Persuasive teachable agent for intergenerational learning

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**NANYANG
TECHNOLOGICAL
UNIVERSITY**

**PERSUASIVE TEACHABLE AGENT FOR
INTERGENERATIONAL LEARNING**

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2016

PERSUASIVE TEACHABLE AGENT FOR INTERGENERATIONAL LEARNING

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Abstract

Teachable agents are artificial intelligent computer agents designed around the pedagogical concept that students learn better when they teach others. During the tutoring process with a teachable agent, the students take on the role of the tutor to teach a teachable agent tutee. Students involved in this teaching process have been observed to gain a deeper understanding of the subject matter. Teachable agents are commonly used in the learning of science and mathematics where students are able to learn complex concepts and deep reasoning when they teach the teachable agent using graphical representations such as concept maps.

Literature review on teachable agents have shown that many current teachable agents lack the ability to proactively interact with the students, an important feature required to keep students engaged in learning tasks. As a result, students deviate from the teaching process, and are unable to benefit fully from learning with the teachable agent. In addition, most applications of teachable agents are restricted to the learning of academic subjects such as mathematics and science. As the global population is rapidly and resulted in increased interest in expanding the applications of teachable agents to utilize it as a tool to encourage intergenerational bonding as well as to benefit a wider group of users.

In this thesis, the Persuasive Teachable Agent (PTA) is proposed, a teachable agent based on the theoretical framework of persuasion, computational and goal-oriented agent modelling. Firstly, our proposition is that persuasion theory, which attempts to influence behaviour and attitude change in the users allow the PTA to resolve interaction issues in existing TA by keeping users interested the process of teaching the agent. Secondly, we explore how the application of the PTA can be expanded outside the area of academic learning. In addition, we suggest that the PTA can be used to encourage intergenerational learning among users from different age groups.

Therefore the PTA, an autonomous agent capable of encouraging attitude and behavioural change in humans, can offer a more meaningful and engaging learning experiences for users from different age groups. This research finds that persuasive

feedback actions generated by the PTA provide significant influence on user's decision to participate in intergenerational learning. The PTA plays a crucial role in the development of future persuasive technologies in artificial intelligent agents.

Keywords: Teachable agent, persuasion, persuasive technology, intergenerational learning.

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Acronyms and Abbreviations

Artificial Intelligence (AI)	8
Computer Aided Instruction Systems (CAI systems)	8
Elaboration Likelihood Model (ELM)	17
embodied conversational agents (ECA)	25
Fuzzy Cognitive Map (FCM)	34
Heuristic-Systematic model (HSM)	17
Intergenerational Learning Programme (ILP)	29
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1 Introduction

Teachable agents are pedagogical agents that encourage students to learn through teaching the agents. The development of teachable agents is based on the learning-by-teaching pedagogy which follows the belief that students learn much better for themselves when they teach others.

One area of research in such teachable agents focus on the life-like interaction between students in the tutoring process where deeper learning is generated through verbal and visual simulation, while another area of research in teachable agents involve the development of agent architecture to support learning (Biswas & Leeawong, 2005). Teachable agents also allow students to engage in tutoring of an artificial computer agent, and in the process students are able to learn for themselves (Blair, Schwartz, Biswas, & Leelawong, 2006). Thus, with teachable agents, students are able to benefit from the ability to acquire inquiry skills through asking questions, and obtain motivation through the cultivation of a sense of responsibility towards their peer tutee. Research in teachable agents has shown positive results in a student's ability to reflect on complex concepts while they teach the teachable agents. Students have also been observed to be receptive towards taking on the responsibility of teaching the teachable agent and, therefore, learn better in the process (Chase, Chin, Oppezzo, & Schwartz, 2009).

Teachable agents are applied in areas of education and learning in various domains, such as science and mathematics. They have demonstrated positive effects in helping the students gain motivation, increasing self-regulated learning behaviours, and improving learning gains (Chase et al., 2009; Matsuda, Keiser, Raizada, Tu, et al., 2010; Pareto, Haake, Lindström, Sjöden, & Gulz, 2012).

However, in our literature review of teachable agent systems, presented in Chapter 2, it is shown that existing teachable agents lack proactive social interaction, causing frustrations among student (Agneta Gulz, Haake, Silvervarg, Sjöden, & Veletsianos, 2011). As a result, they are not able to fully engage in learning with the teachable agents. In order to overcome this limitation in the research of teachable agent systems, this study investigates the possible solutions to improve social interactions between the

student and teachable agents. Persuasion theory is a well-established theory in social psychology that aims to influence one's attitude or behaviours. This study integrates persuasion principles into existing teachable agents. With persuasion, the teachable agents influence positive attitudes and behaviours by actively engaging with the users. The inclusion of persuasion influence supports positive social interactions between the users and teachable agents.

Moreover, as most existing teachable agents have targeted students in schools, and are applied in specific areas of education and learning domains, such as the areas of mathematics (Carlson, Keiser, Matsuda, Koedinger, & Rosé, 2012) and science learning (Biswas & Leeawong, 2005), there exists a limit in the areas in which the teachable agents can be applied.

The aim of this research is to improve on existing teachable agents by resolving the issues such as the lack of social interaction between users and teachable agents by engaging users through persuasion. As well as expanding the application of teachable agents to benefit a wider group of users. In order to improve the way teachable agents interact with its users and to expand their applications, the PTA is proposed in this research. PTA is a novel teachable agent developed based on the persuasion theory. By introducing persuasion theory into existing teachable agents, the improved PTA will be able to generate positive influence over individual users, and enable users from different generations to come together in one setting to share and learn from the knowledge taught to the teachable agent. In this way, a wider range of population can benefit from the positive learning effects from teaching the teachable agent.

In this study, the PTA is designed with persuasion capabilities to support intergenerational learning. The PTA designed is also able to understand the learning motivation and abilities of individual users in the process of tutoring the agent. The improved PTA in this study can encourage social interaction with its users and provide autonomous persuasive feedback to encourage users in teaching the agent.

Furthermore, in this study, the application of the PTA has been extended to support intergenerational learning, which helps to build bonds and enhance interaction between young and older generations. The inclusion of multiple tutors in intergenerational learning with the PTA provides a way to motivate cross-generation

learning, thus helping them to lead a more fulfilling life by learning and sharing their knowledge with users from other generations. This also helps to build strong relational bonds between the different generations of users.

One way in which the PTA designed in this study can improve intergenerational learning is through the use of technology. There is a potential digital divide between the younger and the older users. Younger generations who are born in the digital world are comfortable with the use of technology, while their grandparents or parents may not be able to feel easy about adopting the new technology (Prensky, 2001). This study believes that through collaborative use, technology can be used to improve the quality time family members spend with their children. To improve intergenerational relationships through technology and close the gap in the digital divide, the PTA is implemented into a virtual learning game that is designed to support intergeneration bonding. The older adults or the elderly will be motivated through gameplay, learning and teaching, to participate in intergenerational learning activities with the younger users.

This study hopes to contribute to a future where the use of technology such as the PTA can help to encourage children to spend more time with their parents and grandparents, as well as to encourage the younger generation to interact with the older generation.

1.1 Research Objectives

The following are the research objectives within the scope of this research.

1. Overcome existing problems in teachable agents.

The first and foremost objective of this research is to address the current problems in teachable agents. A literature review of current teachable agents reveal that teachable agents lack the proactive interaction capability required to keep users interested in teaching and learning with the agent. Therefore, one of the objectives of this study is to improve the teachable agent, so as to help keep the users more engaged with the teachable agent.

2. Design PTA to infuse persuasion theory in teachable agents to encourage learning.

The next objective following the identification of issues in teachable agent systems is the design of a teachable agent system that is able to understand a user's learning ability and motivation so that the PTA will be able to influence a user's attitude and behaviour in learning and teaching.

3. Implement PTA in intergenerational learning.

Current teachable agent systems are applied in specific learning domains such as math and science. This research aims to expand the application of PTA to areas of informal learning, so as to benefit wider groups of users. At the same time, the PTA provides a platform in which knowledge from different age groups can be shared in an intergenerational learning setting.

4. Test and evaluate PTA for intergenerational learning.

The objective of this research also covers the testing and evaluation of the PTA in terms the effects of intergeneration learning to benefit future works on teachable agent research.

1.2 Research Questions and Hypotheses

Given the background of this research, the following are the research questions to be answered and hypotheses to be tested in this study.

Question 1: *Are users from different age groups interested in intergenerational learning with the PTA?*

Hypothesis 1:

It is predicted that users from the younger age group are more interested in intergenerational learning with the PTA compared to users from the older age group.

Question2: *How do different age groups perceive the PTA during intergenerational learning?*

Hypothesis 2:

With the PTA, the hypothesis is that users from the older age group will have a better perception on intergenerational learning with PTA compared to the younger age group.

Question 3: *What are the differences in learning experiences with the PTA for the different age groups in the intergeneration learning setting?*

Hypothesis 3:

The hypothesis is that the younger group will have a better learning experience in intergenerational learning with the PTA.

Question 4: *Does the PTA improve general user's experience compared to the traditional teachable agent?*

Hypothesis 4:

With the PTA, the general user's experience is predicted to be improved compared to the users' experience with the traditional teachable agent.

1.3 Organization of the Thesis

In the first section of the report, the rationale for the research in PTA for intergenerational learning is introduced. The first and foremost aim of this research is to overcome the existing problems in teachable agents and to expand its application from classroom learning subjects such as science and mathematics to informal learning content with enhanced intergenerational learning relationship.

Chapter 2 of this thesis introduces artificial intelligence and agent technology, followed by a literature review on the teachable agent as a pedagogical agent introducing related work on teachable agents in supporting classroom learning and compares the key capabilities of different teachable agent systems, highlighting issues of different teachable agent systems in current research. The second part of the literature review examines the various persuasive theories that are used in social psychology to influence attitudes, and discusses how persuasion can be used in computer interaction to generate positive attitudes in users of systems. The final part of

the literature review will touch on intergenerational learning with case studies which introduce programmes initiated by various agencies to promote learning among the different generations to encourage bonding.

Chapter 3 of this thesis focuses on the current work in the initial design and development of PTA. A preliminary experiment was conducted to test the initial design of PTA. Issues and challenges regarding the initial design and the improvements to the design of PTA will be discussed.

In Chapter 4 of this thesis, the actual implementation of the PTA in the latest improved version Virtual Singapura (VS) Saga, a 3D virtual learning platform will be introduced. A user study on the effectiveness PTA for intergenerational learning and the results and findings of the study will be discussed.

Lastly, Chapter 5 is the conclusion highlighting the contributions in the current work on PTA, and the report ends with the future work in the implementation of PTA for intergenerational learning.

2 Literature Review

This chapter first reviews works on the theoretical foundation of the pedagogical use of teachable agents. The development of teachable agents is traced from computer aided learning with intelligent learning systems. Then, different teachable agent systems are compared in terms of the domains in which they are applied. The capabilities and drawbacks of each teachable agent are analysed.

The literature review also examines various persuasion theories in social psychology used to change individual opinion and attitudes on a specific subject matter. The discussion section describes how the persuasion theories can be used to improve the current teachable agent systems.

Lastly, the literature review looks into the works on intergenerational learning, a relatively new domain, which proposes that the teachable agent can be applied to benefit a wider user group of different ages.

2.1 Teachable Agents

Teachable agents are pedagogical agents whom students can teach in order to improve learning. The development of teachable agents is based on the learning-by-teaching pedagogical theory which believes that students learn much better for themselves when they teach others.

There are several areas of research developments in teachable agents. The first area focuses on the creation of a life-like teachable agent tutee and use verbal and visual simulation to motivate deeper learning in the student tutor. Another area of research is the development of a teachable agent system architecture to support learning (Biswas & Leeawong, 2005). Teachable agents allow for student to engage in tutoring an artificial computer agent, and in the process student are able to learn for themselves (Blair et al., 2006). Thus, with teachable agents, they are able to acquire inquiry skills in asking questions, as well as motivate and cultivate a sense of responsibility towards their peer tutees.

2.1.1 Development of Teachable Agents

Computers have a history of being used to support learning. Computer Aided Instruction Systems (CAI systems) which are used to scaffold learning has its roots traced to Pressey's 1925 instructional system, which was made up of a punch-board device and multiple-choice machine (Mann, 2008). The disadvantage of the traditional CAI system is that it requires users to memorize learning materials repeatedly, which decreases student interest and motivation in learning (Arnold, 2000). This led to the emergence of Artificial Intelligence in Education (AIED) and the development of the Intelligent Learning Environment (ILE) where Artificial Intelligence (AI) is used in CAI systems to support learning, which improves the interaction experience between users and system learning (Blandford, 1994).

Within the ILE, there is the Intelligent Tutoring Systems (ITS) which tends to imitate the process of human to human tutoring by replacing human tutors with a computer (Chan & Baskin, 1990). There are also advocates of alternative learning models (Self, 1990) who have inspired researchers to investigate alternative methods of teaching such as mimicking the teaching process in the traditional classroom within the ITS. For example, Chan and Baskin (1990) used the learning-by-teaching model to develop an ITS where multiple agents take on the role of the teacher and learning companion (Chan & Baskin, 1990).

DENISE system (Nichols, 1993) is an ITS that was developed to support the learning of economics using the learning-by-teaching pedagogy. The DENISE system aims to improve the cognitive and motivational aspects of learning by allowing students to construct causal relations using question and answer dialogue sequences where students take on the role of the tutor teaching the computer. However, when using the system, it was found that the lack of natural interaction caused user's frustration (Nichols, 1994).

To simulate a more naturalistic interaction between users and the system, a branch of research has focused on developing learning companion agents to increase the user's attention and keep human users motivated in learning (Chan & Baskin, 1990). EduAgent is one such learning environment that incorporates an artificial learning companion in learning Mathematics developed to accompany students with different

levels of competencies and to engage in meaningful conversation with students (Hietala & Niemirepo, 1998). With the development of systems such as EduAgent, there was an interest in studying the motivation for the student to learn with learning companions. Thus, it is suggested that not only does the level of competency of the learning companion affect how well the collaboration between the human user and the learning companion turns out, but that the personality and ability of individual users should also affect the way the learning companion communicates with the human user in keeping them motivated in learning (Hietala & Niemirepo, 1998; Uresti, 2000).

At MIT Lab, "Learning Companion" was built to recognize a user's emotion and to provide intervention in order to guide them towards productive learning tasks (Cooper, Brna, & Martins, 2000; Kapoor, Mota, & Picard, 2001). Virtual agents that are based on the learning-by-teaching pedagogy were integrated into CAI system to help users to learn more effectively (Fumiaki, Hiroshi, & Hidekazu, 2000).

Countering the drawbacks of monotonous learning in CAI systems and to maximize the potential benefits of learning-by-teaching pedagogy, teachable agents are developed to improve learning experience when users tutor an artificial intelligence learning companion. AI allows computers and machines to make human-like decisions, solve problems accordingly, therefore enabling them to perceive reason and act rationally (Russell & Norvig, 2009). An intelligent agent is an autonomous computer agent that acts or operates in an environment with reasoning and learning based on observation through sensors to achieve certain goals. With the integration of Artificial Intelligence (AI), teachable agents are developed to improve learning by providing an adaptable learning environment, tailored to an individual user's needs and capability. In a teachable agent learning environment, users are expected to explicitly teach the agent to carry out complicated learning tasks (Biswas, Schwartz, & Bransford, 2001).

Betty is a teachable agent developed by G. Biwas and colleagues at "AAA lab", Stanford University and "Teachable Agent Group" at Vanderbilt University (Biswas & Leeawong, 2005; Blair et al., 2006) to be used in the domain of science topics. Students teach the Betty teachable agent by modifying concept maps by linking relations between concepts, visual representations of knowledge and reasoning

mechanisms (Novak, 1990). The central idea of science topics is made clear to the students. With the Betty teachable agent, students are able to evaluate the progress of Betty's learning by observing the agent's explanation to a problem.

Within the Betty's Brain system, the "Protégé Effect" (Chase et al., 2009) was observed where students take on responsibility for their teachable agent, believe they were learning for their tutees, and therefore students were more willing to put significantly more effort towards learning and as a result benefited from the enhanced Betty.

The Betty system uses Hidden Markov Models (HMM) (Rabiner & Juang, 1986) generated from student behaviour activity logs to measure self-regulated learning based on learning behaviours in a student's associated activities. According to established studies in cognitive science, self-regulatory and meta-cognitive skills are beneficial to students beyond classroom learning (Zimmerman, 1990). Users can become better students for future learning, displaying autonomy and control even when they no longer have access to self-regulation learning environment (Leelawong & Biswas, 2008). The results generated from the Betty's Brain system demonstrate that students show better learning performance and metacognitive behaviours than those who only learn for themselves. With meta-cognitive feedbacks from the mentor agent, students display advanced focus and monitoring behaviours in teaching the teachable agent (Biswas, Jeong, Kinnebrew, Sulcer, & Roscoe, 2010).

SimStudent is a teachable agent developed at Carnegie University. The original goal of SimStudent was to facilitate authoring of cognitive tutors, a learning-by-tutored problem system which simulates classroom instructional environment in teaching mathematics. The system acts out the role of the teacher providing students with information (Matsuda, Cohen, Sewall, Lacerda, & Koedinger, 2007). The first and foremost reason for setting up a teachable agent in SimStudent is that it would take up a lot of time for students to wait for their turn to teach and learn from each other. A teachable agent would allow students to teach the agent and simulate the learning-by-teaching environment. Secondly, in actual person to person tutoring, the tutees may not benefit as much as the tutor (Matsuda, Keiser, Raizada, Tu, et al., 2010). SimStudent is incorporated into Artificial Peer Learning environment (APLUS), where

students are able to tutor SimStudent, the artificial peer learner, in a learning-by-teaching environment (Matsuda, Keiser, Raizada, Stylianides, et al., 2010).

SimStudent is a machine learning agent that has the potential to predict a human learner's performance. When students are faced with new problems, SimStudent is able to observe the cognitive skills used by the students, so as to extract a cognitive model, which it can use to explain solutions to students. The purpose of the teachable agent environment in SimStudent is to build a platform to support the learning-by-teaching pedagogy while keeping the cost of setting up such an environment low to counter the drawbacks of conducting peer tutoring in classrooms.

Subsequently, the developments of pedagogy agents have been directed towards studies to explore the cognitive, affective and social aspects of the interaction between students and agents (Kim & Baylor, 2006). This led to the incorporation of personality traits in visual representation and conversational ability in teachable agents. Using Enhancing Agent-Learner Interaction (EnALI) (Veletsianos, Miller, & Doering, 2009) as a guiding framework and an existing teachable agent learning environment, Sjöden and colleagues developed a system which included a teachable agent with added social and conversational abilities. The study on the system highlighted the importance of agent context, users' knowledge and understanding the way users communicate (Sjöden, Silvervarg, Veletsianos, Haake, & Gulz, 2011).

2.1.2 Progress in Teachable Agent Research

Improvements on Betty's Brain system has been made to explore the relationship between teachable agents' feedbacks and students' performance in the system. Agent prompts in Betty Brain are designed to encourage reflective interaction (Wu & Looi, 2008). It is shown that dialogue and action responsiveness has strong relations to the learning gain in the Betty's Brain system. On the other hand, SimStudent has included a natural language conversation component between the user and the teachable agent (Carlson et al., 2012). Text classification is used to train models in order to differentiate and categorize students' feedbacks and enable interactions between students and teachable agents. Attempts have also been made to improve the believability of teachable agents by simulating emotions and modes of empathetic expression in immersive learning environments with the integration Affective

Computing (Picard, 1997). Teachable agents that can express emotions as a result of a students' interaction are often introduced as affective teachable agents. The purpose of an affective teachable agent is to evoke user's interest in tutoring the agent.

The affective teachable agent was introduced in a Virtual Learning Environment (VLE), Virtual Singapura (VS) for Lower Secondary Science learning in Singapore designed with goal-oriented reasoning, categorizing a set of emotions based on the Ortony Clore Collins (OCC) model (Ortony, Clore, & Collins, 1990). OCC allows the teachable agent to generate appropriate emotional responses based on what the students have taught the agent (Ailiya, Shen, & Miao, 2011).

The Teachable Agent Arithmetic Game (TAAG) has been developed to help 5th-grade students learn math in Sweden (Pareto et al., 2012). The competitive nature of teachable agents are explored as well, as the teachable agent was implemented in a game environment where students learn through collaboration or compete as a single player, or as two players, either with another student, a non-teachable computer agent or other teachable agents (Sjödén, Tärning, Pareto, & Gulz, 2011).

Dynalearn is a project that consists a teachable agent that mimics a less capable student that allows for learning-by-teaching pedagogy to be applied in an intelligent learning environment. The novelty of Dynalearn is in the qualitative reasoning model generated by the student which can be compared to other students as well as experts, thus allowing the system the automation to provide appropriate feedback and recommendations (Bredeweg et al., 2010).

More recently, a teachable agent known as the Tangible Activities for Geometry (TAG) is developed using digitally augmented devices to help students learn geometry by solving problems in physical space. This is a different approach to teachable agents in virtual environments (Muldner, Lozano, Giroto, Burleson, & Walker, 2013). In TAG, a robot named Quinn is constructed using the LEGO Mindstorm robot mounted with an iPod displaying facial expression. The students are to solve geometry problems by issuing a command to Quinn where Quinn executes the command and checks if the solution to the current problem is correct. Quinn is able to display emotions based on the TAG feedbacks to show the student how it feels through a gender neutral voice message. The current studies on TAG focus on the impact of

attributes on the interaction between Quinn and the student (Muldner, Giroto, Lozano, Burleson, & Walker, 2014).

The following table (Table 2-1) is a comparison of the existing capabilities and features of the different teachable agent systems.

Table 2-1 Overview of existing capabilities and features of teachable agent systems

Teachable Agent	Artificial Intelligence				HCI (Conversational Ability)	3D Virtual Environment	Competition/ Cooperation
	Machine Learning	Decision Making	Affective Computing	Embodiment			
Betty's Brain		✓		✓	✓		
SimStudent	✓			✓	✓		✓
Virtual Singapura			✓	✓		✓	
TAAG							✓
DynaLearn				✓	✓		
TAG			✓	✓			

In Table 2-1, all teachable agents in the literature involve a learning companion. The majority of teachable agents are able to conduct a conversation with the users. Artificial intelligence such as machine learning, decision making and affective computing are used in systems such as the Betty's Brain, SimStudent, Virtual Singapura and TAG. SimStudent and TAAG are teachable agents systems that are used in mathematics learning. Both teachable agents have used competition and cooperation to engage learning. The teachable agent in Virtual Singapura is the only teachable agent that is developed in a 3D virtual environment.

2.1.3 Teachable Agents Related Issues

Teachable agents are based on the concept that learners are able to achieve deeper learning when they take on the role of the tutor (Bargh & Schul, 1980; Gartner, 1971), as in the tutoring process learners are able to gain more complete knowledge by

refining their concepts through explaining and reorganizing their own knowledge (Coleman, Brown, & Rivkin, 1997).

In the tutoring process, tutors are found to be more prepared to teach their peer tutees as compared to when they are learning for themselves (Annis, 1983). Tutors also benefit from explanation and questioning interactions with tutees, as they reflect upon the problems in the tutoring process thus stimulating deeper reasoning (Craig, Sullins, Witherspoon, & Gholson, 2006). Research on learning-by-teaching systems also found tutors benefited from the tutoring process as much as the tutee (Chi, Siler, Jeong, Yamauchi, & Hausmann, 2001). Besides improved understanding of the subject matter, there are considerable affective and cognitive gains during the tutoring process (Lublin, 1990; McNall, 1975). Low-performing tutors are found to be motivated to perform better with teachable agents (Sjödén, Tärning, et al., 2011). As preparation to teach requires them to organize their knowledge, they are observed to learn a great deal through assessment as well as reflection during the tutoring process (Biswas & Leeawong, 2005).

Despite the advantages of the amount of knowledge gained during tutoring, there are several drawbacks with learning with teachable agents. First, novice tutors are not able to gauge their own understanding of the topic that they are teaching. This may cause them to commit errors or make mistakes when judging other sources of information (Azevedo & Cromley, 2004). Second, learning-by-teaching requires the tutors to be self-monitored and self-regulated. Tutors who have little experience or low prior knowledge in teaching may not be able to handle tutee enquiries (Roscoe, Wagster, & Biswas, 2008). Moreover, tutors also do not fully benefit from learning-by-teaching if the teachable agent tutee does not react to the tutor by providing adequate responses from the tutoring (Graesser & Person, 1994). In order for tutors to fully benefit from tutoring the teachable agent, they have to be motivated to tutor the teachable agent (Uresti, 2000).

There are also several challenges highlighted by Gulz et al. (2011), with regards to the design of pedagogical agents in intelligent tutoring systems including satisfying “learners expectation of agent’s knowledge and social profile”, “dealing with learner’s engagement in off-task conversation” and “managing potential abuse of the agent”

(Agneta Gulz et al., 2011), especially with open-ended learning environment as in Betty's Brain (Segedy, Kinnebrew, & Biswas, 2012) and conversational SimStudent (Carlson et al., 2012). Therefore, there are suggestions to design specific "off-task" interaction that in particular help to build rapport and trust, provide breaks in between learning to improve engagement (A. Gulz et al., 2010).

The importance of providing appropriate feedback is also echoed in earlier studies on SimStudent. The teachable agent in SimStudent showed that a tutor's "prior knowledge has a strong influence on the tutor learning", therefore a teachable agent that has the ability to provide feedback on appropriate problems is more effective for tutor learning (Matsuda, Keiser, Raizada, Stylianides, et al., 2010). Segedy (2011) suggests the use of a combination of "metrics", such as "responsiveness" and "performance" as a benchmark to determine whether the student tutors need more support or feedback (Segedy, Kinnebrew, & Biswas, 2011). Segedy also proposed the use of cognitive and meta-cognitive model derived from Hidden Markov model from student tutors' behaviour to understand their learning strategies, thus applying suitable level scaffolding and feedback.

The Teachable Agent Arithmetic Game (TAAG) was used to evaluate the student tutor's performance, attitude and self-efficiency. The results showed positive improvements in conceptual arithmetic understanding and self-efficiency, but however did not support positive attitudes towards math (Pareto, Arvemo, Dahl, Haake, & Gulz, 2011). More recent research on the teachable agent indicate interest in understanding the benefits of social interaction of users through tutoring and interacting with teachable agents (Ogan et al., 2012), as well as studying the motivational factors for learning-by-teaching in teachable agents (Carlson et al., 2012). A significant portion of work on teachable agents is dedicated to simulating peer-like interactions between users and teachable agents, providing support and feedback in open-ended teachable agent learning environment as well as encouraging competition and collaboration among users and teachable agents.

Table 2-2 shows the comparison between the existing teachable agent systems in terms of their issues, innovations and application domains.

Table 2-2 Issues, innovation and application domain of teachable agents systems

Systems	Issues	Innovation	Application Domain
DENISE	Lack of natural interaction caused user's frustration	Learning-by-teaching pedagogy	Economics
EduAgent	User's personality and ability affect their preference for the strength of their teachable agent learning companion.	Artificial learning companion	Mathematics
Betty's Brain	Understanding user's expectation of agent knowledge and ability. Dealing with open-ended conversation, off-task engagement.	Artificial Intelligence	Science
SimStudent		Machine Learning	Mathematics
Virtual Singapura	Users do not fully engage in learning with TA.	Affective Computing	Lower Secondary Science
TAAG	User's attitudes towards math do not improve after using TA, compared to the group that does learn without TA.	Collaborative and Competitive Learning	Mathematics
DynaLearn	Lack of clarity and relevance of recommendations, insufficient support in learning and modelling processes.		Environmental Science
TAG	More understanding on capitalizing social and affective elements in TA.	Social Robot	Mathematics

In Table 2-2 the majority of teachable agents are applied in mathematics and science learning, other applications include economics in the DENISE and environmental science in the DynaLearn teachable agent system. As can be seen from the literature review on teachable agents, none of the systems have been applied to intergenerational learning. Therefore, there is also a need to look into ways to alter user's attitudes towards the subject domain, and expand the application of teachable agents.

2.2 Persuasion Theories and Persuasive Technologies

As research on existing teachable agents lack the study on social interaction in teachable agents, this study proposes to integrate the theory of persuasion in the design of the PTA, as with persuasion, teachable agents will be able to motivate users and generate positive attitudes and behaviours, through persuasive feedback support.

Persuasion is a fundamental interaction between human beings, in the attempt to influence others by modifying attitudes, beliefs, intentions, motivations or behaviours (Gass & Seither, 2010) and widely is applied in areas such as rhetoric, social psychology, communications, advertising and public relations. Simon (2001), defined persuasion as the “human communication designed to influence the autonomous judgment of others” (Simons, 2001). In section 2.2 of the literature review, two closely related theories of persuasion that contribute to the development of the PTA, namely, the Heuristics-Systems of Model (HSM) and the Elaboration Likelihood Model (ELM) of persuasion will be introduced.

In recent years, persuasion theories are increasingly used in the design of technologies that aim to change attitudes and behaviours. Such technologies are known as persuasive technologies. In section 2.3 of the literature review, the development of persuasive technologies will be reviewed, looking at the various persuasive frameworks and models that have emerged from persuasion theories and how they have been used to address issues in user interactions in systems design.

At the end of this section of the literature review on persuasion and persuasive technologies, various applications of persuasive technologies in healthcare and education will also be reviewed. The review of works in persuasive technologies and its application helps us to further define the PTA and identify the areas where the PTA can be used.

2.2.1 Heuristic-Systematic Model

Heuristic and systematic views of persuasion regard that the person receiving the message is concerned with assessing the validity of the message’s overall conclusion (Chaiken & Shelly, 1980).

The Heuristic-Systematic model (HSM) involves heuristic processing and systematic processing. HSM is a dual process model that explains the way persuasive messages are perceived. During heuristic processing, the message recipient uses little effort in processing and assessing the validity of the message. Instead, judgments are formed based on existing learned memory. The experiment conducted by Chaiken and Shelly (1980) on source and message concluded that the content of the message out-

weigh the likeability of the source (Chaiken & Shelly, 1980). In terms of persistence change, content-mediated opinion change lasted longer than source-mediated persuasion (Chaiken & Shelly, 1980).

Heuristic processing is useful in presenting messages that require little cognitive effort on the message receiver. On the other hand, systematic processing requires much more cognitive effort in performing the task and requires the recipients understand and evaluate the arguments in the persuasive message in order to accept the message's conclusion (Chen, Duckworth, & Chaiken, 1999).

2.2.2 Elaboration Likelihood Model of Persuasion

The Elaboration Likelihood Model (ELM) of persuasion is another example of the dualistic model developed by Petty, Cacioppo and colleagues (1986). Both ELM and HSM offer broad similarity in the notion that persuasion varying in the degree of issue related thought processes. The central and peripheral routes of persuasion in which attitude change can be achieved according to the ELM theory of persuasion can be seen in Figure 2-1. ELM differs from other models as there is added attention towards retention of change in attitudes through the use of peripheral and the central persuasion routes. The central route of persuasion requires the recipient to take on in-depth consideration of the information presented while the peripheral route requires little or negligible scrutiny (Petty & Cacioppo, 1986).

Figure 2-1 Central and peripheral routes to persuasion (Petty & Cacioppo, 1986)

In the ELM, attitudes formed under the central route are more persistent compared to the attitudes formed under the peripheral route, and behaviours are predictive and resistant to change until clear counter information is presented to alter the merits of the object. The ELM outlines a general theory of attitude change and the underlying framework for persuasive communications.

Elaboration

The ELM recognizes that the characteristic of the recipient of a message varies in the degree of engagement in topic-related thinking in different situations. The term “elaboration” in ELM refers to the process of the degree of “issue – relevant thinking” required by the recipient of the persuasive message. As the likelihood of elaboration increases, the quality of issue-relevant arguments becomes the determinant of persuasion. On the other hand, as the likelihood of elaboration decreases peripheral cues become more important.

Various factors have been identified to influence the degree of elaboration. These factors that influence elaboration falls into two categories: one involves the motivation of the receiver and the other is the ability of the receiver to engage in elaboration. When the recipient is high in motivation and ability, able to process the content of the message, the central route is likely to prevail, while peripheral route occurs when motivation and ability are low (Schwarz, Bless, & Bohner, 1991). Elaboration occurs when both ability and motivation is present (O'Keefe, 2002).

The following are variables that are can increase or decrease message elaboration under the central processing route, based on the amount of ability and motivation of the message recipient (Petty, Cacioppo, Sedikides, & Strathman, 1988).

Factors affecting Elaboration Motivation

Personal Relevance – As messages become more personally relevant to the receiver, the receiver becomes more likely to engage in issue relevant thought. When personal involvement is high, individuals tend to process message content rationally. When personal involvement is low, the content of the message becomes less important, thus seeking the peripheral route rather than the central route in message processing (Petty & Cacioppo, 1981, 1984; Petty, Cacioppo, & Schumann, 1983; Petty et al., 1988).

In ELM, research reports are labelled according to a receivers' level of "involvement" in topic related issues. In persuasion research, "involvement" covers a wide variety of relationships that the message recipient has with the topic, including the judgment of importance and commitment to the issue. According to ELM, involvement is specific to the induction of personal relevance of the topic (O'Keefe, 2002).

Johnson and Eagly (1989), defined "involvement as motivational state induced by an association between an activated attitude and self-concept", which implied that the level of involvement affects the change in attitude. The message recipient is dependent on his or her self-concept that generates the sense of involvement. Johnson and Eagly (1989) distinguished three aspects of involvement, established by self-concept. Value-relevant involvement is activated by one's enduring value; outcome-relevant

involvement depends on one's ability to obtain desirable outcome, while establishing impression-relevant involvement depends on the impression one makes on others.

In their study involving value-relevant involvement and impression-relevant involvement, subjects with high involvement were less persuaded compared to those low in involvement. With outcome-relevant involvement, subjects who were of high-involvement were more persuaded than low involvement individuals (Johnson & Eagly, 1989). Persuasion research on involvement conditions have shown that under conditions of high involvement, the quality of arguments has a greater impact compared to under low involvement conditions. Under conditions with low involvement, peripheral cues such as source expertise, and attractiveness of message source prevailed (Petty & Cacioppo, 1984; Petty, Cacioppo, & Goldman, 1981). Individuals put in much more cognitive effort to elaborate on issues when they are highly involved, thus, taking on a central route of information processing. Whereas under conditions of low involvement, they are more affected by simple heuristic cues such as acceptance and rejections based on source and message characteristics, choosing the peripheral route in processing information (S. Chaiken & Maheswaran, 1994; Petty et al., 1983).

Personal Responsibility – The personal responsibility of an individual determines the amount of effort one is willing to put in evaluating the persuasive message. Petty, Harkins, and Williams (1980) showed that the quality of argument becomes less important with decreasing personal responsibility. With shared responsibility among group evaluators, weak messages are more favourable, whereas individual evaluators preferred strong messages. A mixed message containing both strong and weak arguments does not have an effect on either shared or group evaluation (Petty, Harkins, & Williams, 1980).

Need for Cognition – The receiver's need for cognition can influence the motivation for elaboration and indicate one's inclination towards engaging in cognitive activities. As Cacioppo and Petty (1982) describes, some people enjoy engaging in thinking activities while others do not (Cacioppo & Petty, 1982).

Findings by Cacioppo et al. (1983), shows that individuals with high need for cognition are more likely to discriminate between strong and weak arguments when

evaluating the merits of supportive arguments. They are also more likely to be influenced by the quality of the message presented when forming impressions of the communicator, recall more message arguments regardless of cogency, and they account more cognitive effort compared to those with low need for cognition, (Cacioppo, Petty, Kao, & Rodriguez, 1986; Cacioppo, Petty, & Morris, 1983).

Factors affecting Elaboration Ability

Message Repetition – Message repetition is a characteristic that has been shown to influence the ability of recipients to elaborate on arguments. Cacioppo and Petty, (1989) have shown that repeated messages allow for more exposure and thus, the recipients have more time to elaborate on messages. Compared to one exposure, three exposures to messages increased the effectiveness of persuasion based on strong arguments but showed a counter effect on weak arguments (Cacioppo & Petty, 1989).

Distraction – Interruptions or distractions have been shown to intervene with systematic message processing. The quality of argument becomes less important as there are fewer chances for issue relevant thinking. When the message recipient is highly motivated and has the ability to process the message, distraction becomes a bothersome disrupter to the ability to process information (Petty & Cacioppo, 1986). Recipients with good mood are less affected by distraction, suggesting they did not engage in message elaboration, compared to those who are in a bad mood (Bless, Bohner, Schwarz, & Strack, 1990).

Prior Knowledge – An individuals' ability to elaborate on a message is influenced by their prior knowledge on the topic suggesting that recipients hold salient self-schema that led them to act subjectively when evaluating persuasive messages. This, in turn, causes them to engage in increased issue relevant thinking to counter strong conflicting arguments to their beliefs (Cacioppo, Petty, & Sidera, 1982). Wood (1982), suggested similar notion that subjects who have less prior knowledge are more susceptible to persuasion as it reduces chances of counter-argument on the message (Wood, 1982).

2.3 Persuasive Technology

Technology that is designed to influence attitude and behaviour change are known as Persuasive Technology. Torning and Oinas-Kukkonen (2009) identified 4 areas of research in computer-based fields where persuasive systems and design can be observed, namely, human-computer interaction, computer-mediated communication, information systems and affective computing (Torning & Oinas-Kukkonen, 2009). Technology that is designed to influence attitude and behaviour change are known as Persuasive Technology. Torning and Oinas-Kukkonen (2009) identified 4 areas of research in computer-based fields where persuasive systems and design can be observed, namely, human-computer interaction, computer-mediated communication, information systems and affective computing (Torning & Oinas-Kukkonen, 2009). Persuasive frameworks and models are developed to evoke change of attitude and behaviour through persuasion theory and social influence.

The following section is a review of persuasive frameworks and models that serves as guides for the design in the development of persuasive technologies. These persuasive framework and models help as define the PTA as an intelligent agent that is designed to with the intent to change attitude and behaviours in student tutors through persuasion.

2.3.1 Persuasive Frameworks and Models

Information systems and computerized software that are designed to strengthen, modify attitudes and behaviours or both without coercion or deception are known as persuasive systems (H. Oinas-Kukkonen & M. Harjumaa, 2008).

The Persuasive System Design (PSD) model is a framework created to provide a guideline for persuasive design and software requirements (Harri Oinas-Kukkonen & Marja Harjumaa, 2008). The PSD model is made up of a persuasion context following a three-phrase process, which consists of the *intent*, *event* and *strategy*. According to the PSD model (Oinas-Kukkonen & Harjumaa, 2009), the *intent* comprises of the *persuader* and the *change type*. There are three types of *persuaders*: the endogenous type, who is the creator of the technology; the exogenous, those who distribute the technology; and lastly the autogenous type, who are the users of the technology. The

change type of the *intent* defines the desired behaviour change. The event phrase defines the *use context*, *user context* and *technology context*. The *use* and *user context* help the system designer to understand the specific user issues and needs while the *technological context* helps to evaluate the strength and weakness of the technology used in the system (Wiafe, Alhammad, Nakata, & Gulliver, 2012).

Lastly, the *strategy* phrase consists of the *message* and the *route*. The message considers the form to transform the intended change in behaviour. While the *route* refers to the selection of indirect or direct route or both approaches to persuasion (Torning & Oinas-Kukkonen, 2009). In addition, the PSD model examines the non-functional design principles in persuasive system design such as *primary task support*, *dialogue support*, *system credibility support* and *social support*.

Another key dimension of human-computer persuasion is related to how users interpret persuasive messages from computers. This can be traced to social psychology research in persuasion. Social psychologist, Fishbein and Ajzen proposed the Theory of Reasoned Action (TRA) suggesting that the actions that a person intended to take in a situation can be predicted by their *attitude* and *subjective norm* towards the intended behaviour (Fishbein & Ajzen, 1975). TRA has been applied to the Technology Acceptance Model (TAM) in information system design, to anticipate a user's acceptance of the technology. Elaboration Likelihood Model (ELM) proposed by Petty, Cacioppo and colleagues, is a social psychology theory that explains how individuals perceive persuasive messages. The ELM is a dualistic model, proposing that attitude change takes on either a peripheral route or a central route of thought process. Under the peripheral route in the ELM, there is little thinking to process the information presented whereas in the central route there is in-depth consideration involved (Petty & Cacioppo, 1986).

Together with the PSD framework used for developing and evaluating persuasive systems (Torning & Oinas-Kukkonen, 2009) and ELM model, the 3-Dimensional Relationship between Attitude and Behaviour (3-RAB) model is developed to analyse the *change type*, *user* and *use context* and *route* of persuasion to attitude and behavioural change (Wiafe et al., 2012). The majority of research in persuasive

technologies and persuasion in systems design are towards the applications of persuasive frameworks and the analysis and design persuasion in systems.

2.3.2 Application of Persuasive Technology in Health Care and Education

The applications of persuasive technologies can be seen far and wide. Persuasive technology has been applied to advertising, management, governance and public health. In view of the scope of this thesis, only areas of health and learning will be examined.

Applications in Health Care

In the area of health care, persuasive technologies are often used to encourage healthy lifestyle changes such as changing one's behaviour in making healthier food choices, and exercising more regularly (Pinzon & Iyengar, 2012). One such application involves "just-in-time" feedback to encourage healthier choices. This is synonymous with the concept of Kairos in persuasion, where information is provided at the right moment to influence one's decision. One example of the use of persuasive technology is the use of sensors in our environment to provide context-aware information. Smart devices are used to provide relevant information to make health-related information. The MIT PlaceLab is a research facility that studies the possibilities of technologies to improve the wellbeing of residents in a smart home environment, where sensors and context-aware software are used to provide persuasive information to influence behaviours in a real life scenario (Logan & Healey, 2006).

Another example area in which persuasive technology can be used in health care is the smart pill box which reminds the elderly to take their medications. Such devices can be used to understand the reason why the elderly forget to take their medications. By analysing the behavioural and situational context information, appropriate persuasive information can be provided to remind them to take their medications (Lundell et al., 2006).

Wearable computing is another area in which persuasive technology can be applied. Such devices help users monitor their lifestyle and motivate them to adopt healthy lifestyle changes. Commercial devices include health monitors, pedometers

and activity trackers. These wearable devices help users can keep a log of their food intake, to track their diet and workout routines (Ananthanarayan & Siek, 2012). These devices allow users to track and share their activity logs and share them with friends on social media to motivate them in changing their behaviours through healthy competition.

Applications in Education and Learning

The education field is an area that is fast changing. This requires educators to adapt to a generation of young learners who are comfortable with learning with technology. Digital narrative software, infused with persuasion, has been developed to motivate children to read and write using persuasion principles such as similarity, tailoring and credibility to motivate literary learning (Lucero, Zuloaga, Mota, & Muñoz, 2006).

Persuasive strategies are also adapted in persuasive dialogue systems such as embodied conversational agents (ECA) designed for learning. An example of an ECA that provides supportive and expressive dialogue is the learning companion in the “How Was Your Day?” application, where the ECA provides affective persuasion that aims to influence the user’s attitude positively (Cavazza et al., 2010).

Efforts such as the EuroPLOT project (persuasive learning objects and technologies) (Gram-Hansen, Schärfe, & Dinesen, 2012; Herber, 2011) aim to adapt persuasive design as a component in the pedagogical framework. Persuasive design is also considered in the development of the content design tools and design patterns in the EuroPLOT project to encourage active learning engagement.

The application of persuasive technology in an educational setting can be demonstrated in the HANDS (Helping Autism-diagnosed teenagers Navigating and Developing Socially) project (Mintz & Aagaard, 2012). The HANDS project aims to assist autistic children to develop social skills using smartphone application with the persuasive design. Drawing upon the concept of Kairos, namely delivering the right message at the correct timing and place, the mobile software application uses user-centred design approach expressing the needs of teachers, children and parents. The user-centred design approach considers the user’s limitations, needs and wants at every stage of the software development process (Abrás, Maloney-Krichmar, & Preece,

2004). Teachers are able to develop intervention sequences using a flexible web-based toolkit to support each individual child in their learning.

The application of persuasive technology in educational and learning setting shows potential. With the integration of persuasive design principles drawn from multi-disciplinary research, there are possibilities to extend application of persuasive technologies the in development of teachable agents such as the PTA.

2.4 Intergenerational Learning

According to the Encyclopaedia of the Sciences of Learning, intergenerational learning is defined as “the learning that happens naturally in the home between parents and children and includes the wider family and community,” (“Intergenerational Learning," 2012).

The concept of intergenerational learning stems from the exchange of knowledge and ideas from the older generation to the young and vice versa. With the growing aging population, the idea of “productive aging” where the elderly lead meaningful and active lifestyles was promoted at the end of the 20th century (Brabazon & Disch, 1997; M. Kaplan, Kusano, Tsuji, & Hisamichi, 1998; Newman et al., 1997), where the elderly are highlighted as valuable resources instead of seen as a burden to the society for the growing cost of health care system and public pension (Gonyea, 1999).

2.4.1 Intergenerational Learning Programmes

In 1997, Newman proposed the use of intergenerational programmes as an embodiment of the intergenerational concept that “involved planned ongoing interactions between non-biologically linked children, youth and older adults” (Newman et al., 1997). Kaplan (1998), however, defined intergeneration initiatives as “activities, events and ongoing programs designed to increase cooperation, interaction or exchange between people between sixty years of age and older and twenty years of age and younger (M. Kaplan et al., 1998).”

Recognizing the changes in society that are occurring worldwide, the UNESCO Institute of Education published a monograph, highlighting a series of initiatives in various countries in intergenerational work that drives social and policy changes. The

intergenerational learning programmes highlighted and identified various areas of impact in public policies and recommendations for development and implementation strategies.

Countries such as Germany, Japan, the Netherlands, the USA, and the UK have developed the following three most frequently described models of intergenerational programmes. These frequently described models are, firstly, involving older adults serving children. Secondly, children and youths serving older adults or the old, and lastly, the young serving the communities (Boström et al., 1999).

In 1999, the UNESCO Institute of Education (UIE) held a meeting in Dortmund among countries where researchers from China, Cuba, Germany, Japan, the Netherlands, Palestine, South Africa, Sweden, the United Kingdom and the United States came upon a definition for the concept of intergenerational programmes (Boström, 2003), “Intergenerational programmes are vehicles for purposeful and ongoing exchange of resources and learning among older and younger generations” (Boström, Hatton-Yeo, & Ohsako, 2000).

Intergenerational learning programmes are channels in which purposeful exchange of resources and learning among the older and younger generations can be achieved (Boström et al., 2000). The goal of ILP is to create opportunities, where interactions between the young and old promote social growth and learning in informal settings (Newman & Hatton-Yeo, 2008). Informal learning occurs when people learn from one another, which includes values, attitudes knowledge and skills (Tuijnman & Boström, 2002).

M.S. Kaplan (2002) describes intergenerational programmes as those used in schools which benefits student learning and the communities involved, particularly the elderly participants, where young people are given the opportunity to “interact, support, and provide care for one another” (M. S. Kaplan, 2002). Boström (2003) also additionally observes the potentially beneficial social interaction between teachers, grandparents and the child which results from the increased amount of time the child spends in new social structures outside of the family such as day-care centre and schools (Boström, 2003).

Cross-generational relationships are rewarding. However, due to the changes in modern lifestyles, there is less time for bonding. This could be due to work or school commitments resulting in less time for the child to interact with their parents, or children moving away from their parents. As a result, the older generation has fewer chances to spend time with their children or grandchildren.

Table 2-3 shows a series of programmes initiated by the European Commission aimed at examining the challenges of aging and looking at areas in which the elderly contribute to the society (*ICT For Seniors' And Intergenerational Learning - Projects funded through the Lifelong Learning Programme from 2008 to 2011*, 2012). These programmes are some examples of the areas in which the PTA can be applied to encourage intergenerational learning.

Table 2-3 European commission intergenerational programmes

European Commission Intergenerational Programmes 2008-2011
A.L.I.CE - Adults Learning for Intergenerational Creative Experiences
BASIC-LIFE: Basic Web 2.0 Skills by Learning in Family Environment
Community Media Applications and Participation
Connect in Laterlife – Social Networking for Senior Citizens
CROSSTALK: Moving stories from across borders, cultures and generations
CT4P- CyberTraining -4-Parents
Detales: Digital Education Through Adult Learners' EU-Enlargement Stories
eScouts – Intergenerational Learning Circle for Community Service
Intergenerational ICT Skills
LEAGE – Learning Games for older Europeans
LIKE – Learning through Innovative management concepts to ensure transfer of Knowledge of Elderly people
Mix@ges – Intergenerational Bonding via Creative New Media
My Story – creating an ICT-based inter-generational learning environment
OWLE50+- Older Women Learning and Enterprise
PEER – Sapere aude! Dare to be wise!

SETIP – Senior Education and Training Internet Platform
SIGOLD – Turning the silver challenge into the golden opportunity
Silver: Stimulating ICT Learning for Active EU Elder
TKV – The Knowledge Volunteers
VinTAge – Valorisation of Innovative Technologies for Aging in Europe
W@ve 2.0 – Meeting Social Needs of Senior Citizens through Web 2.0 technologies

2.4.2 Intergenerational Learning Programmes in Singapore

According to the Committee on Aging Report on Ageing Population in 2006, there are existing programmes organized by the community for facilitate intergenerational learning. This report recommends that more can be done to provide learning as well as greater intergenerational bonding initiatives opportunities to the seniors (*Committee on Ageing Issues Report on the Ageing Population*, 2006).

More recently, Singapore sought to provide more opportunities for the seniors to engage in lifelong learning in order that they stay relevant and keep their mental awareness. One initiative is the Intergenerational Learning Programme (ILP) by the Council for the Third Age (C3A) setup in 2011, which provides an opportunity for the elderly to engage in lifelong learning where youths are matched with senior “teachers” in a classroom-based learning programme to encourage intergeneration bonding (“Intergenerational Learning Programme (ILP),” 2011).

Family Services Central (www.family-central.sg) is a service appointed by the Council for the Third Age (C3A) as the main organizer in conducting these ILPs in Singapore. Photography, wellness, web design IT, floral arrangement and photo editing courses such as “Basic Photoshop for Photographers” are organized regularly for seniors above 50 years of age. These courses are initiated by school clubs, student groups as service learning initiatives. The aim is to provide an opportunity for youths to learn important life lessons and values through interaction with the elderly while the seniors gain skills and knowledge from their younger counterparts (“Intergenerational Learning Programme ”, 2011).

2.4.3 Intergenerational Games – Research

Intergenerational learning can be achieved through play, as the younger and older generations can benefit from the exchanges which take place during intergenerational play (Davis, Larkin, & Graves, 2002). Research has been done in the area of interactive games which aim at keeping families members engaged through intergenerational play. Various intergenerational games have been developed to facilitate this research.

Table 2-4 shows the list of intergenerational games that are reviewed. Curball is one of the applications that allows for interactive play between the elderly and their grandchildren. The concept of the game is based on the Curling and Bowling game. The players in the Curball game are required to “throw” a tangible ball embedded with sensors in order to manoeuvre a virtual ball through augmented reality to the end of the board. The Curball game encourages communication between the older person and the other player e.g. the grandchild (Kern, Stringer, Fitzpatrick, & Schmidt, 2006).

Table 2-4 List of intergenerational games in research

Year	Game Title	Innovation	Description
2006	Curball	Encouraging play activity among the elderly, and child	Prototype collaborative game based on bowling game which uses tangible devices, sensors and augmented reality components, the game can be played between an older person and a child.
2008	Age invaders (AI)	Adaptable game parameters to suit simultaneous gaming of elderly and young, thus compensating for elderly disadvantages	An interactive intergenerational social – physical game that the elder can play with children in physical space, in real-time or remotely through the internet.
2010	Family Quest	Study of the nature of intergenerational play using active theory as a conceptual and analytical framework	A multi-user 3D educational game where parents and children ages 9-13 come to together to play Quest Atlantis.
2012	Xtreme Gardener	The study showed challenges of paired social interaction between younger and older players	This game requires cooperative gameplay while players to tend to a virtual garden with silhouette interaction.

Age invader (AI) is a multi-player game where players interact in physical space or participate in the game over the internet. This is a physical game, with additional games that require puzzle solving. AI is a game that stimulates cognitive and physical health, as well as encourage collaboration and bonding among the seniors and young (Khoo, Cheok, Nguyen, & Pan, 2008).

Family Quest is a study based on a multiplayer 3D game. The game reveals the dynamics of intergenerational play between Players ages 9-13 and their parents (Siyahhan, Barab, & Downton, 2010). Family Quest is analysed using Active Theory. The components of the activity are broken down into items such as tools, goals, norms and rules which are constantly evolving in relation as a result of the activity system (Cole, 1996; Greenberg, 2001).

Xtreme Gardener is a game which requires the cooperation between a pair of players to nurture a set of virtual garden plates using silhouette interaction as modes of control, the study highlights the challenge of designing intergenerational bonding games (Rice, Yau, Ong, Wan, & Ng, 2012).

In addition to the reviewed work presented in the literature review, the Virtual Singapura (VS) case study is presented in Appendix A. VS is a virtual learning environment developed as an educational game platform for science learning. The VS platform has been further developed as Virtual Singapura (VS) Saga which is presented in Appendix B, where the PTA has been implemented.

2.5 Discussion

Based on the literature review, problems and issues in existing teachable agents are identified. Moreover, to our best knowledge, there is a current research gap in applying persuasion to teachable agents. While learning-by-teaching has been proven to benefit the young (Chase et al., 2009; Sjöden, Silvervarg, et al., 2011), so far, none of the teachable agents reviewed have the ability to apply persuasion to help engage users in the learn by teaching process. There is currently no research in applying the theory in the context of intergenerational learning as the majority of intergeneration games research is focused on engaging players from different generations through gameplay.

The literature review shows there is a need to develop a teachable agent with persuasive features to improve social interaction between users and teachable agents. And expand the application of teachable agents to benefit users of different ages through intergenerational learning.

3 Persuasive Teachable Agent (PTA)

The Persuasive Teachable Agent (PTA) is an artificial intelligent computer agent that has the ability to be taught, to think, to learn and reason according to the interaction of its users, and to influence positive learning experience through persuasion

In this section, the PTA is defined and the PTA architecture is introduced. The persuasion reasoning will be presented to explain the relationship between the persuasion theory, agent and computation model. We will introduce the persuasive reasoning, allowing the PTA to generate the persuasive actions that the agent carries out to influence users to teach the PTA. A preliminary experimental results and an illustrative example of the PTA will be presented. Formative assessment of the initial PTA in a virtual learning environment will also be discussed.

We will discuss the issues and challenges in the initial design of the PTA, followed by the improvements to the PTA.

3.1 PTA Architecture

The PTA architecture consists of the environment where the user teaches the agent by constructing a concept map using the learning-by-teaching pedagogy, the events tracker, knowledge base, teachability reasoning and persuasion reasoning. Figure 3-1 is the diagram of the PTA architecture.

Figure 3-1 Diagram of persuasive teachable agent architecture

The PTA architecture in Figure 3-1 can be expressed as a tuple in the form of:

$$PTA = (E, P, K, Tr, Pr)$$

- *E*, **Environment**
 - The set of environment in which the agent interacts with
- *P*, **Events Tracker**
 - The set of precepts or events that the agent perceives from the environment
- *K*, **Knowledge Base**
 - A place that stores the knowledge the agent has learnt from the user
- *Tr*, **Teachability Reasoning**
 - The ability for the agent to reflect on the knowledge taught
- *Pr*, **Persuasive Reasoning**
 - The reasoning model for the agent to derive persuasion

As shown in the diagram in Figure 3-1, the events tracker receives the user learning activity data and the knowledge that the users have taught the teachable agent from the environment. The knowledge base stores the PTA's knowledge that the agent learnt from the user, while the teachability reasoning is made up of the learning cycle and the reasoning cycle (Ailiya et al., 2011). The learning cycle tracks the relationship links in the concept map where the users are drawn into the process to teach the teachable agent, whereas the reasoning cycle provides the appropriate responses of the PTA according to the user's inquiries and reflects on the responses in the environment.

The persuasion cycle *PPrA* can be defined as:

- *P*, **Perceive**: Perceives the events that the user participates in the environment.
- *Pr*, **Persuasive Reasoning**: Analyses the user's motivation and ability towards teaching the PTA based on the participating events in the environment.

- **A, Action:** Generates actions to encourage change in learning attitudes and behaviours.

The diagram in Figure 3-2 shows that the relationships between the persuasion theory, agent and computational models in Persuasive Reasoning. The reasons for selecting these models will be explained.

Figure 3-2 Theoretical, agent and computational models in Persuasive Reasoning

Persuasive Reasoning in the PTA uses the Elaboration Likelihood Model (ELM) (Petty & Cacioppo, 1986) theory of persuasion as its theoretical basis. The ELM is a useful model to conceptualize attitude and behaviour change widely applied in the field of advertising and marketing (Petty et al., 1983). The aim of the PTA in this study is to generate positive attitude and behaviour change in users in order to keep them motivated in interacting with the PTA, thus the ELM model of persuasion is used to model the Persuasive Reasoning in the PTA.

The Goal Net agent model (Shen, Miao, Tao, & Gay, 2004) is used to model decision processes in which the PTA selects the persuasive strategies to influence the users. The Goal Net agent model is used on autonomous, adaptive agents in dynamic situations, and is able to achieve complex goals by combining multiple sub-goals. The PTA mental model and its implementation can be modelled using the Goal Net model.

The Fuzzy Cognitive Map (FCM) (Kosko, 1986) computes the user's motivation and ability parameters. The FCM is a simple and flexible method to model factors affecting decisions in a visual graph. Since the PTA is implemented in a virtual

learning environment, the Persuasive Reasoning with the FCM is chosen which is useful in structuring a virtual world that is dynamic and changes over time.

In the following section, the ELM, Goal Net agent model and FCM computational model will be further described.

3.1.1 Elaboration Likelihood Model of Persuasion

Elaboration Likelihood Model (ELM) is a well-established theory in the field of persuasion. ELM uses a dualistic approach, modelling attitude change through central and peripheral routes (Petty & Cacioppo, 1986).

According to ELM, if an individual is motivated and has the ability to perform a behaviour he or she is likely to take on the central route of persuasion, in which their change of attitude is more persistent. The individual is more likely to think deeply about the relevant issue. On the other hand, if one is less motivated and does not have the ability to perform a behaviour, one is likely to adopt the peripheral route of persuasion, where attitude change is less enduring and one is less interested in elaborating on issues.

The PTA in this study integrates the ELM persuasion theory to instil lasting attitude change towards learning by applying appropriate persuasive strategies based on the user's motivation and ability levels. By categorizing events that occur in the environment, the PTA is able to determine the motivation and ability level based on the users' choices to participate in events. Factors influencing motivation and abilities are selected based on the ELM to match the events in the environment. The following Table 3-1 shows the factors influencing motivation and ability in the PTA.

Table 3-1 Factors influencing motivation and ability based on ELM

Factors influencing Motivation and Ability	
Motivation	Personal Relevance
	Personal Responsibility
	Need for cognition
Ability	Prior Knowledge
	Distraction
	Repetition

Motivation is assessed according to the personal relevance, personal responsibility and need for cognition factors derived from the ELM persuasion theory. These motivation factors correlate to events that the user participates in within the environment. Personal relevance relates to how relevant the event is related to the learning topic for the users. Personal responsibility relates to whether the event reflects the user's responsibility for his or her learning. And the need for cognition factor reflects whether the user is enjoying the learning process.

Ability is assessed through the events that correlate to prior knowledge, distraction and repetition factors. Prior knowledge determines whether the user has the knowledge resources required to teach the PTA. Events related to prior knowledge increase the user's knowledge so they can be better equipped with the knowledge to teach the PTA. Distractions are events that reduce the user's ability and are evaluated based on the number of distracters present in the environment. Because repetition increases the cognitive processing ability, the number of attempts the user teaches the PTA determines the user's cognitive processing ability.

The ELM is a useful framework for understanding the user, specifically what drive the users to learn and their ability to perform the task in teaching and learning with the PTA. With the ELM the PTA is able to conceptualize the change in attitude about learning in users in terms of their motivation and ability.

3.1.2 Goal Net Agent Model

The persuasive reasoning component is based on a goal-oriented model (Kolp, Giorgini, & Mylopoulos, 2001; Liu & Liu, 2002) for agent modelling known as Goal Net (Shen, Li, Miao, Gay, & Miao, 2005; Shen et al., 2004). The Goal Net is composed of states represented by nodes in which the agents need to complete to achieve its goal. Figure 3-3 shows an example illustration of the Goal Net model.

Figure 3-3 Example illustration of Goal Net

The *transition* in the Goal Net model is represented by an *arc* with vertical bars that associate the *task list* and *task function* the agent has to complete to move on to the next state. *Arcs* are represented by directed arrows that connect the relationship between *states* and *transitions*. A *composite state* (shaded node) can be broken down into *atomic states* (blank node) which consist of a single *state*, via *transitions*. An agent's goal within the Goal Net is to obtain the final desired *goal state* through the completion of sub-goals in a sequence.

There are four temporal relationships during the transition between input and output states: sequence, choice, concurrency and synchronization. The hierarchical structure of Goal Net allows for complex goal-oriented models to be constructed using a composite of sub-goals.

Sequence: is a direct causal relationship from state i to state $i+1$, as shown in Figure 3-4

Figure 3-4 Sequence relationship in Goal Net

Concurrency: is a simultaneous completion of tasks from state i . For example, state $i+1$ and state $i+2$ can be achieved at the same time, as shown in Figure 3-5.

Figure 3-5 Concurrency relationship in Goal Net

Choice: is a selective connection from one state to other states. For example, the agent may choose from state $i+1$ or state $i+2$ to proceed to the next state, as shown in Figure 3-6.

Figure 3-6 Choice relationship in Goal Net

Synchronization: is a convergent of multiple input states into a single output state. For example, state i and $i+1$ is converged to a single output state $i+2$, as shown in Figure 3-7.

Figure 3-7 Synchronization relationship in Goal Net

There are three types of transitions which are, *direct*, *conditional*, and *probabilistic*.

Direct Transition: is represented by a vertical line, indicates that the input and output state is a fix action or sequence of actions where there is no selection mechanism involved.

Conditional Transition: is represented by a diamond that indicates a transition after the completion of rule-based reasoning and selects actions according to runtime conditions.

Probabilistic Transition: a hexagon represents a transition that uses probabilistic inference to select actions in an uncertain situation.

Goal Net has advantages in modelling autonomous, adaptive agents in dynamic situations. Therefore, complex goals can be achieved by combining multiple sub-goals.

Mental models of the agent, as well as its implementation, can be modelled with Goal Net.

3.1.3 Fuzzy Cognitive Map Computational Model

FCMs were first proposed by Kosko (1986) to represent causal relationships with fuzzy feedback in dynamic systems. A collection of concepts is interconnected to reflect cause-effect relationships in the FCM dynamic system. Figure 3-8 is a diagram of a simple FCM.

Figure 3-8 Simple FCM, directed edge shows the causal flow between concept nodes.

The casual relationships in the FCM are represented by links between nodes (concepts) and directed edges (causal relationships). The weighted causal relationships in the FCM quantify the strength of the causal effects (Groumpos, 2010). FCM is a widely accepted method to model interrelated causal relationships between different factors affecting decisions in a visual graph representation.

The simplicity and flexibility of the FCM allow it to be applied in a wide variety of applications. Some of the applications FCM include expert systems that solve decision problems (Taber, 1991), in finance to solve stock investment analysis (Lee & Kim, 1997), and in the medical field (Stylios, Georgopoulos, Malandraki, & Chouliara, 2008). The FCM is particularly useful in structuring virtual worlds, due to its dynamic nature that allows changes over time (Dickerson & Kosko, 1993). In a simple FCM as shown in Figure 3-9, concept values C_i are values in real numbers $[-1, 1]$ and the causal edges are values in $[-1, 0, 1]$. The edge matrix for the simple FCM is presented as connection matrix E listing the causal links between the nodes.

$$E = \begin{matrix} & \begin{matrix} C1 & C2 & C3 & C4 \end{matrix} \\ \begin{matrix} C1 \\ C2 \\ C3 \\ C4 \end{matrix} & \begin{bmatrix} 0 & 1 & 1 & 0 \\ 0 & 0 & 1 & -1 \\ -1 & 0 & 0 & 0 \\ 0 & 0 & 1 & 0 \end{bmatrix} \end{matrix}$$

Figure 3-9 Connection matrix E shows the causal relationships in FCM.

The two main components of the FCM are *causal concepts* and *causal relationships*. *Causal concepts* are represented by nodes which can model, *events, actions, goals or lumped-parameter processes*. While *direct edges* represent the *causal relationships* between concepts, a positive sign “+” stands for the causal increase, whereas a negative sign “-” indicates a causal decrease. Arbitrary numbers are assigned in weighted FCM to give value to the increase or decrease in causal strength. The *causal relationships* in the FCM listed as a connection matrix that E between which concept node in C_i (Dickerson & Kosko, 1993). The strength of the edges e_{ij} of concept C_i (i^{th} column) takes on the value $[-1, 1]$ which indicates negative or positive causal relationships. For example, if edge e_{ij} is negative, -1, C_i decreases C_j . On the other hand, if edge e_{ij} is positive, 1 C_i increases C_j .

The advantage of the FCM is a quick and easy method to represent and acquire knowledge. Moreover, knowledge can be obtained from multiple expert sources and easily combined into a single FCM without restrictions to the number of concepts. FCM can be easily changed by adjusting the strength of the weights. It is also easy to modify changes in the model.

As such, FCM is suitable to be applied in a situation where human behaviour is a major factor or where problems are complex due to a large number of factors and there are no right or wrong answers. The FCM is also useful when limited data is available, missing or incomplete (Özesmi & Özesmi, 2004).

3.2 Persuasive Reasoning in PTA

The persuasive reasoning component is based on a goal-oriented model for agent modelling know as Goal Net (Shen et al., 2004). An agent’s goal within the Goal Net is to obtain an optimal state through the completion of sub-goals in a sequence. The

fuzzy cognitive map transition in the Goal Net structure is used to translate the external states of the world and user's activities into internal states that decide on the agents reactions in dynamic situations (Cai, Miao, Tan, & Shen, 2006).

The goal of a PTA is to direct user to stay on the central route of ELM with an attitude change, where the receiver's attitude changes towards an intended behaviour. In this case, the persuasive reasoning Goal Net is composed using the Goal Net, FCM and the ELM persuasion theory to persuade users to teach the PTA.

3.2.1 Persuasive Reasoning Goal Net

Figure 3-10 Persuasive Reasoning Goal Net.

The diagram in Figure 3-10 shows the Persuasive Reasoning Goal Net. The Persuasive Reasoning Goal Net receives events from the events tracker once the agent encounters the user. Once the events from the environment have been received, the Persuasive FCM is activated as a *transition* in the Goal Net. In Figure 3-10, the Persuasive FCM is shown as the fuzzy cognitive map transition in the Goal Net structure translates external states of the world and users activities into internal states that decide the agents reactions in dynamic situations (Cai et al., 2006).

The Goal Net structure provides temporal control over events that occur within the dynamic environment while the fuzzy cognitive map handles the internal reasoning based on the influence of external environmental factors. The outcome is a fuzzy cognitive Goal Net reasoning that uses external events as a basis to model complex internal states of the agent. The agent then proceeds select and persuasion strategies and execute actions in the environment.

If the user possesses both motivation and ability to teach the agent the persuasive reasoning ends. If the user has the low ability and/or low motivation, the persuasion strategy planner will be activated. The appropriate peripheral cue is selected based on the student's motivation or ability, and actions are carried out in the environment. The PTA persuasive reasoning returns to its initial state once the actions are carried out

3.2.2 Persuasive FCM

External events influence the user's motivation and ability in teaching the PTA. Thus, the PTA needs to understand the events in the environment and how each event influences the motivation and ability of the users to learn and teach the teachable agent. The concept value of motivation and ability enables the PTA to select the appropriate persuasion strategy and action to act upon in the environment.

According to ELM persuasion theory, motivation is influenced by personal relevance to the issue, personal responsibility and one's need for cognition. The ability to elaborate on the issue depends on the presence of distracters. The user's ability to participate in an event also depends on the repetition of the task and prior knowledge to the issue.

Figure 3-11 Causal relationships between external events and peripheral cue.

The Persuasive Fuzzy Cognitive Map (Persuasive FCM) is a fuzzy map based on the ELM persuasion theory that shows the causal relationships between external events. Figure 3-11 is the graphical representation of the Persuasive FCM. Factors affecting motivation and ability that influence the PTA's actions are based on the ELM theory of persuasion. The final persuasive FCM consists of the persuasive FCM with weighted edges. The initial Persuasive FCM was designed based on the on Virtual Singapura (VS) case study presented in Appendix A.

The learning motivation and ability to encourage users to teach the PTA are affected by the external events that the users engage in within the VS learning environment, where the dotted nodes representing the external events that are causally linked with directed edges. The peripheral cues are indicated with a shaded node in the Persuasive FCM. These peripheral cues are actions initiated by the PTA in the environment.

The Persuasive FCM is designed based on the findings during the field study of VS learning environment in Singapore secondary schools. The causal relationships that are interlinked between external events and factors influenced both motivation and ability, and these relationships are crucial for the PTA to determine the types of peripheral cues that the agent performs within the environment, as some of the peripheral cues provided by the PTA influences the decision of users to learn and teach the PTA in the learning. The following is the definition of the Persuasive FCM.

The Persuasive FCM is defined as a set of *Concept* = $\{C_1, C_2, \dots, C_n\}$ where,

$$C_i \in \textbf{Motivation} \cup \textbf{Ability} \cup \textbf{PeripheralCue}$$

The external events in the environment that user participate in. These external events determine his or her motivation and ability. **RL**, **RS** and **NC** are event sets that are linked to **personal relevance**, **personal responsibility** and the **need for cognition** respectively affecting an individual's motivation. And **PK**, **DT**, **RP**, refers to **prior knowledge**, **distracters** and **repetition** event sets that affect an individual's ability to perform a task. Each external event n is given an initial state value [0], as the user participates in a particular event the state value of event n becomes [1].

Within each event sets, there are n number of events,

$$\textbf{RL} = \{RL_1, RL_2, \dots, RL_n\}$$

$$\textbf{RS} = \{RS_1, RS_2, \dots, RS_n\}$$

$$\textbf{NC} = \{NC_1, NC_2, \dots, NC_n\}$$

$$\textbf{PK} = \{PK_1, PK_2, \dots, PK_n\}$$

$$\textbf{DT} = \{DT_1, DT_2, \dots, DT_n\}$$

$$\textbf{RP} = \{RP_1, RP_2, \dots, RP_n\}$$

Motivation, refers to internal characteristics of the user that compels him or her to learn and seek out new knowledge. Motivation is defined as:

$$\textbf{Motivation} \in \textbf{RL} \cup \textbf{RS} \cup \textbf{NC}$$

Personal relevance, personal responsibility and need of cognition are factors in the ELM persuasion theory that influence an individual's motivation.

Ability, refers to skill required by the user to teach the teachable agent. According to the ELM persuasion theory, an individual's ability is influenced by one's prior knowledge, the presences of distracters during processing of information and repetition to persuasive message presented. Ability is defined as:

$$\mathbf{Ability} \in \mathbf{PK} \cup \mathbf{DT} \cup \mathbf{RP}$$

The persuasion actions that the teachable agent performs in the environment are referred as **PeripheralCues**. **PeripheralCues** include hints from **ExpertSourceSet**, **AttractiveSourceSet** and emotions from **AffectSet**.

$$\mathbf{PeripheralCue} \in \mathbf{ExpertHintsSet} \cup \mathbf{AttractiveSourceSet} \cup \mathbf{AffectSet}$$

ExpertHintsSet, **EH** contains a set of hints from expert source that the teachable agent provides to help the user overcome difficulties during the teaching process where,

$$\mathbf{EH} = \{EH_1, EH_2 \dots EH_n\}$$

AttractiveSourceSet, **AS** is a set of popular individuals that the teachable agent will recall. These individuals provides support to the users.

$$\mathbf{AS} = \{AS_1, AS_2 \dots AS_n\}$$

AffectSet, **AF** is a set of emotions that teachable agents display in the environment to influence a user's learning motivation and ability.

$$\mathbf{AF} = \{AF_1, AF_2, \dots AF_n\}$$

Each item, n from the **ES**, **AS** and **AF** takes on a value of $[1, 0]$, and is activated when a peripheral cue have been selected and carried out in the virtual environment. The state value of motivation, Mot^t at time t is the sums of RS, RL, NC state vectors, multiply by their respective weight value of WRS , WRL , and WNC . Similarly, state values of ability and peripheral cue, Ab^t and $PeriCue^t$ are the results of the sum of individual state vectors multiply by their respective weight values.

$$Mot^t = RS * WRS + RL * WRL + NC * WNC$$

$$Ab^t = PK * WPK + DT * WDT + RP * WRP$$

$$PeriCue^t = EH * WEH + AS * WAS + AF * WAF$$

The state vector of the Persuasive FCM can be expressed as

$$A^t = [Mot^t, Ab^t, PeriCue^t]$$

A new value for each concept is updated due to the activation of a new event in the virtual environment can be computed as,

$$A^{t+1} = f(A^t * W + A^t)$$

Where A^{t+1} is the new state vector of concepts C_i and C_j , and A^t is the previous state vector of A^t multiply by the weight matrix W of the persuasive FCM.

3.2.3 Persuasive Strategy Planner

In the Persuasive Strategy Planner sub-goal shown in Figure 3-12, the PTA selects the persuasion strategy based on the motivation and ability values from the Persuasive FCM. Once the persuasive strategy to improve motivation or ability is selected, a peripheral cue is selected in the Persuasion Strategy Selection sub-goal. The peripheral cues are based on the ELM (Cacioppo et al., 1986) theory of persuasion, where an individual under the peripheral route are influenced by attractive expert source, or strong arguments and affect.

Figure 3-12 Persuasion Strategy Planner sub-goal of the Persuasive Reasoning Goal Net.

3.2.4 Persuasive Strategy Selection

In the Persuasive Strategy Selection sub-goal shown in Figure 3-13, the persuasive strategy is selected based on the motivation and ability value. If either motivation or ability value is low, a suitable peripheral cue is selected. The persuasive action is generated and executed in the environment.

Figure 3-13 Persuasion Strategy Selection sub-goal of the Persuasion Strategy Planner

3.3 Preliminary Experimental Results

The persuasive FCM model based on the VS virtual learning environment (Appendix A) is simulated in the following scenario examples that demonstrate the Persuasive FCM model. This simulation was conducted using the Fuzzy Cognitive Mapping software (FCMapper). The FCMapper is an Excel based FCM analysis tool freely available (Lee & Kim, 1997).

Experiment 1: In this simulated experiment, we assume that User A engages in a series of events involving gradually change personal relevance by gradually applying diffusion, osmosis and evaporation. In step 1, User A applies diffusion. Step 2, User A applies diffusion and osmosis. Step 3, User A applies diffusion, osmosis and evaporation

Table 3-2 shows the experiment results of the motivation, ability and peripheral cue values from the Persuasive FCM using the FC Mapper analysis tool. Motivation, ability and peripheral cue are concept nodes shown previously in the Persuasive FCM in Figure 3-11. The experiment shows the steps from 1 to 3 in which the user's personal relevance increases with each action of applying concepts of diffusion, osmosis and evaporation events in the learning environment.

Table 3-2 Motivation, ability and peripheral cue values from Persuasive FCM

Concepts	Motivation	Ability	Peripheral Cue
Step 1: Apply Diffusion	0.923	0.9139	0.864
Step 2: Apply Diffusion and Osmosis	0.931	0.9140	0.863
Step 3: Apply Diffusion, Osmosis and Evaporation	0.936	0.9141	0.862

As shown in Table 3-2, with each step in applying the action in the learning environment there is an increase in concept value of the personal relevance. The increase in concept value of the personal relevance corresponds to the increase in the concept value of motivation and ability. As the user's motivation and ability increases, the peripheral cue needed to stimulate interest decreases gradually. Based on the concept values of motivation, ability and peripheral cue from the Persuasive FCM iteration, the PTA will determine the persuasion strategy to execute in the sub-goal of the Persuasive Reasoning in the previous section.

3.4 Formative Assessment of the PTA Model

Several case studies were conducted throughout the development of the PTA model in VS virtual learning environment. The following are the descriptions of the case studies conducted from the year 2013 to 2015.

A preliminary study was conducted in 2013 on the VS test platform for the initial assessment of the PTA model (Lim, Ailiya, Miao, & Shen, 2013). In this version of VS we have devised a set of questionnaire to evaluate the users' motivation and ability based on the ELM persuasion theory. To evaluate motivation the users are asked to rate the questions in Table 3-3 on a 5-point Likert scale ranging from 1 = strongly disagree to 5 = strongly agree.

Table 3-3 Questionnaire statements for evaluating motivation

Motivation	Statement
Personal Relevance	The topic that I'm learning is useful to me.
Personal Responsibility	I always finish the tasks that are assigned to me.

Need for cognition	Thinking is idea of fun.
--------------------	--------------------------

A separate set of observable behavioural criteria in Table 3-4 is used to evaluate the users' ability in test platform.

Table 3-4 Criteria of evaluating ability

Ability	Criteria
Prior Knowledge	Completion of lesson tutorial
Distraction	Presence of background music, pop-up windows, on-going chat
Repetition	Number of attempts to complete tasks

The PTA actions are selected using the initial design of the Persuasive Strategy Selector in Figure 3-14. The persuasive strategies are selected based on the evaluation outcome of the users' level of motivation and ability. The PTA actions are selected from the list of persuasive feedback actions in Table 3-5 and Table 3-6.

Table 3-5 Persuasive feedback action for low motivation

Low motivation	Persuasive feedback action
Increase Personal Relevance	Would you like to select a topic that is more useful for your learning?
Increase Personal Responsibility	The teachable agent will need your help in completing the concept map.
Increase Need for Cognition	The time limit to complete the concept map has been extended for you to explore more on the topic.

Table 3-6 Persuasive feedback action for low ability

Low ability	Persuasive feedback action
Increase Prior Knowledge	Please complete the tutorial to learn more about the topic
Decrease Distraction	The background music is too loud. Do you like to turn down the volume?
Increase Repetition	Do you want to construct the concept map?

An informal interview was conducted on two groups of testers who interacted with a version of VS. The control group tested on a version of the VS with a teachable agent without persuasion and compared with the treatment group who tested the version of VS with the PTA prototype. The initial results showed that the treatment

group of testers responded that they are more willing to teach the PTA during the learning process compared to the responses from the control group.

In 2014, a separate study was conducted on the PTA with a clearer model for Persuasive Goal Net allowing for tracking on the user's learning ability. In this study, the events in the VS test platform were defined, such that the events respond to factors that determine the users' level of motivation, eliminating the need for a questionnaire to find out the users' level of motivation. An informal interview was conducted over the advantages of PTA compared to the traditional teachable agent (Lim, Ailiya, Miao, & Shen, 2014). Table 3-7 is a summary of the interview and some of the suggestions that were brought up during the interview.

Table 3-7 Summary of interview

Advantages of PTA	Improvements to PTA
<ul style="list-style-type: none"> • Responsive especially when avatar is idling • Provides appropriate responses at correct timing • Provides guidance to the activities in the Virtual Learning Environment 	<ul style="list-style-type: none"> • Needs to a wider range of emotions and more variety of actions • Further integration of the PTA in actual teaching phrase.

The test users had indicated positive interest in learning with the PTA in the VS test platform. They have also responded that PTA was interactive and they were willing to teach it. The PTA also appeared to be actively interacting with the test users and provided a suggestion that was related to the learning stages that they were currently in. They had also described that the PTA as “a friend in need”, therefore they were more likely to teach the PTA as the test users had treated the PTA as a friendly companion. It was also highlighted that PTA had to continue to be persuasive even when they were already teaching it. This indicated that the PTA had to continue to be persuasive so as to help the users reflect on the concept that was taught to the PTA.

The informal interviews conducted have provided useful formative feedback during the developmental stage of the PTA leading to the improvements in VS saga. However due to the small sample size of the study group, there was no statistical significance analysis drawn from these studies. However, these small group studies provided an iterative analysis of the PTA during the design process of the VS saga.

Although we have received positive feedback from the test users, there are several technical problems in the initial version of the PTA. First, the persuasion reasoning in this version of the PTA is not fully autonomous. This means that the PTA needs to evaluate the users' motivation based on the questionnaire in the VS test platform. Second, the Persuasive FCM in this version is too rigid and does not support addition or removal of events in the VS test platform. These limitations in the initial versions of the PTA have led us to make several improvements to the Persuasive Goal Net in 3.4.2 and the Persuasive FCM in 3.4.3 and have implemented the improved version of the PTA in the VS Saga virtual learning environment.

3.4.1 Discussion on Issues and Challenges

From our formative assessment, the PTA is able to respond more intuitively to suit the user's learning requirements. Users are motivated to teach the PTA. The improved PTA is able to respond better to individual learning needs of the users based on their ability and motivation. At the same time, the PTA possesses the capability to provide strategies to encourage social interaction which will keep users engaged while teaching the PTA.

Although this initial PTA model addresses the issues in the teachable agent, namely, the lack of interaction between the teachable agent and the users. However, the initial version of the PTA model still displayed several limitations, as highlighted in during the formative assessment of the initial PTA model discussed in 3.5.

First, the design of the initial PTA model focuses on the implementation of persuasion theory in the teachable agent model, which improves the ability of the PTA to persuade the users to teach the teachable agent. However, the initial PTA model lacks integration of the agent's ability to practice on the knowledge taught by the user. Moreover, in terms of reusability, the initial PTA model adopts a quantitative model that was difficult to reuse in terms of computational processes. Last, the initial PTA model was largely based on a theoretical model which presents a gap in the practical implementation of the PTA model in a real world game engine.

3.5 Improvements to the PTA

As part of a collaboration on a final year project with Zeng (2015), the original PTA model, Persuasive Goal Net and Persuasive FCM was redefined and integrated in the new version of the VS Saga virtual learning environment (Zeng, 2015). The improved PTA model is based on the previous Persuasive Reasoning in section 3.2 of this thesis.

In this section, the remodelling of the PTA model, the additional refinement to the Persuasive Reasoning Goal Net and Persuasive FCM will be explained.

The main contribution to the improvements to the PTA is the theoretical model of the PTA and the VS Saga virtual learning environment that was setup for the implementation of the PTA. The improvements to the original version of the PTA model include a complete integration of the *Persuasion Reasoning*, *Teachability Reasoning* and *Practicability Reasoning*. The original *Persuasion Reasoning* is simplified and fully combined with the *Teachability Reasoning* and *Practicability Reasoning*. The *Teachability Reasoning* and *Practicability Reasoning* have been added to the improved Persuasive Goal Net to reflect on the PTA's ability to be taught and practice the knowledge taught by the user.

An improved version of the PTA model allows for a reusable quantitative model where the *Persuasion Reasoning* model could be applied to different contexts. This means that future applications of the *Persuasion Reasoning* can be reused in other knowledge domains and implementations in future work. A refined version of the system architecture that describes the implementation of the reusable PTA control structures was proposed and developed in a 3D virtual environment.

3.5.1 Redefining PTA Model

The improved PTA model shown in Figure 3-14 is redefined by a tuple:

$$PTA = (E, ET, K, Rs, R, A)$$

Figure 3-14 Improved PTA Model

- ***E*, Environment**

- The set of environment states perceived by the agent.

- ***ET*, Precepts /Events Tracker**

- The set of precepts or events that the agent perceives from the environment.

- ***K*, Knowledge Base**

- The knowledge base of the agent, which consists of the following subsets.
 - *Goal Net Model*, is the set of Goal Net structures which controls the characteristics and drives the agent towards its goals pursuit
 - *FCM Model*, stores the FCM structure that derives the values of motivation and ability.
 - *Domain Knowledge*, stores the expert knowledge related to the learning topics.
 - *Learnt Knowledge*, stores the knowledge that the agent learnt from the knowledge taught
 - *Runtime Data*, stores data such as the events information and their history that is generated during runtime.

- ***Rs*, Reasoning Selection**

- The selection mechanism set the agent has to adopt to select reasoning in R for each cycle.

- **R , Reasoning Set**

- The set of reasoning for the agent to perform, which and can be further defined by the tuple: $R = (P, Tr, Pr)$ where,
 - P , is the *Persuasion Reasoning* mechanism that enables the agent to persuade the user.
 - Tr , is the *Teachability Reasoning* that allows the agent to learn from the knowledge taught.
 - Pr , is the *Practicability Reasoning* that allows the agent to practice on the knowledge learnt.

- **A , Action**

- The set of actions to be performed by the agent in the environment.

In addition, the improved PTA model enables the agent through the following three different cycles:

- Persuasion Cycle: $EtRsP(KA)$
 1. *Perceive*: The agent's perceptions on the events in the environment.
 2. *Reasoning Selection*: The agent selects a suitable reasoning according to its perceptions.
 3. *Persuasion Reasoning*: The agent goes through reasoning to determinate the types of persuasion based on the user's level of motivation and ability. The agent then selects the appropriate persuasion cue according to its perception if persuasion is required.
 4. *Knowledge Base*: The agent retrieves the persuasion cue from the knowledge base if persuasion is required.
 5. *Action*: The agent executes the persuasion cue if persuasion is required.
- Teaching Cycle: $EtRsTrK$

1. *Perceive*: The agent's perceptions on the events in the environment.
 2. *Reasoning Selection*: The agent selects a suitable reasoning according to its perceptions.
 3. *Teachability Reasoning*: The agent acquires the knowledge taught and through its teachability reasoning, interprets the knowledge into knowledge representations.
 4. *Knowledge Base*: The agent stores the interpreted knowledge representation in the knowledge base.
- Practicing Cycle: *EtRsPr(KA)*
 1. *Perceive*: The agent's perceptions on the events in the environment.
 2. *Reasoning Selection*: The agent selects a suitable reasoning according to its perceptions.
 3. *Practicability Reasoning*: The agent decides the appropriate responses to the user's queries according to its knowledge.
 4. *Knowledge Base*: The agent retrieves the response from the knowledge base if the response is pre-determined.
 5. *Action*: The agent's response according to the user's query.

The improved PTA model based on the earlier proposed PTA architecture offers a clearer view of the agent reasoning capabilities and flexibility for the PTA to select its reasoning functions according to its precepts of the environment, thus, allowing the PTA to be more autonomous.

3.5.2 Modelling Teachability and Practicability Reasoning with Goal Net

Significant additions to the PTA architecture are the *Teachability Reasoning* and *Practicability Reasoning* in the *R*, Reasoning Set cycle. The *Teachability Reasoning* and *Practicability Reasoning* is modelled with the Goal Net agent model and integrated into the Goal Net model of PTA, forming the highest level of the Goal Net in the PTA which is known as the main routine is shown in Figure 3-15.

Figure 3-15 Goal Net Model of PTA Main Routine

The following Table 3-8 shows the PTA definition and the corresponding states and transitions in the main routine in Figure 3-16.

Table 3-8 PTA definition corresponding to States/Transitions in Main Routine

PTA Definition	States/Transitions
<i>Et</i> , Event Tracker	Detect Event, Event Detected, Interpret Event, Event Interpreted
<i>Rs</i> , Reasoning Selection	Select Reasoning
<i>Tr</i> , Teachability Reasoning	To Learn Knowledge
<i>Pr</i> , Practicability Reasoning	To Practice Knowledge Learnt
<i>P</i> , Persuasion Reasoning	To Persuade

The main routine runs continuously as long as the agent continues to pursue its goal. The agent checks for an update of events in each cycle. If one or more events are detected, it will select the reasoning based on the events perceived. After each cycle, the agent will return to its original start node and begins a new cycle.

There are three sub-goals, namely, *Teachability Reasoning*, *Practicability Reasoning* and *Persuasion Reasoning* in the main routine. These sub-goals allow for

the agent to select the appropriate reasoning goals according to the events in the environment.

Teachability Reasoning Sub-Goal

The Teachability Reasoning sub-goal in Figure 3-16 illustrates the agent's desire to learn new knowledge. In this sub-goal, the agent requires the user to teach itself. Once the response is received by the agent, it checks if the request has been accepted or rejected. If the user agrees to teach the agent, the goal net initiates teaching. Once teaching is initialized the agent acquires the knowledge after it saves the stored the knowledge it received and the cycle ends.

Figure 3-16 Teachability Reasoning Sub-Goal Net

Practicability Reasoning Sub-Goal Net

The Practicability Reasoning sub-goal in Figure 3-17 starts with the agent's query in its knowledge base which retrieves the knowledge it has learnt from the user. Through its reasoning, the agent generates either a correct solution or a wrong solution based on the knowledge in its knowledge base.

This simulates the agent's capability to practice its knowledge and provides a means for the agent to reflect on the knowledge learnt through feedback on the user's teaching. If the result of the reasoning is the correct solution, the agent will carry out the solution. On the other hand, if the result of the reasoning is a wrong solution event, in the next cycle of the Goal Net of PTA, the agent will go through the Persuasion Reasoning Goal Net in an attempt to improve the user's motivation.

Figure 3-17 Practicability Reasoning Sub-Goal Net

Persuasion Reasoning Sub-Goal Net

The Persuasion Reasoning Sub-Goal shown in Fig. 3-18, is adapted from the Persuasive Reasoning Goal Net. In this sub-goal, the goal of the agent is to persuade the user to improve their ability and motivation.

Figure 3-18 Persuasion Reasoning Sub-Goal Net

Similar to the Persuasive Reasoning Goal Net, the Persuasion Reasoning Sub-Goal starts with the calculation in the Persuasive FCM. Following that, the user's motivation and ability are assessed. The agent then selects a reasoning based on motivation and ability level of the user by comparing the results to predetermine the baseline values. If both motivation and ability is high, the cycle ends and no further actions are required. If either motivation or ability is low, the agent will then select an appropriate persuasion cue that aims to improve the user's motivation and ability and execute the cue. The Persuasion Reasoning Sub-Goal Net will end after the cues have been executed and return the next node in the main routine.

3.5.3 Quantitative Modelling of the Persuasive FCM

To facilitate the computational processes, the Persuasive FCM is divided into the Main FCM and the Sub FCM as shown in Figure 3-19.

Figure 3-19 Remodelled Persuasive FCM

The Main FCM is formed by the stem nodes made up of the causal concepts namely, peripheral cue, as well as, motivation and ability which are connected to the factors that affect the input of motivation and ability forms which the *stem nodes*. In addition to the Main FCM, the Sub FCM is connected to the *stem nodes*. Multiple *leaf nodes* (dotted circles) are attached to the stem, each *leaf node* an event in the environment that has direct influence to any of the input factors related to motivation and ability.

The improved Persuasive FCM model allows for greater flexibility and computational efficiency if future events in the environment were to be added, as these events could be included in the *leaf nodes*.

3.5.4 PTA System Architecture Design

To further close the gap between the theoretical model and the implementation of the PTA, the version of the PTA system architecture has been improved in this study as shown in Figure 3-20. The improved system architecture is more flexible as it is independent of the topics of learning. The embodiment of the PTA is not restrictive and it can be deployed and implemented in other environments.

Figure 3-20 Improved PTA system architecture design

The following Table 3-9 shows the components in the PTA system architecture and its corresponding functionalities and roles.

Table 3-9 Functionalities and roles of components in PTA system architecture

Components	Functionality/Role
Goal Net Interpreter	Control the goal-oriented behaviours of the PTA.
PTA Control	Implement functions, coordinate PTA goal-oriented behaviours.
Event Control	Deals with the creation, logging, processing and removal.
FCM Calculation	Performs FCM computational processes.
UI Control	Control the interface elements in the PTA environment.
Data Access	Connects to the database and performs queries.

Goal Net Interpreter

At the top level of the PTA, the system architecture is the Goal Net Interpreter. The purpose of the Goal Net Interpreter is to control the goal-oriented behaviours of the PTA through its reasoning cycle. The Goal Net models in the PTA are created in the Goal Net Designer (Han, Zhiqi, & Chunyan, 2007) and stored in the Goal Net database.

The main purpose of the Goal Net Interpreter is to load the saved Goal Net models from the Goal net database and interpret the Goal Net models dynamically in real-time. The Goal Net Interpreter also determines the tasks the PTA is to perform so as to pursue it as a goal during the state transition in the main route of the PTA Goal Net. After the tasks are determined, the Goal Net Interpreter then updates the PTA Control to perform the tasks assigned.

PTA Control

The role of the PTA control is to implement the functionalities in the PTA. The PTA Control performs the task functions as shown in Table 3-10 by acting upon the instructions from the Goal Net Interpreter. This is done by breaking down the tasks into tasks and sub-tasks and sends them to other components by calling on the corresponding modules in these components so that the components are able to work together towards the goal of the PTA.

Table 3-10 Task Functions to be implemented by the PTA Control

Goal Net Model	Functions to be Implemented	
Main Routine	DetectEvent InterpretEvent	SelectReasoning Finish
To Learn Knowledge	RequireTeaching CheckResponse InitializeTeaching Acquire Knowledge	SaveKnowledge GenerateRejectionEvent Finish
To Practice Knowledge	QueryKB Reasoning CarryOutSol	GenerateWrongSolEvent Finish
To Persuade	FCMCalculation CheckMotAbi SelectCue	ExecuteCue Finish

For the PTA to realize the three reasoning cycles in the PTA definition, the PTA Control has to implement the task functions that are associated with the transitions in the PTA Goal Net models. The following are the Goal Net models in the PTA and their associated functions to be implemented by the PTA Control.

Event Control

The Event Control corresponds to the **Event Tracker** *ET* in the PTA definition. It handles the lifetime of an event such as the creation, logging, processing and removal

of events. The PTA Control also uses the Event Control to handle events in the PTA Goal Net model.

The Event Control keeps track of the events by checking for new events at predetermined intervals and log newly generated events in the Event Log in the Event Control. The Event Control prioritizes the events and determines the processing sequence of the events when the checking is performed as well as decides on the number of interaction events to process in batches.

The Table 3-11 below shows the event category and the examples of the few types of events that can be tracked in the PTA environment.

Table 3-11 Events tracked in the PTA Environment

Event Category	Event	Example
Learning Behaviour	Dialogue event	<ul style="list-style-type: none"> The user refuses to teach the PTA during dialogue. The user is distracted by a non-player character.
	Location event	<ul style="list-style-type: none"> The user has arrived at the designated location.
	Time event	<ul style="list-style-type: none"> The user has been inactive for more than 5 minutes.
Learning Achievements	Collection of rewards	<ul style="list-style-type: none"> The user has been awarded a reward for completing the mission.
	Completion of mission	<ul style="list-style-type: none"> The user has completed the mission.
Knowledge Data	Make an error	<ul style="list-style-type: none"> The user makes an error in teaching the PTA.
	Feedback event during teaching	<ul style="list-style-type: none"> Generating the correct solution from the knowledge acquired from the user.

FCM Calculation

The FCM Calculation component processes the computational aspects in the Persuasion Reasoning in the PTA. The FCM model is loaded from the database and stored in the FCM Calculation component when the PTA is initialized, the PTA Control activates the FCM Calculation in the Persuasion Reasoning Cycle to compute the motivation and ability values.

UI Control

The UI Control component provides the module that enables the agent to perform the actions as defined in the PTA definition in the environment. This includes the embodiment of the PTA in the environment either as a 2D or 3D avatar. The UI Control allows for the user the graphical interface to control the PTA in the environment.

Database Access

The Database Access component allows for the other components to access the database. Multiple databases may be accessed through the Database Access component. For example, the Goal Net Interpreter is able to access the state and transitions in the Goal Net database. Another example is when the FCM Calculation component loads the FCM model from the FCM database.

3.5.5 Discussion on the Improvements to the PTA

To summarise the improvements to the PTA, the reasoning component to the PTA is fully integrated with the combination *Persuasion Reasoning*, *Teachability Reasoning* and *Practicability*. The *Persuasion Reasoning* is simplified with a quantitative model allowing the PTA to be used in different contexts. This allows greater flexibility for the PTA to be deployed in other applications platforms in the future. The improved PTA reasoning allows for timely persuasive feedback for the users to be given out autonomously. This will keep users interested in interacting with the PTA as the persuasive feedback is personalised according to the level of individual learning ability and motivation.

The improved system architecture provides better controls for the PTA to handle multiple functionalities and prepare the PTA for deployment in the applications such as the 3D game engine. With the final improvements to the PTA reasoning and system architecture, the PTA is implemented in the VS Saga virtual learning environment which is further elaborated in Appendix B of this thesis.

3.6 Conclusion

In comparison to the existing teachable agent in the previous version of VS, the PTA is able to respond intuitively to suit the student's learning requirements. The improved PTA is able to respond better to individual needs of the user based on his or her ability and motivation.

The improved PTA systems architecture in the VS Saga bridges the gap between theoretical concepts of the PTA model and the actual implementation of the PTA in a 3D game engine. At the same time, the PTA possessed the capability to provide strategies to encourage social interaction with the PTA, which will keep users engaged while teaching the PTA.

The following chapter is a follow-up to the user study on intergenerational learning using the PTA VS saga, based on the research questions and the hypothesis of this thesis.

4 Persuasive Teachable Agent for Intergenerational Learning

In this chapter, the methods and the procedure to the study of the PTA for intergenerational learning will be introduced. The post-game questionnaire in Appendix C is used and the types of data collected will be described. The data collect in the study will be analysed. The conclusion to the hypotheses will be provided and future improvements to the PTA will be discussed.

4.1 Methods

To our best knowledge, there are no data and studies on intergenerational learning with teachable agents. The question is whether the PTA, a teachable agent with persuasion capabilities can benefit intergenerational learning. Our study explores how different generations would respond to the PTA in the virtual learning environment.

To assess the PTA in terms of its usage in intergenerational learning, this study is designed using the phenomenological research approach. The phenomenological research method involves discovering phenomena by gathering information through qualitative research methods, for example, by interviewing the participants, discussion and observing the participants in a situation (Lester, 1999). The aim of the phenomenological research is to describe the phenomenon in an accurate manner, while at the same time refrain from any bias, staying with the facts (Groenewald, 2004). The advantage of the phenomenological method is that it can be applied to a single case or unforeseen or specifically selected sample participants (Lester, 1999). This method is appropriate for our study as it is efficient and covers a wide range of scenarios. Moreover, the phenomenological approach allows us to fine-tune the PTA during the developmental process.

The purpose of this study is to evaluate the perception and the user experience on intergenerational learning while interacting PTA. Two types of data were collected during this study. The first type of data collected involves the participant's in-game progress and behaviours in the VS saga virtual learning environment (Appendix B). The second type of data is the assessment of their perceptions of the PTA and learning

experience in the post-game questionnaire (Appendix C). A set of questions on user's experience from a questionnaire used in an earlier study done in 2009 on a teachable agent without persuasion (Ailiya, 2013) is also included in the questionnaire. The result from the 2009 study serves as a comparison to the current study on user's experience with intergenerational learning with the PTA. Additional notes and observations made by the researcher during the sessions are also used in the interpretation of the results obtained. The following are the details of the data collection procedure.

A total of 10 participants took part in the pair study; with the age of the youth ranging from 9 to 12 and the age of the older participants in their late 30s. Out of the 10 participants, two of them are Indians and the rest of the participants are Chinese. All of the youths are upper primary students. Out of the older participants, there are 2 polytechnic graduates, 2 university graduates and one a post-graduate.

4.1.1 Procedure

The participants were briefed on the purpose of the study, followed by an invitation to complete a 20 minutes interactive session where they are required to test the VS saga. After this, they are given 15 minutes to complete a post-game questionnaire.

Once their consent is obtained, the participants were required to fill up their social-demographic data which consist of their personal background, gender, age and highest education attained. The participants were also required to complete the rest of the questionnaire after trying the game.

4.1.2 Post-game Questionnaire

The post-game questionnaire consisting of 32 questions was given out to each of the participants. A sample of the post-game questionnaire is included in Appendix C.

Personal Background

Section A of the questionnaire consists of 4 questions relating to the demographics and personal background of the participants. The questions in the post-game questionnaire were assessed on a 5-point Likert scale.

General Intergenerational Relationship Background

In the Section B of the questionnaire, there are four questions, numbered 5 to 8 that relate to the participant's general intergenerational relationship background. Question 5 is related to the participant's level of interest to spend their leisure time learning with someone older or younger than them, rated on a 5-point Likert scale (Strongly disagree = 1, disagree = 2, neutral = 3, agree = 4, strongly disagree = 5) questions, matrix questions, contingency questions, closed and open-ended questions.

Question 6 is a matrix of factors that affect the participant's decision to spend time in intergenerational learning activities. Participants are required to rate the factors affecting their decisions to spend time on a 5-point scale (Does not affect = 1, little affect = 2, neutral = 3, somewhat affect = 4, greatly affect = 5).

Question 7 is a close-ended question that relates to the kind of activities that interest the participant in intergenerational learning. Question 8 is an open-ended question that allows participants to elaborate on what would motivate them to take part in intergenerational learning.

4.1.3 Learning Experiences with PTA

Section C of the questionnaire consists of 8 questions that are related to the participant's perception of their learning experiences during the PTA. In this section of the questionnaire, participants are asked to rate their learning experiences in the VS saga according to the skills sets they are likely to gain during the test session. The participants were required to rank these questions according to a 5-point Likert scale.

In this section, the participants are to rate their learning experiences and feelings when they are teaching the PTA. The participants are required to rate questions 9 to 16 in the post-game questionnaire in terms of the social skills and learning experiences that participants gained in the session based on a 5-point Likert scale (Strongly disagree = 1, disagree = 2, neutral = 3, agree = 4, strongly disagree = 5).

Social Skills

Question 9 relates to whether the participants have active listening skills that they have gained by taking up the advice from their teammates. Question 10 relates to whether

the participants worked together to take responsibility for PTA's learning process. Question 11 aims to discover on whether the participants took turns to engage with the PTA. Question 12 and 13 relate to whether the participants were able to encourage each other, as well as focus and stay on the task assigned to them in the quests and missions that they have to complete in the VS despite the distracters that are placed in the game.

Problem-Solving Skills

Question 14 relates to the problem skills the participants have encountered in the game. In this question, the participants are asked whether they are able to solve the problems that they had encountered in the VS saga.

People Skills

Questions 15 and 16 are related to the people skills that the participants have felt during the interactive session in VS saga. People skills, in this case, refer to both psychological skills and social skills. Questions 15 and 16 relate to the people skills learning experience that the participants have gained during the session. Question 15 relates to whether the participants have learnt trust and respect. Whereas question 16 relates to whether the participants have gained understanding and whether the participants have empathized with the teachable agent.

Knowledge, Values and Role in Virtual Learning

Section D is a set of questions from 17 to 19 that relate to the knowledge, values and roles the participants experienced in virtual learning.

Question 17 explores whether they had learnt new knowledge other than information on the science concepts such as osmosis and diffusion. Question 18 relates to what each participant thought about their roles when playing and question 19 relates to the role each user took during the teaching process with the PTA.

4.1.4 Opinion on Learning with the PTA

The opinion on learning with PTA in section E consists of three questions numbered 20 to 22. These questions focused on the participant's attitudes towards interaction with their teammate and the PTA during the test session.

Question 20 relates to whether the participants have engaged in learning during the session. Question 21 probes on whether they are motivated to find out more information on the science topics during the session. Question 22 asks the participants whether the participants felt that they have learnt more when teaching with the PTA with their teammates.

4.1.5 Feelings towards the PTA

In Section F, there are three questions numbered 23 to 25 related to the participant's feelings towards the PTA on a 5-point Likert scale rating. It should be noted that question 20 is coded on a reserve scale. In this section, there are three questions that investigate the participant's feelings towards the PTA. Question 23 probes on whether the participants have felt confident that the PTA would be able to do well. Question 24 asks whether the participants felt nervous when they are interacting with PTA. Question 25 relates to whether the participants felt any strong emotional feelings towards the PTA during the session.

4.1.6 Perceptions towards the PTA

Section G from 26 to 28 are three questions on a 5-point Likert scale related to the participant's perceptions towards the PTA. Question 26 probes on whether the participants felt responsible for the PTA. Question 27 relates to whether the PTA responded as the participants have expected. Question 28 asks if the participants were satisfied with PTA performance on the concept map.

4.1.7 Improving the PTA

Section H is an open-end question that requires the participants to fill in suggestions on improving the PTA to enhance their learning experience.

4.1.8 PTA for Intergenerational Learning in Virtual Environments

Section I consists of 2 questions numbered 30 and 31. Question 30 and 31 are contingency questions. Question 30 relates to how the participants feel about using virtual learning environments such as VS saga to promote intergenerational learning. Question 31 relates to whether the PTA was able to aid intergenerational learning.

4.1.9 Gaming Experience in Virtual Learning Environment

Section J of the questionnaire consists of 12 questions that are related the gaming experience in Virtual Learning Environments. These questions were from in the 2009 version of the VS study (Ailiya, 2013). The assessment of these questions serves as a comparison for this study on the learning gaming experience with the PTA. The last Section K concludes the questionnaire with an open-ended question that probes on any additional comments that relate to the VS saga system or the study.

4.1.10 In-game Progress

In addition to the post-game questionnaire, the participant's in-game progress is tracked for each session of the study. The following are some of the data that are recorded in the background during the paired test sessions.

PTA Performance

The PTA performance to the concept map is a key indicator of how well the participants have engaged in learning. In order to analyse this aspect in learning, the PTA learning results are tracked according to the number of attempts the user tries to teach the PTA. The knowledge that the PTA has learnt from the participants will also provide insights into how well that user has responded to the interaction with the PTA in the VS saga VLE.

Mouse Clicks

In addition to the post-game questionnaire and the events tracked by the PTA, the participant's mouse clicks are recorded. This provides greater insight into the activities and richer information on what the participants are doing in the VS saga system. The information will allow future developers of the VS saga to improve the interface design as well as to aid in the evaluation and analysis of the effectiveness of the PTA in the system.

Time Spent

Another important factor that determines the participants' activities in the VS saga is the time that they spent on each task assigned to them. Therefore, the time between each task to complete will be tracked.

4.2 Data Analysis

The following section describes the detailed breakdown of the data that was collected from the participants in the post-game questionnaire. And the description of the in-game progress data includes the PTA performance, the analysis of the participant's mouse clicks and time spent in the VS saga.

4.2.1 General Intergenerational Relationships

In hypothesis 1, it is predicted that younger group of participants will be more interested in intergenerational learning. Therefore in this section, the participant's level of interest in intergenerational learning is examined. The factors that affect their time spent on intergenerational learning and the types of activities that the participants might be interested in are also explored. The information sheds light on the settings in which the future versions of PTA can be integrated for intergenerational learning.

Level of Interest in Intergenerational Learning

Table 4-1 shows the average rating of the participant's level of interest in intergenerational learning. Figure 4-1 shows the comparison of this average rating of the participant's interest in intergenerational learning.

Table 4-1 Level of interest in intergenerational learning

	Level of Interest Average Rating
Questions	Qn 5
Older Group Percentage Agree	3.75
Younger Group Percentage Agree	5

Figure 4-1 Comparison of perception towards intergenerational learning

From the results shown in Table 4-1, all of the younger participants registered the maximum possible interest in spending time with someone from a different generation. A number of older users however are only interested with one participant indicating only mild interest in spending time with someone from a different generation compared to the younger age group.

Factors affecting decision on time spend on Intergenerational Learning

Table 4-2 shows the average rating on of different factors affecting intergenerational learning interests that were listed in question 6 of the post-game questionnaire (Does not affect = 1, little affect = 2, neutral = 3, somewhat affect = 4, greatly affect= 5). Figure 4-2 is a graphical representation of the results of the comparison of the factors affecting the participant's decision to spend time in intergenerational learning.

Table 4-2 Factors affecting intergenerational learning

Factors	Age Difference	Experience	Time Available	Type Of Activities
Older Group	2	2	3	3
Younger Group	1.75	2.75	1.75	2.25

Figure 4-2 Factors affecting level of interest in intergenerational learning

In Figure 4-2 it is observed that for younger participants, one outstanding factor affecting intergenerational activity interest is prior experience with their partner in other intergenerational activities. For older participants, however, the two key factors affecting their interest in intergenerational activities are time available and the type of activities which they had to take part in.

Activities for Intergenerational Learning

The following Table 4-3 shows the percentage of the group of participants and the types of activities at the participants feel that are conducive to intergenerational learning. Figure 4-3 is the graphical representation of the percentage comparison of the activities.

Table 4-3 Activities for intergenerational learning

	Older Group	Younger Group
Sports	25%	75%
Field Trips	75%	100%
Games	50%	100%
Volunteer Work	100%	100%
Arts/Crafts	25%	50%
Outdoor recreation	75%	75%
Conversation/Talking	50%	75%
Passive recreation	75%	50%
Culture experiences	100%	50%

Figure 4-3 Activities for intergenerational learning

Figure 4-3 shows that a higher percentage of younger participants feel that sports, field trips, games, conversations and arts and craft are suitable activities for intergenerational learning. On the other hand, a higher percentage of older participants feel that passive recreation and culture experiences are preferred activities for intergenerational learning.

PTA for intergenerational bonding and learning

The following Table 4-4 shows the percentage of participants who agrees that the PTA is helpful in encouraging intergenerational bonding and intergenerational learning. Figure 4-4 is a graphical representation of the comparison of the results.

In terms of intergenerational use, both young and old participants felt that the PTA would be useful for the purposes of international bonding and international learning. This is especially true for international learning whereby all older participants felt that the PTA would be helpful in that aspect.

Table 4-4 for intergenerational bonding and learning

	Intergenerational Bonding	Intergenerational Learning
Questions	Qn 30	Qn 31
Older Group Percentage Agree	80%	100%

Younger Group Percentage Agree	80%	80%
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Figure 4-4 Comparison of perceptions towards intergenerational use

According to the results, there is a difference in the types of activities that the participants think that are possible activities for intergeneration learning. There is a clear preference for the younger group to engage in hands-on physical activities such as sports, field trips and arts and crafts. The younger groups are also interested in games as a form of activity for intergenerational learning. However, the older participants preferred passive activities such as recreation and culture activities. One reason for this will be that the older participants are leading less active lifestyles compared to the younger participants. Thus, intergeneration learning activities between the two generations can be one possible way to encourage the older participants to engage in physical active lifestyle.

4.2.1 Perceptions on Intergenerational Learning with PTA

Hypothesis 2 predicts that the older group will have a better perception on intergenerational learning with PTA compared to the younger group. In this section, the participant's perception about the PTA during intergenerational learning will be examined. The participant's opinions and feelings towards intergenerational learning with the PTA will be analysed.

Opinion on intergenerational learning with the PTA

Table 4-5 shows the average rating on the participant's opinion on intergenerational learning based on engagement, motivation and learning with the PTA. The Figure 4-5 is a graphical representation of the comparison of the results between the older and younger group.

Table 4-5 Rating comparison of opinion on intergenerational learning

	Attitude	Motivation	Learning
Questions	Qn 20	Qn 21	Qn 22
Older Group Average Rating	4	4.25	4
Younger Group Average Rating	5	4.75	5

Figure 4-5 Comparison of attitude towards learning average rating

From the data above it can be seen that both younger and older participants displayed positive perceptions of teaching the PTA in an intergenerational setting, in terms of engagement, motivation and learning. This can be because the younger group of participants are more accustomed to learning with technology, thus, they find that learning with the PTA in the virtual learning environment is engaging and motivating compared the older group of participants.

Feelings towards PTA

The following Table 4-6 shows the average ratings of the participant's feelings towards the PTA, in terms of confidence when they interact with the PTA, their level of nervousness and whether if they feel emotional over the PTA in the virtual learning

environment. Figure 4-6 is the graphical representation of the comparison of the results of the participant's feelings towards the PTA.

Table 4-6 Rating comparison of feelings towards PTA

	Confidence	Nervousness	Emotional
Questions	Qn 23	Qn 24	Qn 25
Older Group Average Rating	4	2.5	3
Younger Group Average Rating	4.75	1.5	4.5

Figure 4-6 Comparison of feelings towards PTA average rating

From the data result regarding the confidence and nervousness when interacting with the PTA, it can be seen that on average, younger participants were more confident in making use of the PTA, displaying less nervousness than older participants. As the PTA was designed with youths in mind, younger participants were also better able to relate to it thus displaying stronger emotions towards its actions, situation and prompts.

Perceptions towards PTA

Table 4-7 shows the average ratings of the participant's perceptions towards the PTA, based on their responsibility, expectations, performance of the PTA. Figure 4-7 is the graphical representation of the results.

Table 4-7 Rating comparison on perceptions towards PTA

	Responsibility	Expectation	Performance
Questions	Qn 26	Qn 27	Qn 28
Older Group Average Rating	3.5	4	4.25
Younger Group Average Rating	5	4.5	4.5

Figure 4-7 Comparison of perceptions towards PTA average rating

Relating to their ability to relate and feel for the PTA, younger participants also felt extremely responsible for the agent and its performance, more so than older participants. Both younger and older participants felt that the PTA responded to expectation, and were satisfied with its performance.

4.2.2 Learning Experience with PTA

Hypothesis 3 predicts that the younger group will have a better learning experience in intergenerational learning with the PTA. In this section, the differences in learning experience of the different age groups will be examined. The following are the analysis of the participants' learning experiences in terms of skills, knowledge, values and the roles that they play when they interact with the PTA in the virtual learning environment.

Skills

Table 4-8 shows the average rating and mean score of the different skills gained during learning with the PTA during the session in terms of the social skills, problem-solving skills and people skills. Figure 4-8 shows the graphical comparison of the different skills that the participants have learnt in the VS saga virtual learning environment.

Table 4-8 Rating comparison of learning experiences in Virtual Learning Environment

	Social Skills					People Skills	People Skills	
Questions	Qn 9	Qn 10	Qn 11	Qn 12	Qn 13	Qn 14	Qn 15	Qn 16
Older Group Average Rating	4.5	4	3.25	3.25	4	3.75	4.75	3.75
Younger Group Average Rating	5	5	4.5	3.25	4.75	4.75	4.75	4.5

Figure 4-8 Comparison of learning experience average rating

The results of learning experience show that the younger group has a higher average rating on almost all aspects of the questions in this section on participant's learning experience.

It is traditionally expected that in an intergenerational technology-based setting, a role reversal should be observed with youths taking on the role of leader, and guiding the older participant, who takes on the role of a student. Based on the survey results, however, this was not the case in many aspects. During the session, it was also observed that while the youths were often the leaders when it came to navigating the control, the senior members would, in fact, direct the youths as to how to proceed and what to do. This was especially true when the PTA appeared and cued the participants to continue the task at hand rather than partaking in random activities.

From the survey results and observational notes, it can be seen that the use of the PTA further reinforced the learning aspect of the virtual environment, and the older participants automatically assumed the leadership role which they are accustomed to in learning environments.

Knowledge, Values and Role in Virtual Learning

Table 4-9 shows the average ratings for knowledge, values and the participant's role in the virtual learning environment. Figure 4-9 is the comparison of these three attributes based on the two groups of players.

Table 4-9 Rating Comparison on knowledge, values and role

	Knowledge	Values	Role
Questions	Qn 17	Qn 18	Qn 19
Older Group Average Rating	3.5	4	3.25
Younger Group Average Rating	5	5	4.25

Figure 4-9 Comparison of knowledge, values and roles average rating

From the survey data above as well as observational data, while older participants often took on the role of a leader, when it came to the educational aspects such as teaching the PTA, they allowed the younger participants to take on the role of leader, teaching both them and the PTA, thus facilitating learning by teaching.

4.2.3 User Experience in Virtual Learning

Hypothesis 4 predicts an improvements in general participant users' experience compared to the traditional teachable agent. In this section, there will be a comparison

of the results from a previous study in 2009 and the results from our questionnaire to investigate whether the PTA will improve the user's experience compared to the traditional teachable agent.

In the study in 2009 (Ailiya, 2013), a group of 36 students from lower secondary school from 12 to 14 years old had participated in a study with a version the VS virtual learning environment with a TA without persuasion. This group of students had responded to the same questions that are included in this study. The following is the comparison of the results from the study in 2009 with the results of the PTA in Table 4-10.

Table 4-10 User experience in the Virtual Learning Environment

Questions	Older Group Average Rating	Younger Group Average Rating	2009 Student Average Rating
Q32 Enjoyment	3.75	5	3.75
Q33 Fun	3.75	5	3.75
Q34 Boring	2.75	1	2
Q35 Lose Attention	3	1	2
Q36 Interesting	4.25	5	3.5
Q37 The game has value to me	3.75	4.75	3.75
Q38 The game is useful to learn Science	3.75	5	3.75
Q39 Provides valuable experience	3.75	4.75	3.75
Q40 Willing to play again	4	5	3.75
Q41 Helps me understand the topic	3.75	5	3.75
Q42 Beneficial	3.75	5	3.75
Q43 Important	3.75	5	3

Figure 4-10 Comparison of gaming experience average rating

Figure 4-10 is the comparison of the results on the participant's gaming experience in the VS virtual learning environment. As can be seen from the comparison shown in Figure 4-10, with the addition of the persuasive component in the PTA, the experience of younger participants making use of the virtual learning environment has displayed an increase in all aspects of the survey. This can be attributed to the persuasive component in the PTA specifically designed to target younger users. Interestingly, the responses of the older participants are similar to the responses of the students found in the 2009 study. One possible reason for this is that they were not the target the persuasive element was designed to target and thus displayed a similar response to students exposed to a teachable agent with no persuasive elements.

4.2.4 In-game Progress

Out of all the 5 sessions, almost all of the participants attained a perfect score of 4 in their first attempt. Only in one of the sessions the pair of participants managed to attain the perfect score on the second attempt.

This can be due to the effectiveness of the PTA in assisting the learning on the subject presented in VS saga. As well as the PTA's ability to persuade the participants

to try completing the concept again, by asking the participants to teach the PTA the second time. However, the results in having a perfect score can also be due to the low level of difficulties in the concepts that participants had to teach the PTA. The lack of difficulty is apparent as one of the participants had commented in the post-game questionnaire that the VS Saga virtual learning environment should have more “levels of difficulties”.

Table 4-11 shows the number of mouse clicks on the distractors namely, the rabbit, the stag in the knowledge town and the small girl in the science laboratory. The table also shows the number of prompts by the PTA, the number of clicks the PTA receives and the time that the participants spent in each of three scenarios in the VS saga.

Table 4-11 Mouse clicks, PTA prompts and duration spent

Session	Rabbit Click	Stag Click	Small Girl Click	PTA Click	PTA Prompts	Town Duration (Seconds)	Lab Duration (Seconds)	Tree Duration (Seconds)
S1	1	1	1	17	5	675	290	205
S2	0	1	0	9	3	280	140	150
S3	0	0	0	13	1	710	110	145
S4	0	0	0	5	1	695	310	275
S5	3	1	1	19	7	1605	660	335

Based on the results in Table 4-11, the highest number of clicks on the distractors in the knowledge town in has triggered the highest number of PTA prompts in session 5. This session has recorded the most number of clicks for the non-player characters (NPC) and the longest in-game session out of all the 5 sessions. It is observed that the paired participants had the most persuasive prompts from the PTA.

However, the PTA performance did not suffer because of the interactions with the NPCs, as the participants’ and their PTA have attained a perfect score for the concept map. This shows that the PTA has the potential to guide the participants towards the learning activities in the virtual learning environment.

4.3 Conclusions for Hypotheses

Hypothesis 1:

In hypothesis 1, it is predicted that participants from younger age group will be more interested in intergenerational learning compared to the older age group.

Conclusion 1:

However, from our findings, it is the participants from the older age groups who show more interest in intergenerational learning. One contributing factor for the low level of interest for the younger participants is their lack of experience in interacting with older age group. On the other hand, the age difference has lesser effect on the older age group.

To generate interest for the younger age group, we suggest implementing intergenerational learning in activities that encourage interaction among the different age groups. This is reflected in the higher preference for the younger age group to engage in sports, field trips, games as well as arts and crafts. The younger age group also feel that that conversation and talking is a channel for intergenerational learning. Therefore, future studies will consider the types of activities in which the PTA can be implemented to generate more interest in intergenerational learning among the younger age group.

Hypothesis 2:

According to hypothesis 2, we have predicted that the older age group will have a better perception on intergenerational learning with the PTA.

Conclusion 2:

The findings from our study have shown that the younger age group has higher ratings in terms of attitude, motivation and learning during the intergenerational learning session with the PTA. The younger age group has been shown to be more confident, show stronger emotions and less nervousness when they interact with the PTA compared to the older age group. The younger age group also reported feeling more responsible towards the PTA. They also had a better expectation and satisfaction compared to the older age group.

This observation does not support our initial hypothesis. As the young age group forms a better opinion on the PTA than the older age group towards intergenerational learning.

Hypothesis 3:

In this hypothesis we predict that the younger age group will have a better intergenerational learning experience with the PTA.

Conclusion 3:

In terms of learning experience, the younger age group has a higher rating in learning skills. They have shown higher knowledge and values ratings compared to the older age group and taken up the role to lead in learning. The findings from our study suggest that the younger age group has a better intergenerational learning experience compared to the older age group.

Hypothesis 4:

We have predicted that the PTA improves the general user's experience compared to the traditional teachable agent.

Conclusion 4:

In the comparison of the user experience studies, it is shown that the PTA has improved the user experience for the younger age group. However, the result for the older age group is comparable to the results in the previous study conducted on the teachable agent without persuasive reasoning. This shows that the PTA is more effective in improving user experience for the younger age group, compared to the older users.

4.4 Future Improvements to PTA in VS Saga for Intergenerational Learning

Based on these findings, the inclusion of persuasion to a teachable agent can be seen to have a significant impact on both the educational aspect as well as the user experience of students interacting with the agent. The overall gaming experience has also

improved with the implementation of the persuasion theory in the PTA. Participants have responded to positive learning experience towards learning with the PTA.

However, one key area of improvement which may help in the area of intergenerational use which can be further explored is the extension of the persuasion theory and design to encompass users of all ages, as different users require different topics that interest them. This is reflected in one of the open-ended questions in the additional comments, where one of the participants commented that the topic in the VS saga is “not suitable for young kids”.

5 Conclusions and Future Work

This chapter provides the conclusion to the thesis by summarising the current on work Persuasive Teachable Agent (PTA). A summary of contributions and future works highlights the main contributions and future direction of the PTA.

5.1 Conclusions

In this thesis, the PTA, a novel teachable agent that influences the users learning attitude and behaviours through persuasion is proposed. The PTA is implemented in a 3D virtual learning environment, VS Saga (Appendix B). A study on the PTA in an intergenerational learning setting is conducted.

In the Chapter 1, the background of this research in teachable agents is introduced. By analysing the challenges in existing teachable agents, the research objectives, questions and hypotheses for the thesis is established.

Chapter 2 is the literature review on existing teachable agents where issues and challenges were highlighted. From the literature review, it is found that the teachable agents lack the ability to interact with user. Moreover, there are limitations in the application of teachable agents in academic learning. Persuasion is proposed as the solution to improve the teachable agent ability to interact with the users. Therefore, the literature review also includes current works on persuasion theory and persuasive technologies. To expand the application of teachable agents in areas other than academic learning, research work that involved intergenerational learning where teachable agents can be applied is also reviewed.

In Chapter 3, the PTA and architecture is defined. Theoretical models that the PTA is based on is introduced, namely the ELM model of persuasion (Cacioppo & Petty, 1984), Goal Net agent model (Shen et al., 2004) and the FCM computational model (Kosko, 1986). The choice for these models and how these models are used in the persuasive reasoning for the PTA is explained. Formative assessments are carried out with the initial design of the PTA. And subsequent improvements are made to the design and implementation of the PTA in the 3D virtual learning environment.

Chapter 4, a study on the PTA in intergenerational learning setting is carried out. In the study, the participants have shown interest in using the PTA as a tool for intergenerational learning. The results have indicated that the PTA has improved user experience among the younger users compared to the traditional teachable agent.

5.2 Summary of Contributions

Contribution 1: PTA

The first contribution of this study is the formalization of the definition for the Persuasive Teachable Agent (PTA). The PTA model is a goal-oriented modelling approach that deliberates the teachable agent's goal to select persuasion to influence user's decision to teach the teachable agent.

Contribution 3: Persuasive Reasoning Goal Net

The third contribution is the Persuasive Reasoning Goal Net. The persuasive reasoning model allows the PTA to select persuasive reasoning is based on the Elaboration Likelihood Model (ELM) (Cacioppo & Petty, 1984) of persuasion. To realize the persuasive reasoning in the PTA, the Fuzzy Cognitive Map (FCM) (Kosko, 1986) is applied to the persuasive FCM computational model to compute the motivation and ability for the PTA to reason its persuasive actions. This allows the PTA to select appropriate actions to influence the user's decisions to teach the teachable agent.

Contribution 3: PTA for Intergenerational Learning

The PTA has been implemented to the VS Saga virtual learning environment (Appendix B). An improved PTA model that bridges the gap between persuasion theory and implementation as an intelligent teachable agent is attained. A formal study on the effects of PTA on intergenerational learning has also been conducted.

5.3 Future Work

The research questions and hypotheses have highlighted the research direction of the PTA. The future works in this section are directed towards the implementation and evaluation of the PTA which also covers the potential of PTA research in future projects. The following are some of the possible extensive applications of PTA.

5.3.1 Persuasive Teachable Agent in Citizen Science Projects

The PTA is beneficial for users in terms of improvements in the learning experience. The PTA also encourages users from different age groups to participate in learning activities. There are opportunities to look into areas of interest where users will be interested in participating in group learning activities that are beneficial in terms of building relations across different age groups. Intergenerational learning activities create the opportunity for PTA to be applied in informal science educational projects on a large scale basis, such as a ‘citizen science’ projects.

Citizen science projects are initiatives where volunteers and enthusiasts from different backgrounds participate in scientific research, allowing the data collected to be made available for analysis on a larger scale (Duke, 2012). There are advantages in adopting citizen science in engaging the public in science research, such as the capitalizing of human resources available in solving scientific problems while at the same time and increasing the resources available and reducing the cost involved in conducting large scale experiments by outreaching to a large number of users (Duke, 2012).

Future research directions can also be expanded by exploring the types of information that is exchanged during the interaction with a persuasive teachable agent when driving participants to contribute to citizen science, and examining the potential and issues in applying PTA to intergenerational learning through citizen science projects. For example, in citizen science projects, the PTA acts as central knowledge base collecting activity logs and learning knowledge from users from different age groups, at the same time analysing the information using Goal-Oriented Fuzzy Cognitive Persuasive Reasoning to encourage learning from one another.

5.3.2 Persuasive Gerontechnology

With the global trend gearing towards an aging population, there are various challenges and issues that arise with old age. Technologies are often sought after to solve problems associated with old age such as the deterioration in physical and cognitive abilities. Gerontechnology is an area of study in which technologies are used to benefit the well-being of the aging population (J.L. Fozard, 2005).

Persuasive technology, on the other hand, involves the use of technology to alter attitudes and behaviour without coercion (Fogg, 1999). Persuasive technology can play the part of influencing positive behaviours and attitude among the aged and aging person to enhance the quality of life. However, most of the research in persuasive technologies are targeted at the younger generation, teens and preteens, and trending towards influencing the attitudes and behaviours of adults (King & Tester, 1999). Persuasive gerontechnology, therefore, looks at the area in which technology can provide positive influence towards attitude and behaviours to meet the ambitions, activities and wisdom of the aging society (James L Fozard & Kearns, 2006).

The PTA is a persuasive technology that can be used to enhance the life of the elderly. For example, the PTA can lessen the perceived difficulty in learning a technology as an older person often perceives that mastering a new technology takes significant cognitive effort. Another way in which the PTA can be applied, is the prevention and management of diseases where PTA can be used to encourage the elderly to adopt a healthy lifestyle, through intergenerational learning activities. The PTA has the potential to encourage the elderly to lead a more active life that involves life-long learning and encourages intergeneration bonding.

5.3.3 User Modelling in Persuasive Teachable Agents

User modelling in human-computer interaction allows for systems to understand users in order to build systems that suit individual user's need (Fischer, 2001). Users from different backgrounds possess different skills and personal reasons to engage in learning with teachable agents. Thus, understanding user's ability and motivation becomes important in building adaptive systems to cater for different users. The approach to user modelling in PTA utilizes the combination of persuasion theory and machine learning to generate users' learning behaviour and cognitive processes (Webb, Pazzani, & Billsus, 2001).

The future work in PTA will include the tracking of users' learning activity data collected from the learning environment based on the persuasion theory such as ELM. The data collected can be used to evaluate the level of learning ability and motivation based on their receptiveness to either central or peripheral route of persuasion

(Cacioppo & Petty, 1984). As well as analysing the learning activity data to model user's response to model persuasive strategies that cater to individual users.

5.3.4 Feedback with Question Answering (QA) engine

Studies have shown that feedback support in teachable agent helped students to learn better, especially when they receive self-regulated user feedback from their teachable agents (Tan & Biswas, 2006). For example, teachable agents who are able to ask questions and probe the student tutor encourage reflection and help the student tutor to structure their knowledge (Roscoe et al., 2008). Directed, corrective immediate feedback has also shown to aid in immediate learning. While guided and metacognitive feedback which comes in a form of reaffirming the knowledge that the student tutors have taught the teachable agent helps the tutors to monitor the teachable agent learning progress as well as assess the tutors own learning (Biswas & Leeawong, 2005). The body of research has shown the importance of teachable agent feedback to the student tutors.

The questioning and answering (QA) in the field of information retrieval for computer systems to search for short phrases or sentences, provides precise answers to user's query in the large textual database (Prager, Chu-Carroll, Brown, & Czuba, 2006). QA systems allow for users to ask questions in a natural language that they use in their daily lives and they can receive answers quickly (Hirschman & Gaizauskas, 2001).

The PTA aims to provide appropriate feedback to the student tutors with a QA engine to provide users with the information from the PTA knowledge base so as to keep them motivated in learning. The goal of the PTA feedback is to encourage student tutors to stay focused on learning tasks with the PTA. Future work on the PTA can be aimed towards providing persuasive feedback using a QA engine and observing the effects of persuasive feedback on user from different age groups.

5.3.5 Evaluating and Assessing Persuasive Teachable Agents

Future studies can be extended to include a wider range of effects on users such as behaviour, cognition and emotional changes during interaction with PTA. The studies can also include a larger sample size of participants.

Further experiments can be conducted to evaluate favourable and unfavourable attitude change in learning, and addressing the unfavourable attitude change, an area currently outside of the existing ELM persuasion model.

Author's Publications

Lim, S. F., Chan, M., Borjigin, A., Miao, C., & Shen, Z. (2013, 15-18 July 2013).

Persuasive Teachable Agent User Modeling. Paper presented at the 2013 IEEE 13th International Conference on Advanced Learning Technologies, 307-308.

Lim, S. F., Ailiya, Miao, C., & Shen, Z. (2013). *The Design of Persuasive Teachable Agent*.

Paper presented at the Proceedings of the 2013 IEEE 13th International Conference on Advanced Learning Technologies, 382-384.

Lim, S. F., Borjigin, A., Miao, C., & Shen, Z. (2014, 7-10 July 2014). *Persuasive*

Teachable Agent with Goal Net. Paper presented at the 2014 IEEE 14th International Conference on Advanced Learning Technologies, 461-463.

Yu, H., Yu, X., **Lim, S. F.**, Lin, J., Shen, Z., & Miao, C. (2014). *A multi-agent game for studying human decision-making*. Paper presented at the Proceedings of the 2014 International Conference on Autonomous agents and Multiagent Systems, Paris, France, 1661-1662.

Yu, H., Lin, H., **Lim, S. F.**, Lin, J., Shen, Z., & Miao, C. (2015). *Empirical Analysis of Reputation-aware Task Delegation by Humans from a Multi-agent Game*. Paper presented at the Proceedings of the 2015 International Conference on Autonomous Agents and Multiagent Systems, Istanbul, Turkey, 1687-1688.

Borjigin, A., Miao, C., **Lim, S. F.**, Li, S., & Shen, Z. (2015). Teachable Agents with Intrinsic Motivation. In C. Conati, N. Heffernan, A. Mitrovic, & F. M. Verdejo (Eds.), *Artificial Intelligence in Education: 17th International Conference, AIED 2015, Madrid, Spain, June 22-26, 2015. Proceedings* (pp. 34-43). Cham: Springer International Publishing.

References

- Abras, C., Maloney-Krichmar, D., & Preece, J. (2004). User-centered design. *Bainbridge, W. Encyclopedia of Human-Computer Interaction. Thousand Oaks: Sage Publications*, 37(4), 445-456.
- Ailiya. (2013). *Affective Teachable Agent in Virtual Learning Environment*. (Doctor of Philosophy), Nanyang Technological University. Retrieved from <https://repository.ntu.edu.sg/handle/10356/59271>
- Ailiya, Shen, Z., & Miao, C. (2011). *Affective Teachable Agent in VLE: A Goal Oriented Approach*. Paper presented at the Proceedings of the 2011 IEEE 11th International Conference on Advanced Learning Technologies, 110-114. doi:10.1109/icalt.2011.38
- Ananthanarayan, S., & Siek, K. A. (2012, 21-24 May 2012). *Persuasive wearable technology design for health and wellness*. Paper presented at the Pervasive Computing Technologies for Healthcare (PervasiveHealth), 2012 6th International Conference on, 236-240.
- Annis, L. F. (1983). The Processes and Effects of Peer Tutoring. *Human Learning: Journal of Practical Research & Applications, Vol 2(1)*, 39-47.
- Arnold, D. N. (2000). Computer-Aided Instruction *Microsoft® Encarta® Online Encyclopedia*: © 1997-2000 Microsoft Corporation. All rights reserved.
- Azevedo, R., & Cromley, J. G. (2004). Does training on self-regulated learning facilitate students' learning with hypermedia? *Journal of Educational Psychology*, 96(3), 523-535.
- Bargh, J. A., & Schul, Y. (1980). On the Cognitive Benefits of Teaching. *Journal of Educational Psychology*, 72(5), 593-604.
- Biswas, G., Jeong, H., Kinnebrew, J. S., Sulcer, B., & Roscoe, R. (2010). Measuring Self-Regulated Learning Skills through Social Interactions in a Teachable Agent Environment. *Research and Practice in Technology Enhanced Learning*, 5(2), 123-152. doi:10.1142/S1793206810000839
- Biswas, G., & Leeawong, K. (2005). Learning by Teaching: A new agent paradigm for educational software. *Applied Artificial Intelligence*, 19, 363-392. doi:10.1080/08839510590910200
- Biswas, G., Schwartz, D., & Bransford, J. (2001). Technology Support for Complex Problem Solving: From SAD Environments to AI. In K. D. Forbus & P. J. Feltovich (Eds.), *Smart Machines in Education: The Coming Revolution in Education Technology*. Menlo, Park, CA AAAI/MIT Press.
- Blair, K., Schwartz, D. L., Biswas, G., & Leelawong, K. (2006). Pedagogical Agents for Learning by Teaching: Teachable Agents. *Educational Technology & Society, Special Issue on Pedagogical Agent*.
- Blandford, A. E. (1994). Teaching through collaborative problem solving. *Journal of Artificial Intelligence in Education*, 5(1), 51-84.

- Bless, H., Bohner, G., Schwarz, N., & Strack, F. (1990). Mood and Persuasion A Cognitive Response Analysis. *Personality and Social Psychology Bulletin*, 16(2), 331-345.
doi:10.1177/0146167290162013
- Boström, A.-K. (2003). Lifelong Learning, Intergenerational Learning, and Social Capital From theory to practice (pp. 117-122). Stockholm: Stockholm University.
- Boström, A.-K., Castellon, R. H., Gush, C., –Yeo, A. H., Klerq, J., Kort, N., . . . Veelken, L. (1999). *Intergenerational Programmes: Public Policy and Research Implications an International Perspective*. Retrieved from <http://www.unesco.org/education/uie/pdf/intergen.pdf>
- Boström, A.-K., Hatton-Yeo, A., & Ohsako, T. (2000). A general assessment of IP initiatives in the countries involved. In A. Hatton-Yeo & T. Ohsako (Eds.), *Intergenerational programmes. Public policy and research implications: An international perspective*. Hamburg: UNESCO Institute of Education and Stoke-on-Trent: The Beth Foundation.
- Brabazon, K., & Disch, R. (1997). *Intergenerational approaches in aging: implications for education, policy, and practice*. New York: Haworth Press.
- Bredeweg, B., Liem, J., Linnebank, F., Bühling, R., Wißner, M., Río, J., . . . Gómez Pérez, A. (2010). DynaLearn: Architecture and Approach for Investigating Conceptual System Knowledge Acquisition. In V. Aleven, J. Kay, & J. Mostow (Eds.), *Intelligent Tutoring Systems* (Vol. 6095, pp. 272-274): Springer Berlin Heidelberg.
- Cacioppo, J. T., & Petty, R. E. (1982). The Need for Cognition. *Journal of Personality and Social Psychology*, 42(1), 116-131.
- Cacioppo, J. T., & Petty, R. E. (1984). The Elaboration Likelihood Model of Persuasion. *Advances in Consumer Research*, 11(1), 673-675.
- Cacioppo, J. T., & Petty, R. E. (1989). Effects of Message Repetition on Argument Processing, Recall, and Persuasion. *Basic and Applied Social Psychology*, 10(1), 3-12.
- Cacioppo, J. T., Petty, R. E., Kao, C. F., & Rodriguez, R. (1986). Central and peripheral routes to persuasion: An individual difference perspective. *Journal of Personality and Social Psychology*, 51(5), 1032.
- Cacioppo, J. T., Petty, R. E., & Morris, K. J. (1983). Effects of Need for Cognition on Message Evaluation, Recall and Persuasion. *Journal of Personality and Social Psychology*, 45(4), 805-818.
- Cacioppo, J. T., Petty, R. E., & Sidera, J. A. (1982). The Effects of a Salient Self-Schema on the Evaluation od Proattitudinal Editorial: Top-Down Versus Bottom-Up Message Processing. *Journal of Experimental Social Psychology*, 18, 324-338.
- Cai, Y., Miao, C., Tan, A.-H., & Shen, Z. (2006). *Fuzzy cognitive goal net for interactive storytelling plot design*. Paper presented at the Proceedings of the 2006 ACM SIGCHI international conference on Advances in computer entertainment technology, 56.
- Carlson, R., Keiser, V., Matsuda, N., Koedinger, K. R., & Rosé, C. P. (2012). *Building a Conversational SimStudent*. Paper presented at the International Conference on Intelligent Tutoring Systems, Heidelberg, Berlin, 563-569.

- Cavazza, M., Smith, C., Charlton, D., Crook, N., Boye, J., Pulman, S., . . . Turunen, M. (2010). Persuasive dialogue based on a narrative theory: an ECA implementation *Persuasive Technology* (pp. 250-261): Springer.
- Chaiken, & Shelly. (1980). Heuristics Versus Systematic Information Processing and the Use of Source Versus Message Cues in Persuasion. *Journal of Personality and Social Psychology*, 39(5), 752-766.
- Chaiken, S., & Maheswaran, D. (1994). Heuristic processing can bias systematic processing: effects of source credibility, argument ambiguity, and task importance on attitude judgment. *Journal of Personality and Social Psychology*, 66(3), 460.
- Chan, T.-w., & Baskin, A. B. (1990). *Learning companion systems*. Ablex Publishing Corporation.
- Chase, C. C., Chin, D. B., Opezzo, M. A., & Schwartz, D. L. (2009). Teachable Agents and the Protégé Effect: Increasing the Effort Towards Learning. *J Sci Educ Technol*, 18, 334–352.
- Chen, S., Duckworth, K., & Chaiken, S. (1999). Motivative Heuristic and Systematic Processing. *Psychological Inquiry*, 10(1), 44-49.
- Chi, M. T. H., Siler, S. A., Jeong, H., Yamauchi, T., & Hausmann, R. G. (2001). Learning from human tutoring. *Cognitive Science*, 25, 471-533.
- Cole, M. (1996). *Cultural Psychology: A Once and Future Discipline* Cambridge, Mass.: Harvard University Press, Belknap Press.
- Coleman, E. B., Brown, A. L., & Rivkin, I. D. (1997). The effect of instructional explanations on learning from scientific texts. *The Journal of the Learning Sciences*, 6(4), 347-365.
- Committee on Ageing Issues Report on the Ageing Population. (2006). Retrieved from Singapore: <http://app1.mcys.gov.sg/Publications/ReportoftheCommitteeonAgeingIssuesP2006.aspx>
- Cooper, B., Brna, P., & Martins, A. (2000). Effective Affective in Intelligent Systems – Building on Evidence of Empathy in Teaching and Learning Affective Interactions. In A. Paiva (Ed.), (Vol. 1814, pp. 21-34): Springer Berlin / Heidelberg.
- Craig, S. D., Sullins, J., Witherspoon, A., & Gholson, B. (2006). The Deep-Level-Reasoning-Question Effect: The Role of Dialogue and Deep-Level-Reasoning Questions During Vicarious Learning. *Cognition and Instruction*, 24(4), 565-591. doi:10.1207/s1532690xci2404_4
- Davis, L., Larkin, E., & Graves, S. (2002). Intergenerational learning through play. *International Journal of Early Childhood*, 34(2), 42-49. doi:10.1007/BF03176766
- Dickerson, J. A., & Kosko, B. (1993). *Virtual worlds as fuzzy cognitive maps*. Paper presented at the Virtual Reality Annual International Symposium, 1993., 1993 IEEE, 471-477.
- Duke, M. (2012). 'Citizen Science'. *DCC Briefing Papers*. Retrieved from <http://www.dcc.ac.uk/resources/briefing-papers>
- Fischer, G. (2001). User Modeling in Human–Computer Interaction. *User Modeling and User-Adapted Interaction*, 11(1-2), 65-86. doi:10.1023/a:1011145532042
- Fishbein, M., & Ajzen, I. (1975). *Belief, Attitude, Intention and Behavior: An Introduction to Theory and Research*. Addison-Wesley Publishing Company.
- Fogg, B. J. (1999). Persuasive Technologies. *Commun. ACM*, 42(5), 26-29. doi:10.1145/301353.301396

- Fozard, J. L. (2005). *Impacts of Technology Interventions on Health and Self-Esteem*.
- Fozard, J. L., & Kearns, W. D. (2006). Persuasive GERONtechnology: reaping technology's coaching benefits at older age *Persuasive Technology* (pp. 199-202): Springer.
- Fumiaki, O., Hiroshi, S., & Hidekazu, Y. (2000). Construction and Evaluation of a CAI System Based on "Learning by Teaching" to Virtual Student. *Transactions of Information Processing Society of Japan*, 41(12), 3386-3393.
- Gartner, A. (1971). *Children Teach Children: Learning by Teaching*. New York: Harper & Row.
- Gass, R. H., & Seither, J. S. (2010). *Persuasion, social influence, and compliance gaining (4th Edition)*. Boston: Allyn & Bacon.
- Gonyea, J. G. (1999). Weaving the Social Fabric of Community: Intergenerational Initiatives. *The Gerontologist*, 39(2), 245-247. doi:10.1093/geront/39.2.245
- Graesser, A. C., & Person, N. K. (1994). Question asking during tutoring. *American educational research journal*, 31(1), 104-137.
- Gram-Hansen, S. B., Schärfe, H., & Dinesen, J. V. (2012). Plotting to Persuade—Exploring the Theoretical Cross Field between Persuasion and Learning *Persuasive Technology. Design for Health and Safety* (pp. 262-267): Springer.
- Greenberg, S. (2001). Context as a dynamic construct. *Hum.-Comput. Interact.*, 16(2), 257-268. doi:10.1207/s15327051hci16234_09
- Groenewald, T. (2004). A phenomenological research design illustrated. *International Journal of Qualitative Methods*.
- Groumpos, P. (2010). Fuzzy Cognitive Maps: Basic Theories and Their Application to Complex Systems. In M. Glykas (Ed.), *Fuzzy Cognitive Maps* (Vol. 247, pp. 1-22): Springer Berlin Heidelberg.
- Gulz, A., Haake, M., Silvervarg, A., Sjöden, B., & Veletsianos, G. (2011). Building a Social Conversational Pedagogical Agent: Design Challenges and Methodological approaches. In D. a. P.-N. Perez-Marin (Ed.), *Conversational Agents and Natural Language Interaction Techniques and Effective Practices IGI Global*: IGI Global.
- Gulz, A., Silvervarg, A., Sjo, x, de, & n, B. (2010, 5-7 July 2010). *Design for Off-task Interaction - Rethinking Pedagogy in Technology Enhanced Learning*. Paper presented at the 2010 IEEE 10th International Conference on Advanced Learning Technologies (ICALT), 204-206. doi:10.1109/icalt.2010.63
- Han, Y., Zhiqi, S., & Chunyan, M. (2007, 2-5 Nov. 2007). *Intelligent Software Agent Design Tool Using Goal Net Methodology*. Paper presented at the 2007. IAT '07. IEEE/WIC/ACM International Conference on Intelligent Agent Technology, 43-46. doi:10.1109/IAT.2007.25
- Herber, E. (2011). Persuasive Learning Design *Wissensgemeinschaften Fachtagung (DeFI) 2011, Dresden*.
- Hietala, P., & Niemirepo, T. (1998). The Competence of Learning Companion Agents. *International Journal of Artificial Intelligence in Education*, 9, 178-192.

- Hirschman, L., & Gaizauskas, R. (2001). Natural language question answering: the view from here. *Natural Language Engineering*, 7(04), 275-300.
- ICT For Seniors' And Intergenerational Learning - Projects funded through the Lifelong Learning Programme from 2008 to 2011. (2012). Retrieved from http://eacea.ec.europa.eu/llp/results_projects/documents/publi/ict_intergenerational_learning.pdf
- . Intergenerational Learning. (2012). In N. Seel (Ed.), *Encyclopedia of the Sciences of Learning* (pp. 1627-1627): Springer US.
- Intergenerational Learning Programme (2011). Retrieved from http://family-central.sg/learning_programme.html
- Intergenerational Learning Programme (ILP). (2011). Retrieved from <http://www.c3a.org.sg/ilp>
- Johnson, B. T., & Eagly, A. H. (1989). Effects of Involvement on Persuasion: A Meta-Analysis. *Psychological Bulletin*, 106(2), 290-314.
- Kaplan, M., Kusano, A., Tsuji, I., & Hisamichi, S. (1998). Intergenerational programs support for children, youth, and elders in Japan. 58(01), 200-202.
- Kaplan, M. S. (2002). International Programs in Schools: Considerations of Form and Function. *International Review of Education*, 48(5), 305-334. doi:10.1023/A:1021231713392
- Kapoor, A., Mota, S., & Picard, R. W. (2001). Towards a Learning Companion that Recognizes Affect. *AAAI Technical Report FS-01-02*.
- Kern, D., Stringer, M., Fitzpatrick, G., & Schmidt, A. (2006, 26-28 June 2006). *Curball--A Prototype Tangible Game for Inter-Generational Play*. Paper presented at the 15th IEEE International Workshops on Enabling Technologies: Infrastructure for Collaborative Enterprises (WETICE'06), 412-418. doi:10.1109/WETICE.2006.27
- Khoo, E., Cheok, A., Nguyen, T., & Pan, Z. (2008). Age invaders: social and physical inter-generational mixed reality family entertainment. *Virtual Reality*, 12(1), 3-16. doi:10.1007/s10055-008-0083-0
- Kim, Y., & Baylor, A. (2006). A Social-Cognitive Framework for Pedagogical Agents as Learning Companions. *Educational Technology Research and Development*, 54(6), 569-596. doi:10.1007/s11423-006-0637-3
- King, P., & Tester, J. (1999). The landscape of persuasive technologies. *Commun. ACM*, 42(5), 31-38. doi:10.1145/301353.301398
- Kolp, M., Giorgini, P., & Mylopoulos, J. (2001). *A goal-based organizational perspective on multi-agent architectures*. Paper presented at the International Workshop on Agent Theories, Architectures, and Languages, 128-140.
- Kosko, B. (1986). Fuzzy cognitive maps. *International journal of man-machine studies*, 24(1), 65-75.
- Lee, K. C., & Kim, H. S. (1997). A Fuzzy Cognitive Map-Based Bi-Directional Inference Mechanism: An Application to Stock Investment Analysis. *Intelligent Systems in Accounting, Finance and Management*, 6(1), 41-57.

- Leelawong, K., & Biswas, G. (2008). Designing Learning by Teaching Agents: The Betty's Brain System. *Int. J. Artif. Intell. Ed.*, 18(3), 181-208.
- Lester, S. (1999). An introduction to phenomenological research *Stan Lester Developments* (pp. 1-4). Tauton UK.
- Lim, S. F., Ailiya, Miao, C., & Shen, Z. (2013). *The Design of Persuasive Teachable Agent*. Paper presented at the Proceedings of the 2013 IEEE 13th International Conference on Advanced Learning Technologies, 382-384. doi:10.1109/icalt.2013.117
- Lim, S. F., Ailiya, Miao, C., & Shen, Z. (2014). *Persuasive Teachable Agent with Goal Net*. Paper presented at the Proceedings of the 2014 IEEE 14th International Conference on Advanced Learning Technologies, 461-463. doi:10.1109/icalt.2014.235
- Liu, Z., & Liu, L. (2002). *An agent and goal-oriented approach for virtual enterprise modelling: A case study*. Paper presented at the International Workshop on Engineering Societies in the Agents World, 270-283.
- Logan, B., & Healey, J. (2006, Aug. 30 2006-Sept. 3 2006). *Sensors to Detect the Activities of Daily Living*. Paper presented at the Engineering in Medicine and Biology Society, 2006. EMBS '06. 28th Annual International Conference of the IEEE, 5362-5365. doi:10.1109/IEMBS.2006.260649
- Lublin, J. (1990). Peer Tutoring: A Guide to Learning by Teaching by S. Goodlad; B. Hirst Review by: Jacqueline Lublin. *International Review of Education / Internationale Zeitschrift für Erziehungswissenschaft / Revue Internationale de l'Education*, 36(4), 499-500.
- Lucero, A., Zuloaga, R., Mota, S., & Muñoz, F. (2006). Persuasive Technologies in Education: Improving Motivation to Read and Write for Children. In W. Ijsselstein, Y. W. de Kort, C. Midden, B. Eggen, & E. van den Hoven (Eds.), *Persuasive Technology* (Vol. 3962, pp. 142-153): Springer Berlin Heidelberg.
- Lundell, J., Kimel, J., Dishongh, T., Hayes, T., Pavel, M., & Kaye, J. (2006). *Why elders forget to take their meds: A probe study to inform a smart reminding system*. Paper presented at the 4th International Conference on Smart Homes and Health Telematics-ICOST2006, 98-105.
- Mann, B. L. (2008). *Computer-Aided Instruction*. doi:DOI: 10.1002/9780470050118.ecse935: John Wiley & Sons, Inc.
- Matsuda, N., Cohen, W. W., Sewall, J., Lacerda, G., & Koedinger, K. R. (2007). *Evaluating a Simulated Student using Real Students Data for Training and Testing*. Paper presented at the International Conference on User Modeling, Corfu, Greece, 107-116.
- Matsuda, N., Keiser, V., Raizada, R., Stylianides, G., Cohen, W., & Koedinger, K. (2010). Learning by Teaching SimStudent-An Initial Classroom Baseline Study with Cognitive tutor.
- Matsuda, N., Keiser, V., Raizada, R., Tu, A., Stylianides, G., Cohen, W. W., & Koedinger, K. R. (2010). *Learning by Teaching SimStudent: Technical Accomplishments and an Initial Use with Students*. Paper presented at the International Conference on Artificial Intelligence in Education, 213-221.
- McNall, S. G. (1975). Peer Teaching: A Description and Evaluation. *Teaching Sociology*, 2(2), 133-146.

- Mintz, J., & Aagaard, M. (2012). The application of persuasive technology to educational settings. *Educational Technology Research and Development*, 60(3), 483-499. doi:10.1007/s11423-012-9232-y
- Muldner, K., Giroto, V., Lozano, C., Burleson, W., & Walker, E. (2014). *The Impact of a Social Robot's Attributions for Success and Failure in a Teachable Agent Framework*. Paper presented at the International Conference of the Learning Sciences, Boulder, Colorado, USA, 278-285.
- Muldner, K., Lozano, C., Giroto, V., Burleson, W., & Walker, E. (2013). Designing a Tangible Learning Environment with a Teachable Agent. In H. C. Lane, K. Yacef, J. Mostow, & P. Pavlik (Eds.), *Artificial Intelligence in Education* (Vol. 7926, pp. 299-308): Springer Berlin Heidelberg.
- Newman, S., & Hatton-Yeo, A. (2008). Intergenerational learning and the contributions of older people. *Ageing horizons*, 8, 31-39.
- Newman, S., Ward, C. R., Smith, T. B., Wilson, J. O., McCrea, J. M., Calhoun, G., & Kingson, E. (1997). *Intergenerational Programs: Past, Present And Future*. Bristol, PA: Taylor & Francis.
- Nichols, D. M. (1993). *Intelligent Student Systems: an Application of Viewpoints to Intelligent Learning Environments*. Lancaster University.
- Nichols, D. M. (1994). *Issues in Designing Learning by Teaching Systems*. Paper presented at the Proceedings of the East-West International Conference on Computer Technologies in Education (EW-ED'94), Crimea, Ukraine.
- Novak, J. D. (1990). Concept mapping: A useful tool for science education. *Journal of Research in Science Teaching*, 27(10), 937-949. doi:10.1002/tea.3660271003
- O'Keefe, D. J. (2002). *Persuasion Theory and Research* (Second Edition ed.). SAGE Publications, Inc
- Ogan, A., Finkelstein, S., Mayfield, E., D'Adamo, C., Matsuda, N., & Cassell, J. (2012, May 5-10). *Oh, dear Stacy!'' Social interaction, elaboration, and learning with teachable agents*. Paper presented at the CHI 2012, Austin, TX, USA, 39-48.
- Oinas-Kukkonen, H., & Harjumaa, M. (2008). A systematic framework for designing and evaluating persuasive systems *Persuasive Technology* (pp. 164-176): Springer.
- Oinas-Kukkonen, H., & Harjumaa, M. (2008, 10-15 Feb. 2008). *Towards Deeper Understanding of Persuasion in Software and Information Systems*. Paper presented at the Advances in Computer-Human Interaction, 2008 First International Conference on, 200-205. doi:10.1109/achi.2008.31
- Oinas-Kukkonen, H., & Harjumaa, M. (2009). Persuasive systems design: Key issues, process model, and system features. *Communications of the Association for Information Systems*, 24(1), 28.
- Ortony, A., Clore, G. L., & Collins, A. (1990). *The Cognitive Structure of Emotions*. Cambridge University Press.
- Özesmi, U., & Özesmi, S. L. (2004). Ecological models based on people's knowledge: a multi-step fuzzy cognitive mapping approach. *Ecological Modelling*, 176(1), 43-64.

- Pareto, L., Arvemo, T., Dahl, Y., Haake, M., & Gulz, A. (2011). *A teachable-agent arithmetic game's effects on mathematics understanding, attitude and self-efficacy*. Paper presented at the Proceedings of the 15th international conference on Artificial intelligence in education, Auckland, New Zealand, 247-255.
- Pareto, L., Haake, M., Lindström, P., Sjöden, B., & Gulz, A. (2012). A teachable-agent-based game affording collaboration and competition: evaluating math comprehension and motivation. *Educational Technology Research and Development*, 60(5), 723-751. doi:10.1007/s11423-012-9246-5
- Petty, R. E., & Cacioppo, J. T. (1981). Personal Involvement as a Determinant of Argument-Based Persuasion. *Journal of Personality and Social Psychology*, 41(5), 847-855.
- Petty, R. E., & Cacioppo, J. T. (1984). The Effects of Involvement on Responses to Argument Quantity and Quality: Central and Peripheral Routes to Persuasion. *Journal of Personality and Social Psychology*, 46(1), 69-81.
- Petty, R. E., & Cacioppo, J. T. (1986). The Elaboration Likelihood Model of Persuasion. *Advances in Experimental Social Psychology*, 19, 123-205.
- Petty, R. E., Cacioppo, J. T., & Goldman, R. (1981). Personal involvement as a determinant of argument-based persuasion. *Journal of Personality and Social Psychology*, 41(5), 847.
- Petty, R. E., Cacioppo, J. T., & Schumann, D. (1983). Central and peripheral routes to advertising effectiveness: The moderating role of involvement. *Journal of Consumer Research*, 135-146.
- Petty, R. E., Cacioppo, J. T., Sedikides, C., & Strathman, A. J. (1988). Affect and Persuasion *American Behavioral Scientist*, 31(3), 355-369.
- Petty, R. E., Harkins, S. G., & Williams, K. D. (1980). The effects of group diffusion of cognitive effort on attitudes: An information-processing view. *Journal of Personality and Social Psychology*, 38(1), 81.
- Picard, R. W. (1997). *Affective Computing*. MIT Press.
- Pinzon, O. E., & Iyengar, M. S. (2012). Persuasive Technology And Mobile Health: A Systematic Review. *Persuasive Technology*, 45.
- Prager, J., Chu-Carroll, J., Brown, E. W., & Czuba, K. (2006). Question answering by predictive annotation *Advances in Open Domain Question Answering* (pp. 307-347): Springer.
- Prensky, M. (2001). Digital Natives, Digital Immigrants. *On the Horizon*, 9(5).
- Rabiner, L. R., & Juang, B. H. (1986). An Introduction to Hidden Markov Models. *IEEE ASSP MAGAZINE*, 4-16.
- Rice, M., Yau, L. J., Ong, J., Wan, M., & Ng, J. (2012). *Intergenerational gameplay: evaluating social interaction between younger and older players*. Paper presented at the Proceedings of the 2012 ACM annual conference extended abstracts on Human Factors in Computing Systems Extended Abstracts, Austin, Texas, USA, 2333-2338. doi:10.1145/2223656.2223798
- Roscoe, R. D., Wagster, J., & Biswas, G. (2008). *Using teachable agent feedback to support effective learning-by-teaching*. Paper presented at the 30th Annual Meeting of the Cognitive Science Society Washington, DC.

- Russell, S. J., & Norvig, P. (2009). *Artificial Intelligence: A Modern Approach* (3rd ed.). Pearson Education.
- Schwarz, N., Bless, H., & Bohner, G. (1991). Mood and persuasion: affective states influence the processing of persuasive communications. *Advances in Experimental Social Psychology*, 24, 161 - 199.
- Segedy, J. R., Kinnebrew, J. S., & Biswas, G. (2011). *Investigating the relationship between dialogue responsiveness and learning in a teachable agent environment*. Paper presented at the Proceedings of the 15th international conference on Artificial intelligence in education, Auckland, New Zealand, 547-549.
- Segedy, J. R., Kinnebrew, J. S., & Biswas, G. (2012). *Supporting Student Learning using Conversational Agents in a Teachable Agent Environment*. Paper presented at the Proceedings of the 10th International Conference of the Learning Sciences, Sydney, Australia.
- Self, J. (1990). Bypassing the Intractable Problem of Student Modelling *Intelligent Tutoring Systems: at the Crossroads of Artificial Intelligence and Education* (Vol. AAI/AI-ED Technical Report No.41, pp. 107-123). Norwood, N.J.: Ablex.
- Shen, Z., Li, D., Miao, C., Gay, R., & Miao, Y. (2005). *Goal-oriented Methodology for Agent System Development*. Paper presented at the Proceedings of the IEEE/WIC/ACM International Conference on Intelligent Agent Technology, 95-101. doi:10.1109/iat.2005.80
- Shen, Z., Miao, C., Tao, X., & Gay, R. (2004, 20-24 Sept. 2004). *Goal oriented modeling for intelligent software agents*. Paper presented at the Intelligent Agent Technology, 2004. (IAT 2004). Proceedings. IEEE/WIC/ACM International Conference on, 540-543. doi:10.1109/IAT.2004.1343014
- Simons, H. W. (2001). *Persuasion in society*. Sage Publications, Incorporated.
- Siyahhan, S., Barab, S. A., & Downton, M. P. (2010). Using activity theory to understand intergenerational play: The case of Family Quest. *International Journal of Computer-Supported Collaborative Learning*, 5(4), 415-432.
- Sjödén, B., Silvervag, A., Veletsianos, G., Haake, M., & Gulz, A. (2011). *Extending an educational math game with a pedagogical conversational agent: Challenges and design decisions*. Paper presented at the ITEC 2010, 116–130.
- Sjödén, B., Tärning, B., Pareto, L., & Gulz, A. (2011). Transferring Teaching to Testing – An Unexplored Aspect of Teachable Agents. In G. Biswas, S. Bull, J. Kay, & A. Mitrovic (Eds.), *Artificial Intelligence in Education* (Vol. 6738, pp. 337-344): Springer Berlin Heidelberg.
- Stylios, C. D., Georgopoulos, V. C., Malandraki, G. A., & Chouliara, S. (2008). Fuzzy cognitive map architectures for medical decision support systems. *Applied Soft Computing*, 8(3), 1243-1251.
- Taber, R. (1991). Knowledge processing with fuzzy cognitive maps. *Expert Systems with Applications*, 2(1), 83-87.
- Tan, J., & Biswas, G. (2006). *The role of feedback in preparation for future learning: a case study in learning by teaching environments*. Paper presented at the Proceedings of the 8th international

- conference on Intelligent Tutoring Systems, Jhongli, Taiwan, 370-381.
doi:10.1007/11774303_37
- Torning, K., & Oinas-Kukkonen, H. (2009). *Persuasive system design: state of the art and future directions*. Paper presented at the Proceedings of the 4th International Conference on Persuasive Technology, Claremont, California, 1-8. doi:10.1145/1541948.1541989
- Tuijnman, A., & Boström, A.-K. (2002). Changing Notions of Lifelong Education and Lifelong Learning. *International Review of Education*, 48(1-2), 93-110. doi:10.1023/A:1015601909731
- Uresti, J. R. (2000). Should I Teach My Computer Peer? Some Issues in Teaching a Learning Companion. In G. Gauthier, C. Frasson, & K. VanLehn (Eds.), *Intelligent Tutoring Systems* (Vol. 1839, pp. 103-112): Springer Berlin Heidelberg.
- Veletsianos, G., Miller, C., & Doering, A. (2009). EnALI: A Research and Design Framework for Virtual Characters and Pedagogical Agents *Journal of Educational Computing Research*, 41(2), 171-194.
- Webb, G. I., Pazzani, M. J., & Billsus, D. (2001). Machine learning for user modeling. *User Modeling and User-Adapted Interaction*, 11(1-2), 19-29.
- Wiafe, I., Alhammad, M., Nakata, K., & Gulliver, S. (2012). Analyzing the Persuasion Context of the Persuasive Systems Design Model with the 3D-RAB Model. In M. Bang & E. Ragnemalm (Eds.), *Persuasive Technology. Design for Health and Safety* (Vol. 7284, pp. 193-202): Springer Berlin Heidelberg.
- Wood, W. (1982). Retrieval of Attitude-Relevant Information From Memory: Effects on Susceptibility to Persuasion and on Intrinsic Motivation. *Journal of Personality and Social Psychology*, 42(5), 798-810.
- Wu, L., & Looi, C.-K. (2008). Use of Agent Prompts to Support Reflective Interaction in a Learning-by-Teaching Environment. *Proceedings of the 9th International Conference on Intelligent Tutoring Systems*, 302-311.
- Yu, H., Miao, C., Tao, X., Shen, Z., Cai, Y., Li, B., & Miao, Y. (2009). *Teachable Agents in Virtual Learning Environments: a Case Study*. Paper presented at the World Conference on E-Learning in Corporate, Government, Healthcare, and Higher Education, 1088-1096.
- Zeng, Z. (2015). *Persuasive Teachable Agent in Pedagogical Game*. (Degree of Bachelor in Computer Science), Nanyang Technological University, Singapore.
- Zimmerman, B. J. (1990). Self-Regulated Learning and Academic Achievement: An Overview. *Educational Psychologist*, 25(1), 3-17.

Appendix A – Case Study

Virtual Singapura

Virtual Singapura (VS) is a 3D virtual learning environment (VLE) developed to help students from lower secondary level understand concepts of science topics. Students gain inquiry skills by completing learning tasks through interaction with teachable agents in the VLE. The teachable agent in VS requires students to teach the teachable agent by completing a concept map to simulate the learning-by-teaching process. The students are evaluated based on how well their teachable agents are taught. Figure A-1 is a screenshot of the mini game in VS project.

Figure A-1 Screenshot of the mini game in VS project.

During the field study conducted in multiple lower secondary schools in Singapore, it was observed that student's learning experiences had been satisfactory (Yu et al., 2009). The students enjoyed the ability to fly, float and walk on water, actions which were only possible in the immersive virtual environment. Students also enjoyed participating in mini-games shown such as the "shooting game", where they were required to generate "food" with other team players collaboratively by combining carbon dioxide molecules with water molecules as shown in Figure A-1.

Figure A-2 Screenshot of the student avatar flying

Based on the qualitative data collection during the field study, it was observed that most of the activities that the students enjoyed were not related to learning with the teachable agent. For example students prefer to chat with one another on the messaging platform or explore the “flying” feature in the 3-D environment shown in Figure A-2. Figure A-3 shows some examples of some of the learning activities that the students should be engaging in. The activities include conducting experiments in the “virtual laboratory” or learning new knowledge in the “knowledge farm”.

Figure A-3 Screenshot of the learning activities.

The VS case study has prompted us to improve the existing teachable agent so that students will find interacting with teachable agents more engaging. So as to keep them interested in teaching the teachable agent. Therefore, an improved version VS Saga is developed with the PTA implemented.

Appendix B – Implementation of PTA in Virtual Singapura

In this section, the implementation of the PTA in a 3D game engine will be described in detail. Firstly, the Unity 3D game engine in which the PTA is deployed will be introduced, followed by a walk-through of the Virtual Singapura (VS) Saga storyline. The walk-through of VS will serve as a guide on how the PTA will be used by the user to simulate learning-by-teaching with the PTA.

Developing VS Saga using Unity 3D Game Engine

The VS Saga is developed in the Unity 3D game engine, which is easy to use, multi-platform game engine. This allows for applications to be created for mobile devices, PC, consoles and websites. The PTA is implemented in the Unity 3D game engine using the PTA model and system architecture.

Virtual Singapura (VS) Saga Storyline

The VS Saga 3D virtual learning environment (VLE) is developed for lower secondary level science learning. Figure B-1 shows the screenshot of the main navigation interface of the VS saga.

Figure B- 1 Main navigation in VS Saga

Unlike the previous version of VS, the VS Saga is a three part learning journey that follows the storyline of the avatar of the player who is the user helping the town dwellers on an island by completing a series of missions. Through the completion of these missions, the user will be able to learn science concepts. Towards the end of the mission, they will be able to teach the PTA that is embodied by a water molecule. Having taught the water molecule PTA, the water molecule will be able to travel to a sick banana plant, thus saving it from dying.

The VS Saga consists of a three-part storyline, namely, the knowledge town, the science laboratory and the tree scenes. Details on each part of the storyline will be introduced in the following section.

Knowledge Town

The knowledge town is where the user takes on the role as the player avatar that has just landed on the island, as shown in Figure B-2.

Figure B-2 Knowledge town in VS Saga

The user will meet the water molecule PTA which then informs him or her of the need to learn more about science topics such as osmosis and diffusion by visiting exploring the island to meet other non-player characters (NPC)s. In the process of talking to different characters, the user will be able to pick up information on the

transportation of water molecules within a plant. Throughout the knowledge town, there are also NPCs that are not related to learning. These NPCs are intentionally included in the scene to distract the user from their learning. Table B-1 shows the sequence of storyline and interaction between the user avatar and the NPCs.

The objective of the PTA is to encourage the user to stay on their learning tasks and complete their mission by talking to NPCs regarding information related to their learning mission. In order to achieve to this, the PTA will have to go through its *Persuasive Reasoning* to understand the user's motivation and ability, thus allowing it to apply appropriate persuasion cues. The persuasion cues given by the PTA are aimed at influencing the user's decision to stay on track in completing their learning mission.

Table B-1 Screenshot, related storyline and non-player characters in knowledge town

Screenshot	Storyline and Non-Player Characters
<ol style="list-style-type: none"> Meeting the Water Molecule PTA. <ul style="list-style-type: none"> Water molecule welcomes user. Water molecule introduces itself and the mission in the VS saga.
<ol style="list-style-type: none"> Talk to Madam Mah on the beach. <ul style="list-style-type: none"> Madam Mah welcomes the user. User accepts the mission to meet the Sharman near the giant durian.

3. Talk to the Sharman near the giant durian.
 - Learn the concept of diffusion from the Sharman.
 - User accepts the mission to get the perfume from Madam Sammy.
 - User refuses to learn the concept of diffusion.

4. Talk to Madam Sammy near the stilt houses on the beach.
 - Madam Sammy reminds the user to learn diffusion if not done so.
 - Receive the potion item.
 - User receives the new mission to deliver the potion to the mayor near the coconut tree.

5. Talk to the Mayor near the coconut tree.
 - Learn osmosis from the mayor
 - The mayor invites the user to the science laboratory to practice the science concepts that they have learnt.
 - User refuses to learn about osmosis.

6. Talk to animals on the island.

Animals are NPC scattered around the main island and serves as distracters.

Science Laboratory

After learning the related information from the NPCs in the knowledge town, the user proceeds to the science laboratory as shown in Figure B-3. The science laboratory allows the user to practice on the knowledge and information that the user has acquired in the knowledge town.

Figure B-3 Science laboratory in VS Saga

The user can interact with new NPCs at the science laboratory. There is also a diffuser where the user player can simulate the movement of the molecule particles during the osmosis and diffusion process through a series of experiments. This, in turn, helps the user to further retain their knowledge that they have learnt in the knowledge island scene. Table B-2 shows the sequence in which the user player avatar has to complete in this scene.

Table B-2 Screenshot, related storyline and non-player characters in science laboratory

Screenshot	Storyline and Non-Player Characters
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<ol style="list-style-type: none"> 1. Meeting the future teacher. <ul style="list-style-type: none"> • Learn to conduct simulation experiments. • User accepts the task to conduct experiments. • User refuses to conduct experiments.
<ol style="list-style-type: none"> 1. User proceeds to the “diffuser 5K” simulation tank. <ul style="list-style-type: none"> • User starts the experiment by clicking on the control panel.
<ol style="list-style-type: none"> 2. User conducts the diffusion simulation experiment.
<ol style="list-style-type: none"> 3. User conducts the osmosis simulation experiment. <ul style="list-style-type: none"> • Future teacher instructs the user to proceed to the next tree scene to teach the PTA.

<p>4. Talk to Village Girl.</p> <ul style="list-style-type: none"> Village characters such as the Village Girl in the Science Laboratory are distracters.
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Tree

The last scene of the VS saga is the tree as shown in the screenshot in Figure B-4. This is where the user teaches the water molecule PTA about the concepts of osmosis and diffusion.

Figure B-4 Save the banana plant mission in the tree scene

In this scene, user has to practice the knowledge he or she has learnt from the knowledge town and the science laboratory by teaching the PTA through a concept map. Table B-5 shows the screenshot, the related storyline and NPCs that interacts with the user in this scene.

Table B-3 Screenshot, related storyline and non-player characters in the tree scene

Screenshot	Storyline and Non-Player Characters
<ol style="list-style-type: none"> 1. User meets the sad PTA water molecule near a dying banana plant.
<ol style="list-style-type: none"> 2. User is asked to teach the PTA water molecule. <ul style="list-style-type: none"> • User agrees to teach the PTA water molecule by completing the concept map. • User declines to teach the PTA water molecule.
<ol style="list-style-type: none"> 3. The PTA reasons on the knowledge taught by the user. <ul style="list-style-type: none"> • The PTA water molecule enters the banana plant through the roots and the banana plant is revitalised • The PTA water molecule fails to enter the roots and ask the user to teach again.

PTA in VS Saga

The PTA has several controls that manage its task functionalities. In this section, the functionalities in the PTA Control, UI Control and Event Control will be discussed according to the context in VS saga.

PTA Control

Main Routine

When the Main Routine is executed, the PTA control activates the Event Control every 5 seconds so as to check for events. If one or more events are detected, the Main Routine decides on the events that are to be processed first in the current cycle and determines the reasoning cycle the events should go through.

Persuasion Reasoning

If the Persuasion Reasoning Sub-Goal Net is activated the FCM calculation will determine the ability and motivation based on the events in VS saga. The values will be compared with the pre-determined baseline values to evaluate if the motivation or the ability levels are low. If these values are lower than the baseline values persuasion cues will be activated and executed through the UI controls. This is when the PTA control calls on the UI control to display the persuasion cues in the VS saga.

Persuasion cues in VS saga include facial expressions showing affect or emotions in the PTA water molecule NPC as shown in Figure B-6.

Figure B-5 Facial expressions and emotion persuasion cues in PTA

As well as dialogue speech displays such as hints from expert source or advice from an attractive source that adheres to the ELM persuasion theory. An example of the PTA emotion and speech persuasion cue is shown in Figure B-7.

Figure B-6 PTA emotion and speech persuasion cue displayed

Teachability Reasoning

The teaching process starts when the PTA requests the user to teach itself through dialogue. Once the request has been accepted by the user, the PTA control will call the UI control to active the concept map, a graphical tool that helps students organise and visualise relationships between concepts in the knowledge of a subject. Figure B-8 shows the screenshot in which the PTA requests the user for teaching.

Figure B-7 PTA requesting user for teaching

The concept map will be displayed in the interface in VS saga, as shown in Figure B-9. The user is required to complete the concept map in order to teach the PTA. If the user rejects teaching the PTA, PTA control then generates a rejection event.

Figure B-8 Concept map that requires the user to complete

Practicability Reasoning

In the Practicability Reasoning Sub-Goal Net, the PTA reasons on the knowledge that the user has taught the PTA. This will determine whether the knowledge is correct. If the knowledge is correct, the PTA Control will generate an animation to show the “revival” of the dying banana plant, signifying that the PTA molecule has gained the information from the user to enter the roots of the banana plant to transport essential water for the plant’s survival. In the case where the knowledge taught is incorrect the PTA control will generate the events through the UI control to display a message to tell the user to repeat the teaching event.

UI Control

The UI control is a component that manages the displays of and user interface (UI) in the VS saga game. One example is the PTA panel that is an interface for the Persuasion Reasoning in the PTA to display persuasion cue. Whenever a persuasion cue is selected through Persuasion Reasoning, the PTA Control will activate the UI Control to display the information selected of the selected cue.

The concept map is where the user teaches the PTA. The user completes the teaching process by dragging the buttons selections on the left and dropping them in

the blank spaces in the concept map. When they click on the “Teach!” button, the contents of the blank spaces will be saved by the UI Control as knowledge learnt by the PTA and a new event will be created for the last example is the banana plant interface. If the user has successfully taught the PTA correctly, the UI Control changes the colour and rotation of the leaves to simulate an animated revival of the dying banana plant, as shown in Figure 3-25 upon the completion of the teaching process.

Figure B-9 Banana plant after the PTA has been taught by the user

Event Control

The Event Control in the VS saga is a supportive controller for events that support the PTA control. There are three types of events that the Event Control tracks in the VS saga, namely the Time Events, Dialogue Events and Teaching Feedback Events.

Dialogue Events

A dialogue event is created whenever there is a dialogue between the user and the NPCs. These dialogue events are created in the dialogue system in the Unity 3D game engine using the SequencerCommand script. Both user and the NPCs dialogues can be set up in the dialogue system. A new dialogue can be created and added to the event log with the event control.

Time Events

The Event Control tracks the duration in which the user is inactive in the Time Event. This is done with a timer that keeps track of the amount of time the user is not engaging in learning activities by interacting with the NPCs in the VS saga. If a dialogue event is detected, the timer will be reset. In the case of a time-out, a timed event will be generated which indicates that the user is inactive in the VS saga.

Teaching Feedback Events

The teaching feedback event provides feedback to the user's teaching. Two main events are tracked by the Event Control in VS Saga. Namely, the teach success event and the teach failure event.

Events Tracked in VS Saga

Various events are tracked in the VS saga. Table B-10 below is a list of events that are tracked in the VS saga. These events are used by the Event Control to generate responses in the PTA.

Table B-4 Events Tracked in VS Saga

Dialogue Events	
1. Not learning	9. Help Mayor NPC
2. Visiting science laboratory	10. Not teaching the water molecule
3. Learn diffusion	11. Teach the water molecule
4. Learn osmosis	12. Chat with animal NPC
5. Apply diffusion	13. Chat with village girl NPC
6. Apply osmosis	14. Teachability event
7. Not conducting experiments	
8. Willing to conduct experiment	
Time Events	
1. Doing nothing (Time-out)	
Teaching Events	
1. Teach success	
2. Teach Failure	

In addition to the events in the table above, the practicability event is also tracked. However, this does not belong to any of the categories in the Event Control, as the practicability event does not generate any dialogue in the VS saga.

Persuasive FCM in VS Saga

The events tracked in VS saga are categorised into the *leaf nodes* of the Persuasive FCM based on the ELM persuasion. Figure B-11 shows the complete FCM in the VS saga complete with events tracked. Note that only events that affect the motivation and ability are included in the *leaf nodes* of the Persuasive FCM.

Figure B-10 Complete FCM in VS saga

Appendix C – Post-Game Questionnaire

Intergenerational Learning with Persuasive Teachable Agent

Nanyang Technological University, School of Computer Engineering

Information and Consent

Thank you for taking the time to participate in this research study involving the use of a virtual environment to teach lower secondary science. The purpose of this study is to collect information on your opinion of intergenerational learning with a novel artificial intelligent agent which implements persuasion in order to stimulate interest. The results of this study will be used in the writing of a thesis for the fulfilment of the requirement for a degree of doctor in philosophy in computer engineering.

As a participant, you will be asked to test a version of an interactive virtual learning environment titled “Virtual Singapore” with a teammate. Following this, you will need to answer a short written questionnaire. Participation will take approximately 20 minutes for the interactive session and 15 minutes for the survey questionnaire.

There are no known or anticipated risks associated with the participation in this study.

Confidentially

Data collected during this study is intended to be used solely for research purpose. Access to this data will be restricted to only the main investigator of the research thesis and its reviewers.

All information you provide is considered confidential; your name will not be included or in any way associated with the data collected in the study. Furthermore, our interest is in the average responses of the entire group of participants rather than the individual. You will not be identified individually in any way in written reports of this research, and will instead be referred to by a number of the report (e.g. Participant 1). The results of this study will also be made available to participants upon request.

Voluntary Participation

Participation in this study is voluntary. If you wish, you may decline to answer any questions or participate in any component of the study. You may also decide to withdraw from this study at any time and may do so without any penalty or loss of benefits to which you are entitled.

Thank you for your time and assistance in this project. If you have any further questions, I can be contacted at sufang@ntu.edu.sg.

Consent Form

I agree to participate in the study described above. I have made this decision based on the information I have read in the sections shown above. I have had the opportunity to ask and receive any additional details I wish to know about the study. I understand that my participation is voluntary and that I may withdraw from the study at any time.

Name: _____

Signature: _____ Date: _____

A. Personal Background

Please pick a tick in the box next to the answer of choice.

1. Gender

☐ Female ☐ Male

2. Age

☐ 9 and below ☐ 10 – 15 ☐ 16 – 20 ☐ 21 – 29 ☐ 30 – 49

☐ 50 and above

3. Race

☐ Chinese ☐ Malay ☐ Indian ☐ Others

4. How far did you go in school?

☐ Primary ☐ Secondary ☐ Junior College/Pre-university ☐ Polytechnic

☐ University ☐ Postgraduate Studies

B. General Intergenerational Relationship Background

Please complete the following items to the best of your ability. Please read each of the statements and indicate (circle your response: 1-5).

5. What is your level of interest to spend your leisure time learning with a person that is younger or older than you?

Not at all Interested	A Little Interest	Neutral	Interested	Extremely Interested
1	2	3	4	5

6. On a scale 1-5 please rate the level of factors that affect your decision to spend time learning from someone older or younger than you.

	Does not Affect	Little Affect	Neutral	Somewhat Affect	Greatly Affect
Age difference	1	2	3	4	5
Experience interacting with someone from different age group	1	2	3	4	5
Lack of available time	1	2	3	4	5
Type of activities	1	2	3	4	5

7. What kind of activities would you be interested in participating in an intergenerational setting (i.e. interacting with someone older or younger than you)?

- ☐ Sports ☐ Field Trips ☐ Games (card, puzzles, board, etc.)
- ☐ Volunteer work ☐ Arts/Crafts activities ☐ Outdoor recreation
- ☐ Conversation/talking ☐ Passive recreation ☐ Cultural experiences (art exhibitions, museums, etc.)
(walking, watching TV, etc.)
- ☐ Others (Please specify: _____)

8. What would motivate you to learn more with some from a different age group (i.e. someone older or younger than you)?

C. Intergenerational Learning Experiences with Teachable Agent (water molecule)

The following are a number of statements regarding the type of skills that you have acquired during the interactive virtual learning. Please read each of the statements and indicate (circle your response from 1-5) to what extent you agree or disagree with each statement.

Social skills

9. I have actively listened to my teammate's advises and opinions during the session.

Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree
1	2	3	4	5

10. I worked together with my teammate to teach the teachable agent (water molecule).

Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree
1	2	3	4	5

11. I took turns with my teammate to teach the teachable agent (water molecule).

Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree
1	2	3	4	5

12. I am the one who encourages my teammate.

Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree
1	2	3	4	5

13. I have been staying on the tasks assigned to me during the session.

Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree
1	2	3	4	5

Problem-solving skills

14. I have learnt to solve problems that I had encountered in the game as a team.

Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree
1	2	3	4	5

People skills

15. I have learnt to trust and respect my teammate during the session.

Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree
1	2	3	4	5

16. I have more understanding towards my teammate after the session.

Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree
1	2	3	4	5

D. Knowledge, Values and Role in Virtual Learning

The following are a number of statements regarding the knowledge, values and role that you play during the interactive virtual learning. Please read each of the statements and indicate (circle your response from 1-5) to what extent you agree or disagree with each statement.

Knowledge

17. I have learnt new knowledge other than the information (e.g. osmosis and diffusion) in the session.

Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree
1	2	3	4	5

Values

18. Working together to teach the teachable agent (water molecule) with my teammate encourages me to think of others.

Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree
1	2	3	4	5

Role

19. I have taken the lead role in teaching the teachable agent (water molecule).

Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree
1	2	3	4	5

E. Opinion on Intergenerational Learning with the Teachable Agent (water molecule)

The following are a number of statements regarding your attitude during your interaction with the teammate and the teachable agent. Please read each of the statements and indicate (circle your response from 1-5) to what extent you agree or disagree with each statement.

Attitude

20. I was engaged in learning when co-teaching the teachable agent (water molecule).

Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree
1	2	3	4	5

Motivation

21. I was motivated to find out more information (e.g. osmosis and diffusion) during the interaction between my teammate and the teachable agent (water molecule).

Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree
1	2	3	4	5

Learning

22. I had learned more when co-teaching the teachable agent (water molecule) with a teammate than when I am learning alone.

Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree
1	2	3	4	5

F. Feelings towards the Teachable Agent (water molecule)

The following are a number of statements regarding your feelings towards the teachable agent. Please read each of the statements and indicate (circle your response from 1-5) to what extent you agree or disagree with each statement.

Feelings

23. I am confident that the teachable agent (water molecule) will do well.

Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree
1	2	3	4	5

24. I felt nervous about the interacting with the teachable agent (water molecule) during the session.

Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree
1	2	3	4	5

25. I have strong emotional feelings (happy, angry, sad etc.) towards the teachable agent (water molecule).

Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree
1	2	3	4	5

G. Perceptions towards the Teachable Agent (water molecule)

The following are a number of statements regarding your perceptions towards the teachable agent. Please read each of the statements and indicate (circle your response from 1-5) to what extent you agree or disagree with each statement.

26. I felt responsible for the teachable agent (water molecule).

Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree
1	2	3	4	5

27. The teachable agent (water molecule) responded as I had expected.

Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree
1	2	3	4	5

28. I am satisfied with the performance of the teachable agent (water molecule).

Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree
1	2	3	4	5

H. Improvements to Teachable Agent (water molecule)

29. Please tell us how the teachable agent (water molecule) can be improved to enhance your learning experience.

I. Teachable Agent (water molecule) for Intergenerational Learning in Virtual Environments

30. Do you feel that virtual environments such as Virtual Singapura (VS) can help in intergenerational bonding (i.e. closeness, connectedness and kinship ties among family members of over one or more generation)?

☐ Yes ☐ No

31. Do you feel that the teachable agent (water molecule) can help in intergenerational learning (i.e. learning from someone older or younger than you)?

☐ Yes ☐ No

J. Gaming Experience in Virtual Learning Environment

The following are a number of statements regarding your gaming experience in the Virtual Learning Environment. Please read each of the statements and indicate (circle your response from 1-5) to what extent you agree or disagree with each statement.

32. I enjoyed playing the game.

Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree
1	2	3	4	5

33. This game was fun to play.

Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree
1	2	3	4	5

34. I thought this was a boring game.

Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree
1	2	3	4	5

35. This game did not hold my attention at all.

Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree
1	2	3	4	5

36. I would describe this game as interesting.

Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree
1	2	3	4	5

37. I believe this game had some value to me.

Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree
1	2	3	4	5

38. This game is useful for me to learn science.

Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree
1	2	3	4	5

39. I think this game is important in helping me experience what is impossible in the real world.

Strongly	Disagree	Neutral	Agree	Strongly Agree
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Disagree				
1	2	3	4	5

40. I will be willing to this game again because it has some value to me.

Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree
1	2	3	4	5

41. I think by playing this game has helped me understand science topics.

Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree
1	2	3	4	5

42. I believe this game is beneficial to me.

Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree
1	2	3	4	5

43. This game is of importance to me.

Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree
1	2	3	4	5

K. Additional Comments

44. Please let us know any additional comments you may have regarding the system or the study.

Thank you for your participation.