between the two agent conditions is that the behavior frequency is higher in the CTA condition. The level challenge only occurs in CTA condition and only if the student does not choose the highest unlocked level.

3.7.1 The introduction of errors

When it is the agent's turn to play a fact on the game board, it would every other time give an erroneous suggestion. The introduction of error is done to force the learner to react and propose a better solution. The introduction of error was based on theories presented in Section 2.3.2, and a conceptual design is shown in Figure 3.13.

3.7.2 The rejection of correct facts

When the student had suggested a fact and the agent already learned that fact before and, thus, considered it to be correct, he would object to the proposal. Timy would say "I think that you picked the wrong *period/ event /person*". The student then had the option to either affirm or withdraw her suggestion. If she would withdraw, then the agent will continue by suggesting a new fact. Rejection of correct facts is based on theories presented in Section 2.3.1, and a conceptual design is shown in Figure 3.14.

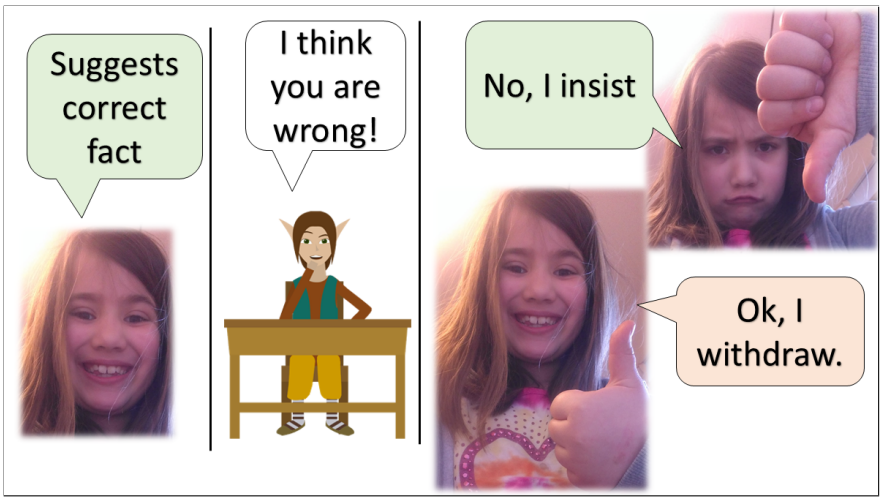


Figure 3.14: Rejection of correct facts

Note: Conceptual design of the *rejection of a correct fact*. The student proposes a correct fact, if her agent objects, the student can then either confirm or withdraw the proposition.

3.7.3 The level challenge

To increase the level of risk-taking, the agent encourages the student to choose a higher level, each time that the student did not already, choose the highest unlocked level. The level challenge is based on theories presented in Section 2.3.3, and was given a conceptual design shown in Figure 3.15).

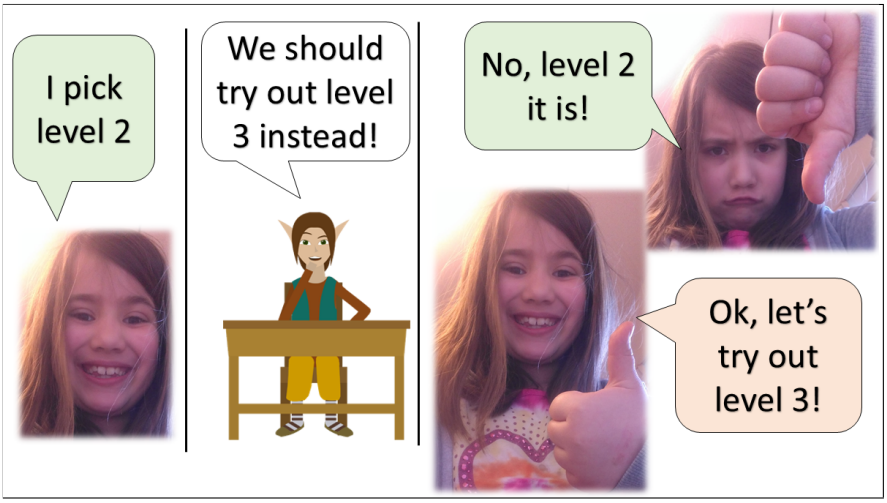


Figure 3.15: Level challenge

Note: Conceptual design of the *level challenge*. The CTA suggests that the student should consider choosing a higher level and the student can either accept or reject the suggestion.

Chapter 4

METHOD

Our research questions were: how will a TA that provides challenge in learning situations, in comparison with a traditional TA, affect how students:

Question no.1 experience their learning and what they learn?

Question no.2 experience and react to their TA's behavior?

Question no.3 experience the learning by teaching effect?

Since our research question was regarding behaviors and experiences in two different agent conditions, a quantitative interventional design was chosen.

4.1 Experimental design

We had a double-blinded 2 X 2 factorial design, with agent condition and level of self-efficacy as the two independent variables. The agent condition was a between-group independent variable, and the self-efficacy group was a within-group independent variable, both variables had two levels each. The resulting student groups are presented below:

Independent variables	CTA	TA
Low self-efficacy	CTA low SE	TA low SE
High self-efficacy	CTA high SE	TA high SE

4.1.1 Independent variables

The study was double blinded since all the students, teachers and 3 (out of 5) test leaders did not know that there existed two different agent conditions or that the students were divided into self-efficacy groups. Two of the five test leaders knew that there we used two different agent conditions, but none was informed of what conditions any of the students were exposed to.

Agent condition There were two agent conditions: 1) the TA condition with a traditional teachable agent and 2) the CTA condition with a challenging teachable agent. Condition TA and CTA were identical besides the fact that the CTA exhibited a higher frequencyce of challenging behaviors as described in Section 3.7. We considered the TA condition to be easier in comparison with the CTA condition since it involved less challenging behaviors.

Self-efficacy in history We wanted to measure students' belief in their own abilities of learning in history. Therefore, we constructed questions that map national "skill requirements" in history (Skolverket, 2011). The students were to rate their *certainty of their ability to learn* those skills, i.e. their self-efficacy in history. The three questions regarded reasoning about historical events and their consequences, how the historical events affected each other, and about historical events, person's and living conditions. See Table A.1 for original questions in Swedish.

- How sure are you that you can learn, at an acceptable level, to reason about why historical events occurred and what were the consequences?
- How sure are you that you can learn, at an acceptable level, about how the historical events affected each other?
- How sure are you that you can learn, at an acceptable level, about historical events, person's and what it was like at that time?

We distributed the questions in a digital questionnaire at the first session before students started to use the TALE. The student's average responses on the three questions would give us a self-efficacy score, for each student in the range of 0-100. The students were then divided into two self-efficacy groups with respect to their SE score: 1) the *high self-efficacy* group was identified as the top $\frac{1}{3}$ SE scores, and 2) the *low self-efficacy* group had the lowest $\frac{1}{3}$ of SE scores. The remaining students with the middle $\frac{1}{3}$ SE scores, would be included in between-group analyses made with respect to agent condition, but not included in analyses with respect to level of self-efficacy.

4.1.2 Dependent variables

Some of our assessments were gathered by using pop-up questions in the TALE during the intervention. Those questions regarded students' experience of protégé-effect and the question format provided a way to get closer to the situation where the protégé-effect may have been experienced by the students, see Table A.2. The GoH events for each student were logged continuously during the intervention. Example of data format is given in Table 4.1.

After the intervention the students responded to a post-study survey, see Table A.3 and A.4. Here is provided an overview of our categories of dependent variables, and we will go more in depth in the section of measures in Section 4.4. The TALE measures and questions can be found (translated) in Appendices A and B.

Achievement Progress, precision, recall and F-score.

Learning experience Experience of entertainment, amount of learning and difficulty.

Reaction to the challenging agent behavior Probability of appropriate student responses towards, introduction of errors and rejection of correct facts.

Experience of the challenging agent behavior Experience of introduction of errors and rejection of correct facts, negative and positive.

Experience of the protégé-effect The student's self-reported knowledge perspective and experience of ego-protective buffer and responsibility.

4.1.3 Statistical analysis

Comparisons between one independent variable, between agent conditions or self-efficacy groups, with respect to a single dependent variable, were performed with one-way ANOVAs (single factor analysis of variance). When we analyzed more than one dependent variable, we used one-way MANOVAs.

When we wanted to explore possible interaction effects between agent condition and the students' level of self-efficacy, we used two-way ANOVAs or MANOVAs (Field, 2013). All significance tests used a decision criteria of p<0.05.

4.2 Pilot study

4.2.1 Objectives

Our objectives with the pilot study were to examine:

- How the study instructions were interpreted and if they were followed.
- If the difficulty levels in the TALE were at a suitable level and the TALE provided sufficient logs.
- How, and if, students experienced the challenging traits of their CTA.
- How the students responded to the first iteration of the questionnaire.

The observations and questionnaire responses from the pilot study were used to revise the TALE, study instructions, and questionnaires accordingly.

Participants

The pilot study was conducted in October 2015, at a school that had four school classes in 6^{th} grade, with a mean size of 16 students per class and they were typically aged $10.7 \pm \frac{1}{2}$ years. We conducted four sessions of 45 minutes with each class, and collected data from 57 students, 33 girls and 24 boys.

Figure 4.1: Pilot study, experimental setting
Note: computer lab in pilot study, with an assistant checking on students and two teachers present.

Apparatus

System settings We used an earlier version of the TALE *Guardian of History* with prototyped challenging behaviors in the CTA condition. Half the students were assigned to the CTA and the TA conditions, respectively. The sessions took place in the school's computer lab.

Questionnaire We divided 31 questions into two questionnaires. The first questionnaire was distributed at the end of session three and consisted of 14 questions. This first questionnaire was to measure students' self-efficacy for learning history and their interest in history. The second questionnaire was distributed at the end of last (fourth) session, to measure how the students perceive their agent's behavior, personality and the level of challenges.

Procedure The sessions took place in the school's computer lab, during the students' scheduled history lesson, with their regular or substitute teacher present. The pilot study consisted of four sessions of 45 minutes for each class. The planned session time was, thus, 3 hours (4*45 minutes). The session time varied between 29 and 72 minutes. Three out of four classes ended up having approximately 3 hours of TALE sessions, measured on a class level[1]. Instructions were provided at each TALE session, initially and verbally, by the test leader[2]. All students were given a booklet containing a written description of the narrative and assignments.

[1]Time measured on a class level: each session time is measured from the first students login, to the last student logged out from the TALE.

[2]The author of this thesis.

4.2.2 Improvement

Approximately half of the students did not seem to take notes by habit and avoided to use their booklets except for login details and did not revisit the booklet to find new assignments. This resulted in that students did not read the introduction text on their booklets, thus, missing the narrative. When the students had questions, the study assistants reminded them of the existence and importance of the booklet, but this was not sufficient. If we would let the TA encourage the use of the booklet, it may be better accepted as a part of the TALE, and, as a result, more used. We had expected the students to progress in the TALE faster than they did. Therefore, the students reached the point where the different agent conditions came into play, relatively late into the sessions. This resulted in 3 quarters of log data where the agents exhibited the same behavior for the average student. The remaining quarter of the data that was post intervention contained challenging agent behaviors and student reactions. The sequence of activities was experienced by the students as somewhat repetitive. The last assignment of the concept map (assignment 9) required a too complex reasoning process by information provided in the TALE during time travels. Approximately two-thirds of the students did not pass the third concept map activity. There was apparently a relatively small incentive for the students to answer out questionnaires seriously. From that, we concluded that we needed to refine the questionnaire design.

In the pilot study it was evident that some students did not comprehend the TA's role being a *teachable* agent. By making the TA more challenging, we may reduce the power of the LBT metaphor, therefore, we wanted to make sure that it is well understood that the TA is teachable and *only* knows what the student teaches him. Since we are introducing errors and rejection of correct answers, we need to justify that the agent is indeed teachable and highlight the narrative, to prevent students from experiencing the TA as dishonest. The errors of the TA should rather be experienced as honest mistakes made by someone being a bit forgetful. To emphasize the TA's role being a tutee, we made an introductional video clip, where the time elf and the guardian of history explain the narrative, the ultimate goal of using the TALE and that the time elf is a bit forgetful. We also altered the leveling system to be more thematic and varied the sequence of kind of activities. The questionnaire was divided into three parts, to reduce the amount of questions distributed at each time.

4.3 Material

We gathered data using structured research instruments, the Guardian of History data logs and three separate questionnaires.

4.3.1 Guardian of History

In GoH there was a guided progress where each completed assignment unlocked the needed resources to continue the next assignment. This was to scaffold the students by providing an easier path through the TALE, revisit assignments at Page 16.

Table 4.1: Data log format

user	eventType	context	time	event	value
378	System	start	2016-02-04 17:13	Login	Agent config: CTA
380	System	start	2016-02-04 17:37	Login	Agent config: CTA
380	User	slottet	2016-02-04 17:37	EnteredSetting	TimeCastle
380	User	slottet	2016-02-04 17:37	StartingInRoom	OutsideCastle
380	User	slottet	2016-02-04 17:37	TriggeredDialog	ChronosOutside
380	System	slottet	2016-02-04 17:37	DisplayedDialogLine	ChronosOutside;start
380	User	slottet	2016-02-04 17:50	ClickedDialogResponse	ChronosOutside;start;Ok
380	User	slottet	2016-02-04 17:50	ClickedDoorToRoom	CastleHall

4.3.2 Data logs

The students in the study used school laptops (Chromebooks). GoH is a web-based application and logged TALE events with user id, event and time stamp continuously to a MySQL server, see Table 4.1 for data format. These logs were after the study managed semi-manually in Excel sheets. The measures originating from TALE logs can be found in Appendix B.

4.3.3 Questionnaires

We conducted the pre and post-study surveys digitally. We divided the questionnaire in parts, based on our prior experience when using questionnaires in the same age group. We also included pictures of the agent in order for the questionnaire to be associated with the TALE in a larger extent and thus hopefully increase the motivation and effort to respond to questions (Baylor, 2009).

Bandura (2006) recommends that one should avoid to lock respondents into a small number of answer categories and instead optimally use scales of 0-100 points, to be able to get finer granularity in given replies. We used an interval scale with an internal representation of 0 to 100. The answers were provided by the students dragging a *handle* to match the students' degree of experienced correctness for each statement. The scale was ranging from e.g. "[it is] not true at all" (stämmer inte alls) to "[it] fits very well" (stämmer mycket bra) (see Figure A.3).

The last seven questions regarded the perceived personality of the agent, and the interval in those questions ranged between two opposite personality characteristics, for example: *unfriendly* to *friendly*. The agent personality questions were responded to in the same format as previous questions, with a handle on a sliding 100-point interval scale. For screenshots of digital questionnaires see Figure A.1 and A.2.

4.4 Measures

4.4.1 Q1: Achievement and learning experience

Various approaches can be used to measure achievement and learning, and all would reflect perspectives on what is seen as desirable knowledge. We used several measurements to see if the students' chosen learning approaches would differ between agent conditions or between self-efficacy groups. How far the student had progressed in the TALE was interesting since it would reflect the level of effort made by the student, but also how well the student understood what actions that were encouraged in the TALE (i.e. degree of cue-consciousness). Precision is a measure of knowledge reliability and indicates: *how often the student is right?* Recall is a way to measure of variety in knowledge: *how much does the student know?* If a student would have a precision of 100%, every fact she suggested was correct, but it does not gives us information of whether she only suggested only a few correct facts. A recall score of 100% means that the student taught her TA all the available correct facts. A high recall score sounds perfect but it does not give us information whether the major part of the taught facts were incorrect. To value both precision and recall, at the same time, we also use a composition of the both learning attributes, an *F-score*[3] a harmonic mean (weighted average) of precision and recall.

Progress (0-24). The achieved level out of 24 possible levels.

Precision (0-100%). $\frac{Taught\ unique\ correct\ facts}{All\ taught\ unique\ facts}$

Recall (0-100%). $\frac{Unique\ correct\ facts}{All\ available\ unique\ facts\ at\ the\ current\ level}$

F-score (0-100%) $2 * \frac{Precision * Recall}{Precision + Recall}$

Learning experience

When a student is experiencing that she is questioned, she might experience the agent interactions as more demanding or difficult. For students that seeks and appreciates challenge, a contradicting agent may be experienced as more fun since he is more active and such students may experience more learning in the TALE. The agents questioning behavior could also easily be interpreted as complaints, thus, less fun.

Learn How much did you learn? Table A.3 Q. no.1.

Fun How much fun was it? Table A.3 Q. no.2.

Difficult How difficult was it? Table A.3 Q. no.6.

[3] F-score, also known as a F1 score, has a value range of 0% to 100%, where 100% is the best value and 0% the worst.

4.4.2 Q2: Reaction to, and experience of, agent's challenging behavior

Students in a user study conducted by Sjöden, Silvervarg, Haake, and Gulz (2011) expressed that they wanted an TA with more "attitude" and our CTA agent might be experienced as such. We want to see if students attribute the agent's questioning as helpful actions or as a lack of respect. The introduction of error behavior could both be interpreted as someone who is uncertain but "at least trying". That behavior could also be as something negative, the agent should not propose facts if he is not sufficiently certain.

We included four questions in the post-study questionnaire, concerning the contradicting behavior of the agent. The first two questions below starts out with *Reject correct* and they are directed to the student's experience of the challenging agent behavior where the agent rejects the student's correct fact propsal. The addition of *negative* and *positive* indicates whether or not the question phrased the challenging behavior as a good or bad thing. The last two questions were in the same manner directed towards the challenging agent behavior where the agent suggests an incorrect fact when it is the agent's turn in the together mode.

RCNeg: Reject correct negative The time elf is contradicting even though it is wrong. Table A.3 Q. no.3.

RCPos: Reject correct positive My time elf is helping me to correct facts when I am wrong. Table A.3 Q. no.5.

IENeg: Introduction of error negative The time elf makes incorrect suggestions, even though I taught it correctly. Table A.3 Q. no.8.

IEPos: Introduction of error positive The time elf is most of the time correct in the teaching room. Table A.3 Q. no.9.

Another aspect of how the challenging behaviors are perceived is the student's response actions. When the agent is suggesting a fact that is incorrect, the student is given the choices to agree or reject that suggestion. In the case where the agent is questioning the students correct suggestion, the student has the same choices, to affirm or to withdraw her suggestion.

We chose to measure the probability (0-100%) for the student to make the appropriate response to the agents challenging behaviors. The *Introduction of Error Quotient* was when the agent proposed an incorrect fact, the appropriate response was to reject that fact. Thus, we take the number of rejections, and we divide it by the number of incorrect agent proposals and gets the probability of the student taking the correct decision. *Reject Correct Quotient* was when the agent objected to the students correct fact proposals, the appropriate response was to affirm the agent's proposal. Thus, we take the number of fact affirmations, and we divide it by the total amount of agent objections to any of the student's proposals. For TALE measure overview, see Table B.

IEQ: The introduction of error-quotient (0-100%).

$$\frac{No.\ student\ reject\ incorrect}{No.\ agent\ proposed\ incorrect}$$

Table 4.2: Agent characteristics

Lowest Rank	⟶	Highest Rank
Unfriendly		Friendly
Shy		Cocky
Insecure		Self-confident
Lacking interest		Curious
Complaining		Encouraging
Forgetful		Remembers well
Stupid		Intelligent

RCQ: The rejection of correct-quotient (0-100%).

$$\frac{No.\ student\ affirmed\ correct}{No.\ agent\ objections\ to\ correct}$$

Challenging behaviors occured in both agent conditions, but they were different in frequency as well as in kind. In the TA condition the introductions of errors happened only when the agent previously had been taught an incorrect fact. This means that the kind of errors the agent would introduce in the TA condition would be more subtle than in the CTA condition. Hence, the agent conditions are not comparable in regard to how the challenging behaviors were reacted upon. Analyses of responses to agent challenging behaviors will therefore be performed only within the CTA condition.

Experience of, vs. the reaction to agent's challenging behavior

We wanted to see if there is a relationship between the students' experience of and, with the actual amount of contradicting behavior the student was confronted with in the TALE.

- The experienced vs. no. rejected correct facts in TALE.
- The experienced vs. no. introduced errors in TALE.

Experience of the agent's personality

An challenging agent that question the student's fact proposals may be experienced to have different personality traits than a traditional agent. Therefore the post-study questionnaire includes seven questions based on *the big five personality traits* (Gosling, Rentfrow, & Swann, 2003). The students were to assign how much that they experienced their agent had, of each characteristic. Questions can be visited in Table 4.2 or for Swedish original questions Table A.4.

4.4.3 Q3: Students' experience of TA induced protégé-effect

Since the TALE is based on the learning by teaching metaphor, we wanted to see if and how a challenging agent would affect how the agent is experienced by the student,

and whether challenging agent behaviors would affect the protégé effect. We used measures that involve factors that are theorized to be part of the protégé-effect, e.g. ego-protective buffer, knowledge perspective, and a sense of responsibility (Chase et al., 2009). Most of these questions (the ones from Appendix A.2) were given as pop-up question, to rate her experience of cooperation with her agent.

Knowledge perspective

The perspective of knowledge being incrementalistic is one of the suggested contributors to the protégé-effect (Chase et al., 2009). Knowledge building takes effort since it is an constructive process and is hypothezised to be associated with deeper understanding and beneficial when engaging in LBT activities. The "entity theory of intelligence" is seen a the opposing perspective on knowledge (Kantowitz, 2009), where skills are seen as fixed or innate. The knowledge perspectives are not, as it may seem, binary, where you have to choose one perspective or the other, but it can also be gradual shift in how much that you would attribute each perspective to explain a person's set of skills. Our questions below aims to capture the two different perspectives by asking the student to rate the levels of impact that effort and talent have on a person's skills in history.

Skill←effort I think that everyone can be good at history if he or she makes an effort. (A.2 Q. no.5).

Skill←talent I do not believe that you can become good at history if you are not talented. (A.2 Q. no.9).

Ego-protective buffer

A teachable agent is suggested to offer an ego-protective buffer and thus, shielding the student from some failure attribution, as she can share the failure with her agent (Chase et al., 2009; Biswas & Jeong, 2010). Therefore want to see if, and how much, the student would attribute her agent's success or lack thereof, to the her own skills in history or teaching efforts. If looking at both questions at the same time, the average value can be an indicator of how much the student feel accountable for the agent's performance, if she experience herself to have an influence on her tutee.

TAsuccess←effort How well my time elf performed on the test, depends on how much effort I made. (A.3 Q. no.7).

TAsuccess←talent How well the time elf performed on the test depends on how good I am. (A.3 Q. no.4).

Responsibility

Responsibility is one of the corner stones in the protégé-effect, both the experience of responsibilty towards the tutee, and that a student would be more prone to actually taking the responsibility to learn (in order to later on teach) (Biswas & Jeong, 2010).

We wanted to measure the student's experienced level, and kind, of responsibility towards her agent. We included the question of whether the student would (make effort to) learn in order to be able to teach and also, if she experienced the responsibility but not express the will to make effort. If the student express herself to feel more motivated to make more effort when she is playing together with the agent it would suggest that the LBT setting resulted in increased learning motivation. The last question (no.6) is the only question that does not regard effort, but only experienced level of responsibility. This question could be used to measure if the experienced level responsibility matched the level of motivation to make more effort.

Learn→teach I want to learn history to be able to teach the time elf. (A.2 Q. no.1).

Effort→teach I am making an effort to teach the time elf as good as possible. (A.2 Q. no.4).

Effort→together I am making a bigger effort to be correct when I am playing with the time elf than when I am playing alone. (A.2 Q. no.7).

Learn→test It is important to me that the time elf passes the test. (A.2 Q. no.6).

Agent induced engagement

If a student would experience the same learning activity to be easier, more fun, or involve more reflection when students do them together with the agent, the agent induced protégé-effect is likely to have affected her motivation or engagement.

Protégé→Easy It is easier to do learning activities together with the time elf than by myself. (A.2 Q. no.2).

Protégé→Fun It is more fun to do learning activities together with the time elf than by myself. (A.2 Q. no.8).

Protégé→think I am reflecting more on things when I do learning activities together with the time elf, than when I do them on my own. (A.2 Q. no.3).

4.5 Participants

We conducted a user study at a school that had 161 (81 girls and 80 boys) 6^{th}-graders over a period of 3 weeks. The were five classes with a mean size of 32 students per class. At the time of the study, the students were typically aged $11.1 \pm \frac{1}{2}$ years.

The students were divided into two groups with respect to their average self-efficacy. The low self-efficacy group, had an average SE-score of 32 points out of 100, and the high self-efficacy group had an average of 88 points. The high SE group, thereby, had 2.6 times higher SE-scores than the low SE group did.

We wanted to balance the agent conditions also with respect to the teachers' gradings of the students in history and Swedish, and received grade data for as few as 95 students (61%). The reason that we did not get grades regarding more students

Figure 4.2: Main study, experimental setting
Note: main study, students sits in their regular classrom and use TALE on Chromebooks.

was that many students had changed school recently to the new school and therefore no available grade estimates. The students' grades were converted in accordance with 4§4 in the Upper Secondary School Ordinance (Gymnasieförordningen), that describes the grade conversion: A:20, B:17.5, C:15, D:12.5, E:10, F:0 (Utbildningsdepartementet, 2010). The students average grade in History was 10.4, and in Swedish language: 12.5. This is approximately equivalent to a the grade E in history and grade D in Swedish language.

4.6 Procedure

The sessions were conducted in the students' regular classroom with their social science teacher or substitute teacher present, and supervised by the researcher. All students used school laptops, that they were familiar with, see Figure 4.2. For all classes the study consisted in; four occasions of an hour-long social science class, which meant approximaly four hours of TALE use. Sessions were conducted according to Table 4.3.

At the first session, we introduced the TALE by explaining that it was a digital study material in history. We explained that it is important to thoroughly test study materials before they can be used on a large scale in many schools. Students were informed that we would not use or publish any personal or identifiable data. We would only analyze students on group levels.

When the student use Guardian of History, for the first time, an introductory video clip is played. The video clip is 3 minutes long and consists of power point slides with recorded speech of the TALE characters. The time elves explain the narrative and the ultimate goal with the TALE: to become the successor of the Guardian of History. The time elves were all given assignments from Chronos to show themselves as perfect candidates for being chosen as the next Guardian of History. Timy mentions himself

Table 4.3: Conducted study sessions

Session	Activities
1	Instructions. Pre-study survey. TALE
2	Short instructions. TALE
3	Short instructions. TALE
4	Short instructions. TALE. Post-study survey

Note: *Instructions*: testleader providing instructions to class before each TALE session. *TALE*: Students engaged in the TALE. *Survey*: Students responding to a digital survey.

having a quite weak memory at times and hopes that students will not get bothered since it is unintentional from Timy's side. He also directs the student to use the booklet that includes the assignments for the student.

The subsequent occasions that the student uses the TALE a shorter video clip is played, in the same fashion intended to remind the student of the narrative and the TA role. Timy welcomes the student back and reminds that he really wants to become the successor of Chronos. Timy reminds about his weak memory and this reminder is used to lift the plausibility that the introduced errors in the CTA version were honest mistakes made by a forgetful time elf.

The students received a booklet each with login details and assignments that were to be completed in the TALE and we gathered them at the end of each session to prevent them getting lost outside the test room. In the booklets there were designated areas to add checkmarks to completed assignments and for the student to take notes inside the booklet which can be seen in Figure C.2. The booklets end up with a final page where the Guardian of History explains it is now time to choose between all the time elves in the castle to find the best-suited successor, see Figure C.3. Timy thanks the student for helping him out with the assignments and suggests that they should play Othello in the living room.

Study assistants were familiar with the assignments[4] and were informed not to answer the students' questions about facts, for instance, whether or not the student answers were correct. The assistants should also encourage the students to read in their booklets or help screens to find answers or strategies to get answers.

[4]The study assistants had to play through all levels in GoH in order to be prepared for the study.

Chapter 5

RESULTS

5.1 Data description

We collected data from 161 students, 81 girls and 80 boys, that used the GoH TALE at one to four sessions during the study. After exclusions there remained 146 students and the balance in regards to self-efficacy score, gender, grades for Swedish and history and minutes spent in TALE was according to Table 5.1. In that table, it is evident that we had 88 students with grades from their teachers in Swedish and history. 137 students responded to the pre-test survey and thus got a self-efficacy score. The post-test survey had the unfortunate low response rate of 88 logged surveys, and this was due to a technological mishap that resulted in the loss of responses from two entire school classes.

5.1.1 Exclusion criteria

Students from pilot study

After the first session, we excluded five boys that had used the TALE before from the data analysis. They were students at the school where we conducted the pilot study, and between our studies they changed school to the current one.

Time

A student could have used the TALE maximally for four hours. For each student, we calculated the difference between login and logout at each occasion, and then summarized the total time that the students had been using the TALE. One student was considered an outlier due to lack of time in the TALE, as the student spent only 0h37m. The rest of the users spent between 1h06m and 3h42m.

Amount of agent interactions

It was in the learning activities in the mode *together* that the intervention mainly took place, so we set a minimum of four rounds of playing in the this mode. Nine students

Table 5.1: Balanced group of students

	Mean	SD	N
Self-efficacy (score)			
TA	62	25	66
CTA	61	26	71
Total	61	26	137
Time (minutes)			
TA	148	28	68
CTA	149	30	78
Total	149	29	146
Gender (girls:1, boys:0)			
TA	46%	0.50	68
CTA	54%	0.50	78
Total	50%	0.50	146
History grade			
TA	11.1	1.8	41
CTA	10.3	3.7	47
Total	10.7	3.0	88
Swedish grade			
TA	13.2	3.6	41
CTA	12.5	3.2	47
Total	12.8	3.4	88

Note: After excluding 15 students, 146 students remained, with this balance in each agent condition and gender, Swedish and history grades, and self-efficacy.

were excluded since they had an insufficient amount of agent interactions.

5.2 Q1: Learning and experience of learning

5.2.1 Learning and achievement

The results of achievement in our agent conditions and and the level of self-efficacy, can be seen in Table 5.3. Students TALE progress was in average 11, out of maximum 24. This corresponded to students being currently on assignment 5 (revisit levels in Page 16). With an initial one-way MANOVA, we examined if agent conditions were related to the achievement measures, see Table 5.4. No significant relationships were revealed.

We took a closer look for within group effects on the level of self-efficacy and found that our achievement measures were increasing in the CTA condition for students with high SE and at the same time, decreasing for students with low SE (see Figure 5.1). Within the CTA condition there was a significant difference between progress

Table 5.2: MANOVA for balanced group of students between agent conditions

ANOVA	df	F	Sig.
Self-efficacy	1	0.03	0.87
Time (minutes)	1	0.02	0.89
Gender (girls)	1	0.98	0.32
History grade	1	1.48	0.23
Swedish grade	1	1.02	0.32

Note: No significant difference between agent conditions and self-efficacy score, time spent in GoH, gender or history or Swedish grades.

Table 5.3: Achievement measures, result

Agent condition		TA			CTA	
Self-efficacy	Low	High	Tot.	Low	High	Tot.
N	20	24	44	24	22	46
Progress	11(3)	12(3)	12(3)	10(3)	12(3)	11(3)
Precision	72%(13)	72%(14)	72%(13)	68%(16)	74%(18)	71%(17)
Recall	63%(16)	65%(13)	64%(14)	64%(14)	69%(16)	66%(15)
F-score	66%(11)	66%(8)	66%(10)	64%(10)	68%(12)	66%(11)

Note: Mean(Standard Deviation) for achievement variables; progress, precision, recall and F-score.

for students with low vs. high level of self-efficacy (see Table 5.5). Precision and recall had a small negative correlation, r=-.28, p<0.01, N=155.

5.2.2 Learning experience

In Table 5.6, we can see that students experienced the TALE, to be less fun than it was experienced difficult, and the students experienced that they learned some history. A (one-way) MANOVA, showed that agent condition was not related significantly to learning experience (see Table 5.7). A two-way MANOVA was used to explore how the level of self-efficacy was associated with the learning experience. Students with a high level of self-efficacy experienced the TALE to be significantly more fun and more difficult, than students with a low level of self-efficacy, see Table 5.8.

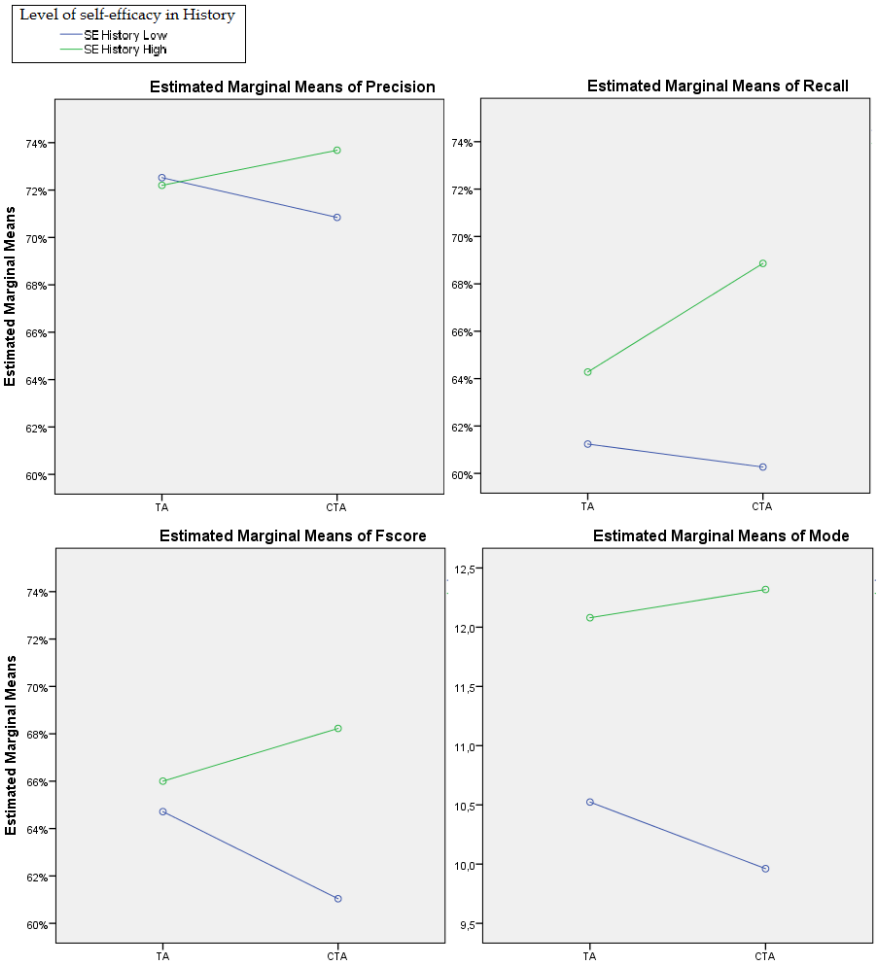


Figure 5.1: Achievement between, and within, agent conditions
Note: Mode = Level in or TALE GoH.

Table 5.4: MANOVA for achievement between agent conditions

Achievement measures	*df*	*f*	*p*
Progress	1	0.73	0.40
Precision	1	0.81	0.37
Recall	1	0.96	0.33
F-score	1	0.05	0.82

Note: Multivariate analysis for achievement on the agent condition.

Table 5.5: MANOVA for achievement within CTA condition

Achievement measures	*df*	*f*	*p*
Progress	1	4.25	$<$**0.05**
Precision	1	1.13	0.29
Recall	1	1.34	0.25
F-score	1	2.04	0.16

Note: Multivariate analysis on the level of self-efficacy within the CTA condition.

Table 5.6: Learning experience, results

Agent		TA			CTA	
SE	Low	High	Tot.	Low	High	Tot.
N	13	15	28	13	14	27
Learn	40(27)	64(32)	53(32)	36(25)	64(27)	50(29)
Fun	31(30)	44(29)	38(30)	22(30)	46(30)	35(32)
Difficult	53(24)	58(18)	56(21)	47(23)	59(29)	53(27)

Note: Mean(Standard Deviation) for the learning experience variables; the degree of learning, fun, and difficulty in TALE.

Table 5.7: MANOVA for the learning experience between agent condition

Learning experience	*df*	*f*	*p*
Learn	1	0.05	0.83
Fun	1	1.04	0.31
Difficult	1	0.07	0.79

Note: Multivariate test for the learning experience and agent condition.

Table 5.8: MANOVA for the experience of learning within agent conditions

Learning experience	*df*	*f*	*p*
Learn	1	11.74	< 0.01
Fun	1	5.60	0.02
Difficult	1	1.65	0.12

Note: Multivariate test for the learning experience and the level of self-efficacy.

Table 5.9: Mean of challenging behaviors

Challenging behavior	CTA	TA	CTA/TA
Introduce Error	20.2	6.1	3.3
Reject Correct	15.2	1.2	12.8
Level Challenge	0.5	-	-
Any challenge	35.4	7.3	**4.9**

Table 5.10: Reactions to agent's challenging behaviors within the CTA condition

Agent condition	CTA		
Self-efficacy	Low	High	Tot
N	24	22	46
IEQ	68%(21)	76%(11)	72%(17)
RCQ	91%(16)	94%(9)	93%(13)

Note: Mean(Standard Deviation). IEQ: The introduction of error quotient. RCQ: The rejection of correct quotient.

5.3 Q2: Reaction to, and experience of challenging behavior

In our data, students in the CTA conditions had 4.9 times more challenging behaviors as can be seen in Table 5.9. The existence of unintentional challenging behaviors in the traditional TA condition was due to students incorrect teaching of their TAs, as described in Section 3.7.

5.3.1 Reaction to challenging behavior

This analysis will only be performed within the CTA agent conditions and not between agent conditions since the introduction of errors and rejections of correct facts were qualitatively different in the agent conditions, and justification can be found in Section 4.4.2.

We looked at the probability for a student to make *appropriate response*[1] to the agent's challenging behavior. The results are presented in Table 5.10. The quotient of rejection of incorrect agent proposals (IEQ) resulted in a positively skewed distribution. We normalized IEQ by using a logarithmic transformation for positive skewness suggested by Field (2013): IEQ-norm=$(lg10(100 - IEQ))$. We then performed an MANOVA for the RCQ and the normalized IEQ, and found a significant relationship between the level of self-efficacy and the IEQ, and the results are presented in Table 5.11.

When comparing the appropriate response rate for the different challenging be-

[1] An appropriate response was to reject incorrect and affirm correct proposals.

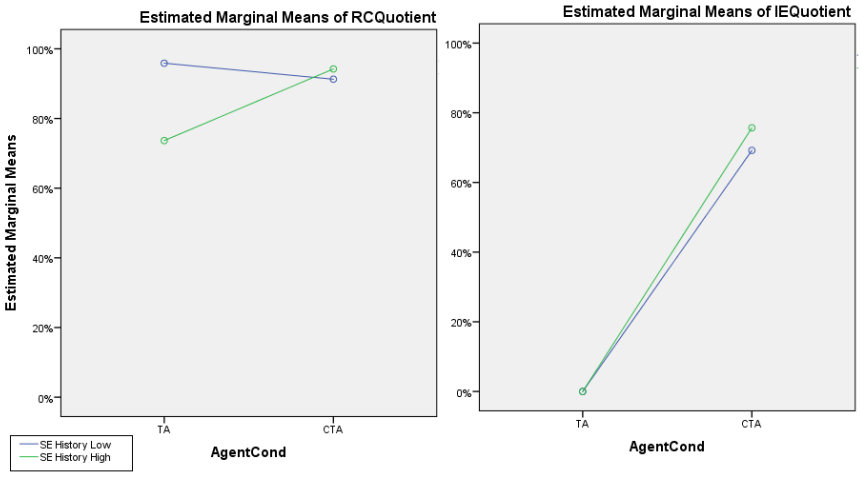


Figure 5.2: Reaction towards agent's challenging behavior

Table 5.11: MANOVA for reaction to challenging behavior, within the CTA condition

Dependent variables	*df*	*f*	*p*
IEQ-norm	1	4.79	**0.04**
RCQ	1	0.69	0.41

Table 5.12: Reaction to challenging behavior, results

Note: Relationship between the level of self-efficacy and reaction to challenging agent behavior. IEQ: The introduction of error quotient. RCQ: The rejection of correct quotient.

Table 5.13: Challenge experience, results

Agent		TA			CTA	
SE	Low	High	Tot.	Low	High	Tot.
N	13	15	28	13	14	27
RCNeg	52(42)	32(37)	41(40)	73(30)	66(35)	69(32)
RCPos	20(22)	18(25)	19(23)	21(26)	31(35)	26(31)
IENeg	64(30)	32(33)	46(34)	77(25)	81(24)	79(24)
IEPos	23(20)	54(29)	39(29)	25(26)	25(26)	25(26)

Note: Mean(Standard Deviation) for the challenge experience variables; the rejection of correct and the introduction of error.

haviors we performed a paired sample t-test between the appropriate response rate for the introduction of error and rejection of correct facts, the latter was significantly better responded to, RCQ (M=90.83, SD=18.3) and IEQ (M=50.4, SD=34.7) conditions; t(106)=1.70, p<0.01.

5.3.2 Experience of agents' challenging behavior

The questions regarding their agents challenging behavior can be revisited in Table A.3, extended with handy shortenings. Students overall express that the TA is not much being helping them or being correct, see Table 5.13. The students' replies on the questions regarding the introduction of errors (IENeg and IEPos) did not have a normal distribution but were negatively respectively positively skewed. Therefore, we normalized them[2]; IENeg-norm=$lg10(IENeg)$ and IEPos-norm=$lg10(100-IEPos)$. We then performed a multivariate variance test for the relationship between agent condition and the experience of the agent challenging behavior, see Table 5.14. Students in the CTA condition rated their agent significantly higher for negatively phrased questions about their experience of agent challenging behaviors (i.e. questions that end with "Neg" in Section 4.4.2).

We performed a paired sample t-test to see if any of the challenging behaviors were better received than the other. The negative attributions of challenging behaviors were not signifianct different: IENeg (M=63.0, SD=32.1) and RCNeg (M=56.5, SD=37.3) conditions; t(87)=1.70, p= 0.09. The positive attribution were significant different: IEPos (M=29.0, SD=27.0) and RCPos (M=21.8, SD=25.2) conditions; t(87)=2.22, p= 0.03.

5.3.3 Experience of the agent's personality

The seven characteristics we use for students to rate their agents with can be seen in Table 4.2 with results. Six of the agent characteristics correlated positively with each other. The characteristic that fell out as an ugly duckling was *Shy* $\longrightarrow$ *Cocky*, as correlated negatively with all other characteristics. The CTA was experienced as a

[2] For IEPos, the value **100**, was both the theoretical, and the observed maximal value.

Table 5.14: MANOVA for the experience of challenging behavior, between agent conditions

Survey questions	*df*	*f*	*p*
RCNeg	1	13.62	**0.00**
RCPos	1	1.10	0.30
IENeg-norm	1	6.30	**0.02**
IEPos-norm	1	1.21	0.28

Note: Relationship between agent condition and the experience of challenging agent behavior. See Table A.3, for definitions.

Table 5.15: Experience of agent characteristics, results

Agent		TA			CTA	
SE(N)	Low(13)	High(15)	Tot(28)	Low(13)	High(14)	Tot(27)
Friendly	51(37)	73(37)	63(38)	53(34)	66(33)	60(34)
Cocky	49(28)	41(27)	45(27)	41(20)	48(25)	45(23)
Self-confident	35(39)	51(33)	44(36)	43(37)	36(39)	40(37)
Curious	60(41)	69(34)	65(37)	56(34)	71(33)	63(33)
Encouraging	37(27)	43(28)	40(27)	33(20)	34(32)	34(26)
Remembers well	26(33)	39(31)	33(32)	37(28)	26(29)	31(28)
Intelligent	27(35)	41(30)	35(33)	31(25)	27(25)	29(25)

Note: Mean(Standard Deviation) for the experience of agent characteristics. To revisit the agent characteristics, see Table A.4.

bit less intelligent and encouraging than the TA agent, but these findings were non-significant.

5.4 Q3: The experience of TA induced the protégé-effect

The pop-up questions in the TALE were intended as measures of different protégé-effect aspects, and they had an average of 52 out of 100. The questions were given when the students were engaged in the TALE. They followed certain events that were assignment based, and this was why we could see a dropping rate of the number of replies from 142 down to 1, it reflects the variety of students progress in the TALE (see Table 5.17). We, therefore, limit our analysis of the pop-up questions to the ones that had a minimum of 20 replies, meaning that we analyzed pop-up questions 1 to 5. The results are given with F and *p*-values in Table 5.18, no significant relationships with respect to the agent conditions was found.

Table 5.16: MANOVA for the experience of the agent characteristics between agent conditions

Agent condition	N	F	p
Friendly	87	0.00	0.98
Cocky	87	0.03	0.87
Self-confident	87	1.22	0.27
Curious	87	2.34	0.16
Encouraging	87	2.74	0.10
Remembers well	87	1.03	0.31
Intelligent-norm	87	1.40	0.18

Note: Relationship between agent condition and the experience of agent personality.

Table 5.17: Pop-up questions, results

No.	Pop-up question	N	Mean	SD
1	Learn→teach	142	59	35
2	Protégé→Easy	111	50	37
3	Protégé→think	91	49	34
4	Effort→teach	35	57	40
5	Skill←effort	27	64	40
6	*Learn→test*	13	68	35
7	*Effort→together*	4	62	43
8	*Protégé→Fun*	3	71	39
9	*Skill←talent*	1	100	.

Note: Question no.6-9 had too few responendts and will not be a part of the analysis. Pop-up questions are available in Table A.2.

Table 5.18: MANOVA for the pop-up questions between agent conditions

	TA		CTA		MANOVA	
	M(SD)	N	M(SD)	N	F	p
Learn→teach	59(36)	68	59(33)	74	0.00	0.97
Protégé→Easy	58(36)	56	42(37)	55	5.14	**0.03**
Protégé→think	51(32)	46	47(36)	45	0.32	0.57
Effort→teach	58(43)	20	54(38)	15	0.08	0.79
Skill←effort	61(44)	16	68(35)	11	0.20	0.66

Note: F and p value were provided by an analysis of variance between agent condition and pop-up questions.

Table 5.19: Attribution of agent's success, results and MANOVA

Agent condition	TA		CTA		MANOVA	
Self-efficacy(N)	Low(13)	High(15)	Low(13)	High(14)	F	*p*
TAsuccess←talent	10(25)	24(41)	4(14)	14(36)	0.91	0.34
TAsuccess←effort	7(14)	24(40)	5(19)	14(32)	0.78	0.38

Note: Mean(Standard Deviation) for the attribution of the agent's success to the student's talent or effort. To the right the MANOVA results of between agent conditions are shown.

Knowledge perspective

The epistemologic questions of whether the student's skills should be attributed to talent or effort were not comparable since we had one reply regarding attribution of skills to talent (Skill←talent). The question regarding attribution of skills to effort (*Skill←effort*) had been answered by 27 students, and we performed a one-way ANOVA, on agent condition, see Table 5.18.

Ego-protective buffer

The questions on whether agent's success should be attributed to the student's talent or effort *TAsuccess←talent* and *TAsuccess←effort* had a large Pearsson Correlation, r=0.92, p<0.01, N=88. Scores based on agent conditions and level of self-efficacy are presented in Table 5.19.

The level of experienced accountability was lower for students in the CTA condition, which can be seen in Figure 5.3 but an indepent sample t-test for the average of both questions and on agent conditions did not detect significant differences. Both questions had a low average score in both conditions (N=88, M=13, SD=28) and divided into agent conditions: CTA (N=47, M=15, SD=31) and for TA (N=41, M=10, SD=25); t(86)=0.94, p=0.35.

Responsibility

Out of the four questions that regarded the experienced responsibility towards the agent, two of them had two few replies: Effort→together (4 replies) and Learn→test (13 replies). The remaining questions, Learn→teach and Effort→teach were analyzed together as the average both, CTA (M=57, SD=36) and TA (M=57, SD=36); t(140)=-0.35, p=0.72.

Agent-induced engagement

The question regarding the experienced level of entertainment (Protégé→Fun) when doing learning activities together with the agent, was not included in the analysis due to the low number of respondents (3 replies). The two remaining questions about how much the student experienced herself to reflect (Protégé→think) and if it was easier

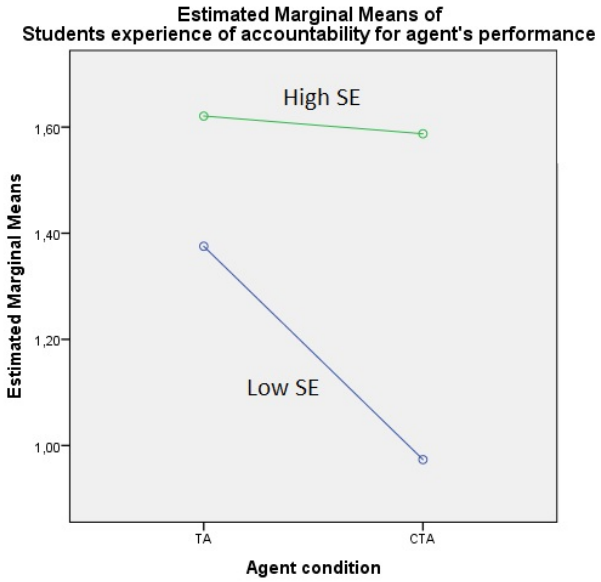


Figure 5.3: Attribution of agent's success to student's talent or effort (normalized values).

with the agent than without him (Protégé→Easy) were analyzed with a MANOVA and presented in Table 5.18.

Chapter 6

DISCUSSION

(Kim, 2004). How did a teachable agent that provides challenge in learning situations, in comparison with a traditional TA, affect how students experience their learning and what they learn, experience and react to their TA's behavior, and how they experience the learning by teaching effect?

6.1 Q1: What and how students learned

Did a challenging teachable agent affect how, or what, students learn when it comes to progress in TALE, fact recall or fact precision?

We expected the students in the CTA condition to have a bit slower progress in the TALE simply since the contradicting and questioning behavior took more time, but the difference was a non-significant 7%. The level of self-efficacy was a better predictor of progress rate, as a high level of self-efficacy would result in a significant 17% faster progress. The learning approaches of precision and recall, and thereby also F-score (harmonic mean between precision and recall) were similar in both agent conditions. There were however interesting tendencies to observe when looking at graph data, the high self-efficacy group improved learning techniques and progress in the CTA condition and the student group with low self-efficacy reacted in the opposite way, by decreasing their performance measures in the CTA condition. These findings would be interesting to pursue further and they were similar, but not as strong, as the findings of Aïmeur et al. (1997).

Apart from this, students rated the learning experience similary in terms of how fun and how difficult it was, as well as how much they learned. The finding that the learning experience did not differ between or within agent conditions is positive from a design point of view since it means that the introduction of challenging agent behavior did not affect the learning experience in a negative way.

The experiences of fun and learning were instead explained by the students level of self-efficacy, where students with a high level of sel-efficacy experienced learning in the TALE to be more fun and that they learned more. This result corresponds to the

findings of Bandura (1994) that students people who has a high level of self-efficacy better respond to difficulties and attributes it as something positive. When seeing the introduced challenges as positive, the overall experience also ends up as being significantly more fun.

6.2 Q2: Experience and reaction to agent challenging behaviors

Did a challenging teachable agent affect students' reactions to, or experience of, the challenging teachable agent behaviors?

It was evident that the challenging behaviors were indeed noticed by the students and we had expected that the CTA would be experienced to exhibit negative behaviors to a larger degree than the TA did. In the same way, we expected the TA to be higher rated for positive behavors, than the CTA. Although there were significant differences in rating of challenging behaviors as negative, there were no differences in ratings of them as positive. Students in both agent conditions experienced the agent to be helpful to the same, low degree. When comparing the two challenging agent behaviors, the questioning of student's correct facts (i.e. rejection of correct facts), was more positively received by the students, than the agent "being wrong"(i.e. introduction of error).

The most common student reaction, in the TA condition, was to accept when the agent proposed an incorrect fact. In the CTA condition, there was a higher appropriate response rate to incorrect fact proposals (i.e. rejection) and it could be a matter of training for students, to question proposed facts. It was evident that students had a higher success in affirming their correct proposals in the CTA condition. By having an challenging agent that 12 times as often as a traditional TA, disagrees with the students' suggestions, students got better at making the appropriate responses. It was more lightly that a student would affirm her own correct proposals than rejecting the incorrect agent proposals, and this result applied to both agent conditions. As pointed out by Aïmeur et al. (1997) a TA that uses the learning-by-disturbing strategy could, through facilitation of practice, improve the student's self-confidence to differ between correct and incorrect facts.

When it came to rating the agent's characteristics such as friendliness, self-confidence, and intelligence, we expected the CTA to be attributed with a less good memory, since the CTA repeatedly suggested incorrect facts which may imply that he was forgetful. There CTA was rated 14% lower with positive personality attributes, and with 20% lower memory capacity, but the differences between groups were not significant.

6.3 Q3: Experience of protégé-effect

Did a challenging teachable agent affect how students experience their agent in regards of protégé-effect: ego-protective buffer, responsibility, and level of agent-induced engagement?

We were curious of how the protégé-effect would be affected by a challenging agent, if it decreased or if it changed qualitatively. The two questions regarding attribution of the agents success, whether it depends on the student's talent or the student's effort, had a strong correlation. This finding suggests that either students did not make a conceptual difference between talent and effort, or that talent and effort were mostly coexisting. This could mean that if a student experienced that she had the talent, then she also experienced that she made an effort.

The attribution of agent's success gives a clue of how accountable the student felt regarding her agent's success, or failure and an agent with challenging behaviors could affect the degree of experienced ego-protective buffer. Students in the TA condition did rate their own impact on their agent's success 15% higher, but it was a non-significant difference. It would have been interesting to follow up with focus group interviews to see if students in the CTA condition expressed that they felt more responsible for the, slow-learning agent, than students with a traditional agent did.

Students in the TA condition rated their will to make effort when they were engaging in learning activities *together* with their agent 38% higher than students in the CTA condition did. The level of self-efficay of the students also had a large impact on the will to make effort and students in the TA condition rated their effort than students in CTA condition, and students with a high level of self-efficacy rated their effort 27% higher than students with a low level of self-efficacy did. The experienced responsibility was rated quite high, with an average of 58, which suggests that the agent did succeed to induce a sense of responsibility in the students.

The experience of engagement when playing together with vs. without the agent with respect to experienced degree of reflection did not show any difference between either agent conditions or self-efficacy groups. However, the students in the TA condition found it easier to play together with the agent than without. This finding confirms that the CTA condition succeeded to be challenging in a larger degree.

6.4 Summary

Our findings suggests that the introduction of errors and rejection of correct facts are perceived to be different than a traditional TA approach. The rejection of correct is better accepted than the introduction of errors and also resulted in a higher appropriate responde rate.

Students gets better at deciding if a fact is correct or incorrect with training, and they also got better at confronting (rejecting) a computer agent.

The protégé-effect was not decreased, although it was not regarded to be as easy to play together with a challenging agent as a traditional agent. But on the other hand, students in the CTA condition were willing to make more effort for the agent. Suggesting that the agent did invite to teaching effort.

6.5 Future work

There are several issues in our experiment that would be interesting to adjust.

Method D'Mello et al. (2012), found during their study that the self-reported level of confusion was not that reliable, and they suggest that the induced confusion should be measured in other ways, for example with pre and post-tests. It would be interesting to see if the results would be different if we had used other ways to measured level of self-efficacy.

Size of confusions The information that is in conflict with previously presented information needs to be provocative enough to induce confusion. Otherwise, it is easily overseen and will not affect learning in any positive way. This is suggested by Aïmeur et al. (1997) addressing that the TA needs to know when to disturb the student. A suggestion is to start out with a student trust-rate (proposed facts that was accepted by the student, divided by, the total amount of agents proposals) at zero and introducing initially larger errors to make the student comfortable to reject the agents proposals and also to make it obvious that the agent makes mistakes.

Kind of confusion A reason for our results not being more substantial, may be that we did not have challenging traits that matched real challenges in learning situations. As described in section 2.3.1, there are other ways to induce confusion example given, unexpected feedback, deviations from norms and expectations and obstacles to goals (D'Mello et al., 2012, p. 5). Also the use of focus group interviews could be a great help to reveal more issues that might not have been captured in our surveys or logs.

Timing of confusion Another suggestion is to vary the frequency of challenging behaviors with the *trust rate* of the student. If the student is prone to reject most of the agents suggestions, her trust-rate is low and the frequency of challenging behavior should be low. But as the student starts to gain confidence in the agent, thus accepting his suggestions to a higher degree, the trust-rate increases and the frequency of the challenges should increase and the size of the errors should decrease.

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Appendices

Appendix A

QUESTIONNAIRES

Figure A.1: Survey example, experience of agent behavior
Note: The questions can be found translated in Table A.3.

Figure A.2: Survey example, experience of agent personality
Translation: *The elf was a person like this:*
The questions can be visited in Table A.4.

Table A.1: Pre-study survey questions regarding self-efficacy

No.	Questions
1	Hur säker är du på att du kan lära dig på ett ok sätt att resonera om varför historiska händelser inträffade och vad som blev konsekvensen?
	How sure are you that you can learn, at an acceptable level, to reason about why historical events occurred and what were the consequences?
2	Hur säker är du på att du kan lära dig på ett ok sätt hur historiska händelser påverkar varann?
	How sure are you that you can learn, at an acceptable level, about how the historical events affected each other?
3	Hur säker är du på att du kan lära dig på ett ok sätt om historiska händelser, personer och hur det var på den tiden?
	How sure are you that you can learn, at an acceptable level, about historical events, persons and what it was like at that time?

Table A.2: Pop – up questions during intervention

No.	Questions
1	Jag vill lära mig historia för att kunna lära tidsalven
Learn→teach	I want to learn history to be able to teach the time elf.
2	Det är lättare att göra läraktiviteter tillsammans med tidsalven än själv
Protégé→Easy	It is easier to do learning activities together with the time elf than by myself.
3	Jag tänker efter mer när jag gör läraktiviteter tillsammans med tidsalven än när jag gör dem själv
Protégé→Think	I am reflecting more on things when I do learning activities together with the time elf, than when I do them by my own.
4	Jag anstränger mig för att lära tidsalven så bra som möjligt.
Effort→teach	I am making an effort to teach the time elf as good as possible.
5	Jag tror alla kan bli bra på historia om de anstränger sig.
Skill←effort	I think that everyone can be good at history if he or she makes an effort.
6	Det är viktigt för mig att att tidsalven klarar provet.
Learn→test	It is important to me that the time elf passes the test.
7	Jag anstränger mig mer för att göra rätt när jag gör läraktiviteter tillsammans med tidsalven än när jag gör dem själv
Effort→together	I am making a bigger effort to be correct when I am playing with the time elf than when I am playing alone.
8	Det är roligare att göra läraktiviteter tillsammans med tidsalven än själv.
Protégé→Fun	It is more fun to do learning activities together with the time elf than by myself
9	Jag tror inte man kan bli bra på historia om man inte har talang för det.
Skill←talent	I do not believe that you can become good at history if you are not talented.

Table A.3: Post-study survey questions

No.	Questions
1	Hur mycket lärde du dig?
Learn	How much did you learn?
2	Hur roligt var det?
Fun	How much fun was it?
3	Tidsalven säger ofta emot fast den har fel.
RCNeg	The time elf is contradicting even though it is wrong.
4	Hur bra det går för tidsalven på provet beror på hur bra jag är.
TAsuccess←talent	How well the time elf performed on the test depends on how good I am.
5	Min tidsalv hjälper mig att rätta när jag har fel.
RCPos	My time elf is helping me to correct facts when I am wrong.
6	Hur svårt var det?
Difficult	How difficult was it?
7	Hur bra det går för min tidsalv på provet beror på hur mycket jag ansträngt mig.
TAsuccess←effort	How well my time elf performed on the test, depends on how much effort I made.
8	Tidsalven föreslår ofta fel fast jag har lärt den rätt.
IENeg	The time elf makes incorrect suggestions, even though I taught it correctly.
9	Tidsalven har oftast rätt i skolsalen.
IEPos	The time elf is most of the time correct in the teaching room.

Table A.4: Post-study survey questions regarding agent characteristics

No.	Swedish	English
13	Ovänlig → vänlig	Unfriendly → friendly
14	Blyg → kaxig och tuff	Shy → cocky
15	Osäker → självsäker	Insecure → self → confident
16	Ointresserad → nyfiken	Lacking interest → curious
17	Klagande → uppmuntrande	Complaining → encouraging
18	Glömsk → minns bra	Forgetful → remembers well
19	Trög → smart	Stupid → intelligent

Appendix B

TALE MEASURES

Time (66-223 minutes).

Progress (0-24). The achieved level out of 24 possible levels.

Precision (0-100%). $\frac{Taught\ unique\ correct\ facts}{All\ taught\ unique\ facts}$

Recall (0-100%). $\frac{Unique\ correct\ facts}{All\ available\ unique\ facts\ at\ the\ current\ level}$

F-score (0-100%) $2 * \frac{Precision * Recall}{Precision + Recall}$

IEQ: The introduction of error-quotient (0-100%).
$\frac{No.\ student\ reject\ incorrect}{No.\ agent\ proposed\ incorrect}$

RCQ: The rejection of correct-quotient (0-100%).
$\frac{No.\ student\ affirmed\ correct}{No.\ agent\ objections\ to\ correct}$

Appendix C

INSTRUCTION BOOKLET

Historiens Väktare

Namn: Student Name

Klass: 6A

Hej Linda!

Jag är en tidsalv och bor i ett tidsslott. I slottet är det historiens väktare som bestämmer men han börjar bli gammal nu, 3000 år. Han tänker välja ut en av oss tidsalver som ska efterträda honom. Han ger oss prov för att se om vi kan tillräckligt mycket om historien.

För att lära sig om historien måste man åka tillbaka i tiden i en tidsmaskin och träffa historiska personer för att lära sig om historien. Jag tror att jag skulle bli en bra historieväktare, men tyvärr blir jag åksjuk när jag åker i tidsmaskinen.

Skulle du kunna hjälpa mig genom att åka med tidsmaskinen och lära mig i lärosalen? Man behöver klara alla uppdrag i den här boken för att bli den nya historiens väktare.

Gå till webbsidan: **webb-page**

Användarnamn: ***Username***

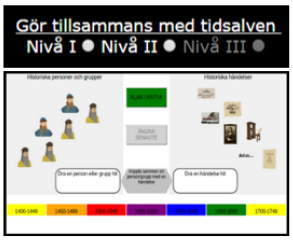
Lösenord: ***pass***

Figure C.1: Booklet, first page
Note: First page in booklet used in pilot study. For description of narrative, see Section 3.1.1.

Historiens Väktare

Vad roligt, vi har kommit långt! Nu vill jag se om jag lärt mig allt du visat mig. Vi ska spela tillsammans. Jag spelar varannan gång och du varannan.

Uppdrag 6 : Nivå 3 på Tidsaxeln, "Gör tillsammans med tidsalven".
Spela tillsammans med alven och se om den lärt sig bra.



Visa alven Nivå 1	Visa alven Nivå 2	Visa alven Nivå 3

Figure C.2: Booklet, teaching assignment

Translation TA: *Great, we came this far! Now I want to see if I learned everything that you taught me. We will play together. We take turns.*
Instructions: *Assignment 6: Level 3 on Timeline, "Do together with the time elf". Play together with the tim elf and see if it learned well.*

Figure C.3: Booklet, last page

Translation TA: *Puh, now you have taught me a lot. I would never have been able to do it without you! If you want to, we can take a break and play a bit of Othello. Othello is in the livingroom. I am a quite qood Othello player, so it will be difficult for you to win.*
Chronos: *You [Name] were so skilled to teach the time elf that much! Now I will chose the best time elf as my successor. Thanks for your help.*

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