Intelligent Pedagogical Agents in Immersive 3D Virtual Learning Environments

Dissertation in fulfillment of the requirements for the
Doctoral degree in Computer Science

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Intelligente Pädagogische Agenten in Immersiven Virtuellen 3D-Lernumgebungen

Dissertation zur Verleihung des akademischen Grades
Doktor in Informatik

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Abstract

Immersive virtual environments are promising to support new methods of learning. They offer 3D visualizations for remote online collaborations and contextualized learning opportunities to distant learners at their convenient times and pace. In utilization of immersive environments for learning, virtual worlds are found to be practical implementations that have already been used by different universities to support 3D virtual education. Rather, lack of interactive pedagogical support to scaffold learning activities and engage learners in those environments shows a gap in relation to wide possibilities of e-education innovations. This dissertation proposes filling the found gap through the use of *Intelligent Pedagogical Agents (IPAs).* Those agents resemble lifelike characters deployed in the environment to provide pedagogical functions with AI support. Being viewed as 24/7 available central points of interaction between the learner and the environment, equipping the IPAs with abilities to engage the learners and provide pedagogical support are desired. For that target, the dissertation provides literature reviews on IPAs, the immersive learning environment, and supporting AI methods. It presents a solution approach with a dedicated conceptual framework for IPA in immersive learning environments. The conceptual framework adopts pedagogical supporting models to facilitate the role of the pedagogical agent in the immersive learning environment and propose an intelligent immersive learning layer added to the environment.

The dissertation further presents a proof of concept of IPA scenarios in Open Wonderland virtual world environment to show IPA capabilities, learn from its implementation, and use it for evaluation. The proof of concept incorporates a multi-modal communication function, based on question answering through the Artificial Intelligence Markup language (AIML), text-to-speech synthesis, and gestures. A practical intelligent agent framework, with a Belief-Desire-Intention (BDI) model, is selected and integrated with the virtual world to support its decision making. The intelligent agent approach further facilitated abstraction and simulation of IPA interactions to isolate implementation challenges, and provide input to prototype implementations. With the proof of concept, the IPA engages the learner in various learning scenarios through approaching its proximity, conversations, tutorials, learner observation upon interaction with a 3D learning object, and providing supporting feedback.

The dissertation reports a qualitative evaluation study and experiment, performed by a team of six experts in relevant areas that include computer science, cognitive science, e-education, and virtual worlds. The experiment studied key proof of concept elements in relation to four learning scenarios with distributed control between the learner avatar and the IPA, to test hypotheses relevant to scenario effects on learning attributes such as motivation,

engagement, and the learning experience. The evaluation provided supporting feedback to the importance of the specific scenarios with emphasis on the IPA proximity, conversation, tutoring, and observation to increased learner engagement, motivation, guided instruction, and increased learning experience. The study showed support to key elements, such as preference for the conversation tool and importance for interaction with a pedagogical agent. Through the qualitative nature, and with open questions, the study also provided input for future improvements. That includes support for question making, further IPA feedback details, and perspectives for situations and application types that the IPA can further contribute to e-education with immersive environments.

Kurzfassung

Immersive virtuelle Umgebung sind eine vielversprechende Technologie, um innovative Lernmethoden zu unterstützen. Sie ermöglichen dreidimensionale Visualisierungen für räumlich entfernte Zusammenarbeit und bieten kontextbezogene Lernmöglichkeiten in Fernunterrichtsszenarien, wodurch Lernen zu selbst bestimmbaren Zeiten und Orten ermöglicht wird. Eine beliebte Möglichkeit immersive Umgebungen im Bereich Lernen einzusetzen ist die Verwendung von Virtuelle Welten. Diese werden bereits von verschiedenen Universitäten verwendet, um dreidimensionales virtuelles Lernen zu ermöglichen. Ein Mangel an interaktiver pädagogischer Unterstützung, um Lernaktivitäten zu fördern und Lernende in diesen Umgebungen zu motivieren, führt allerdings zu einem Defizit im Vergleich zu innovativen E-Education Technologien. In dieser Dissertation wird versucht diese Lücke mit der Hilfe von Intelligenten Pädagogischen Agenten (IPA) zu füllen. Diese Agenten simulieren naturgetreue Charaktere in der virtuellen Umgebung und bieten pädagogische Funktionen mittels KI-Unterstützung. Als ständiger Knotenpunkt von Interaktionen zwischen Lernen und der Umgebung ist es notwendig die IPA mit den Fähigkeiten auszustatten die Lernenden zu motivieren und pädagogisch zu unterstützen. In dieser Disseration werden daher Fachliteratur im Bereich IPA, immersiven Lernumgebungen und unterstützende KI-Methoden aufgearbeitet. Daraus wird ein Lösungsansatz mit einem konzeptionellen Framework für IPA in immersiven Lernumgebungen entwickelt. Dieses Framework adaptiert pädagogische Modelle, um die Rolle des pädagogischen Agenten in der immersiven Lernumgebung aufzuzeigen und stellt eine intelligenten, immersiven, pädagogische Schicht vor, welche der virtuellen Umgebung hinzugefügt wird.

In weiterer Folge wird in dieser Dissertation ein Prototyp eines IPA in der Virtuellen Welten Umgebung Open Wonderland vorgestellt. Die Zielsetzung dieses Prototypen ist das Potenzial von IPA in einem Proof of Concept aufzuzeigen, von der Implementierung erste Ergebnisse abzuleiten und diesen für erste Evaluierungen heranzunehmen. Der Prototyp vereint eine multimodale Kommunikationsfunktion, welche aus einem Fragenbeantwortungssystems mittels der Artificial Intelligence Markup Language (AIML), Text-To-Speach Systemen und Gesten besteht. Ein praktisches Intelligente Agenten-Framework, mit einem Belief-Desire-Intention (BDI)-Modell wurde gewählt, um Entscheidungsprozesse in die Virtuelle Welt zu integrieren.

Der Intelligente Agenten-Ansatz vereinfacht die Abstraktion und Simulation von IPA-Interaktionen um die Implementierungsherausforderungen zu isolieren und gibt Feedback zur Implementierung des Prototypen. Im Prototypen unterstützt der IPA die Lernenden in verschiedenen Lernszenarien mitteln Konversationen, Tutorials, Observierung von Lernenden und Interaktionen mit 3D-Objekten, und anschließendem Feedback.

Die Studien werden mit der Beurteilung und Evaluierungselementen der Lernszenarien basierend auf dem entwickelten Prototypen vervollständigt. Eine qualitative Evaluierung, durchgeführt mit einer Gruppe von Experten, zeigt wie die Elemente des Prototypen und die entwickelten Lernszenarien zu einem verbesserten Lernerlebnis beitragen. Ins Besonderem können erhöhte Motivation und Engagement der Lernenden und ein verbessertes Lernerlebnis aufgezeigt werden.

STATUTORY DECLARATION

I declare that I have authored this thesis independently, that I have not used other than the declared sources / resources and that I have explicitly marked all material which has been quoted either literally or by content from the used sources.

…………………………… ………………………………………………..
Date (Signature)

Acknowledgment

I would like to thank all who have helped me in completing this dissertation. First, I would like to thank my advisor, Dr. Christian Gütl for dedicating his time and efforts to support completing the dissertation. I am very thankful for his patience and caliber and for the skills I acquired throughout the PhD program. I am thankful to the second reader, Dr. Vanessa Chang for the time and effort to read the dissertation.

I would like to thank the IICM team in Graz University of Technology and the AEMT research group for their help, support, and the nice atmosphere and environment I enjoyed throughout the program. I would like to thank Fr. Maria-Luise Lampl for the continuous help throughout the different stages of the program and providing administrative support. I would like to thank the expert group at Graz University of Technology who participated in a study experiment, and for providing feedback and valuable opinions. I would like to thank the MIT / TealSim team for providing such a module and for the opportunity to experience it.

I would like to thank my parents for supporting me and guiding me throughout my entire life; and special gratitude to Dr. Salama Soliman for his continuous encouragement and support for learning advancement.

Finally, I have special thanks and appreciation to all those who promote education and support learning with their background, skills, and research caliber to create new learning opportunities for everyone.

Mohamed Salama Soliman

Graz, Austria, April 2014

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1. Introduction

The research problem of intelligent pedagogical agents in immersive learning environments can appear to be either easy or challenging. But it can be thought as interesting work to contribute to with what can be possible by avoiding the obstacles and target to improve technology support for education. This Chapter discusses the motivation for this problem, the goals and research questions, and methodology and structure. Motivation for the research problem is discussed in Section 1.1. The goals and specific research questions are discussed in Section 1.2. Section 1.3 discusses progression, the methodology taken as well as the structure of the thesis. Section 1.4 gives contributed publications with the thesis.

1.1. Motivation

Investigations in employing different possible tools of ICT in education are ongoing. Efforts in adoption of new possibilities to support online learners have resulted in new forms of learning with partly positive learning results. One of the prominent environments is immersive environments that have shown to provide new forms of learning support and new application domains in relation to other forms of e-Education. Immersive environments, when used for learning, offer more features than availability and convenience to remote learners. Being able to immerse in the environment allows learners to obtain new types of learning experiences and patterns that are new. The ability to meet remote online learners and collaborate with them visually is definitely a characteristic of a new generation of virtual worlds that represent a practical form of the immersive environment. The utilization of virtual worlds for education has been proliferating with several examples discussed in the thesis demonstrating universities increased attention. It remains to investigate the learning support to have a strong focus for e-education researchers. The scalability and convenience for such environments has been already shown in specific environment reaching millions of users. It is important to consider how the recent decades of paradigm shift have changed the technological usage and reliance patterns and whether it affects learners and learning. This has reshaped the user expectations and interests in the medium of usage for learning. Prenksy (2001) has demonstrated that with a new and different generation of user concept; named digital natives. It is essential to utilize ICT advancements and discover new methods of learning to the interest of digital native learners. However, it should not be performed in isolation of learning understanding and evaluation of the impact of those environments.

Remote experimentation and simulation are example application types showing the immersive environment ability to afford benefits for new possibilities of instruction delivery compared to physical university or school labs (Scheucher, Bailey, Guetl, & Harward, 2009). 3D virtual experimentation and training in hazardous situations (Edward, Lourdeaux, Barthès, Lenne, & Burkhardt, 2008) demonstrates how the use of the immersive environment becomes even essential rather than desired. With the potential for immersive environment to be utilized for learning purposes, learning support is sought.

Increasing interactivity is an important goal for better education. With the nature of the new digital natives and the emergence of e-education forms, increasing interaction with an educator in virtual learning environments is also required. With the potential scalability and the change in the usage pattern, times and locations of the usage, the need for automated learning support even becomes important. 24/7 availability of instructional support in relation to increased number and demands of users, the potential to find virtual educational peers online enable new possibilities. A virtual teacher in those environments can act as a mediator to offer learning services to the learner. While the use of pedagogical agents for education is not new, it is interesting to imagine how a virtual teacher can help in learning in the learning environment while considering technological constraints. Rather, it remains very critical to know the methods of support that are possible that can enable a virtual teacher. Is it necessary to resemble a human or be lifelike in mimicking behavior? However, with the potential limitations, complete reliance on the virtual teacher is not assumed.

Given the technological advancements, new possibilities are arising. For example, the artificial intelligence research topic and practice can also support methods with specific dedication to education. In research, the use of pedagogical agents added new possibilities in various attempts to support learning. And in immersive environments, there is a potential to fill the gap of education support and provide new possibilities for autonomous and intelligent learning support when considering deploying intelligent pedagogical agents in the environment of interest.

Seeking autonomous support and exploring new aspects for learning with intelligent pedagogical agents in immersive virtual learning environments is sought in the thesis. It is accompanied with aims of discovery of potential benefits of integrating intelligent pedagogical agents and discovering the challenges on implementations and obtaining best solutions. The thesis attempts to thoroughly investigate the topic and answer relevant research questions.

1.2. Goals and Research Questions

The goal of this thesis is to support improvements of learning in immersive virtual learning environment by adopting intelligent pedagogical agents. With the general idea for research target, the following are the research questions and targets:

- What are the methods of incorporating an intelligent pedagogical agent in an immersive virtual learning environment?
- In seeking the implementation, an approach for supplying the IPA and the environment with intelligence abilities is sought.
- Upon incorporating the intelligent pedagogical agent, does the IPA supply new learning approach?
- Adopting intelligent pedagogical agents mandate research on what educational theoretical models support its adoption in an immersive environment? What learning activities can be suitable to the environment? And how it affects the design of pedagogical agents?

A proof of concept showing the realization is an important objective to enable the discovery of such methods and a theoretical conceptual model is sought to view how the pedagogical can function. With the proof of concept's availability, investigating the tools and methods with it becomes possible. A sub goal in order to achieve an IPA in immersive environment is the immersive environment. The immersive environment of Open Wonderland is selected and used for development and implementation. An important goal is the establishment of a practical intelligent agent platform.

1.3. Methodology and Structure

In order to target the research goals and answer research questions, different phases are taken: literature surveys, a solution approach that attempts to establish a conceptual view about the problem, and prototype development to provide a proof of concept, give implementation specific insights, and act as an apparatus for evaluation. Literature surveys incorporate foundational learning theories, pedagogical agents, immersive environments, and intelligent methods for learning. The foundational learning theories study highlights the need to further understand the shifting role of instruction in virtual learning environments in relation to the instructor role and the newly faced challenges. The literature survey on pedagogical agents targets a better understanding of the pedagogical agent, its functional constituents, key aspects, and its potential effects. With a focus on the immersive environment, its core knowledge is important in a step that precedes its pedagogical agent adoption. Thus the survey on immersive environments includes understanding its constituents, characteristics, what it offers in general and to learning in particular with its limitations, and what learning methods it suits. While a better understanding to pedagogical agents, and the environment, is reached, it is still necessary to equip the pedagogical agent with methods to give learning support accordingly. The survey on intelligent methods for learning focuses on identifying how, in more detail, the pedagogical agent can be equipped with intelligent methods to support its operation and objectives.

Given the details about the pedagogical agent, its learning component, its supporting methods, and the environment, a conceptual framework that views all comprehensive components with more stress on its operational offerings in the environment is sought. It is found after visiting and studying relevant conceptual models in research literature within the problem scope. Identifying the requirements and analyzing them in relation to the basic constituents of the pedagogical agent, the environment, and the learning support is necessary in relation to an outlook to shape a solution approach. The conceptual framework relates the important models found to the immersive environment offering to learning support by the pedagogical agent. Thus the conceptual model targets a better view, common understanding, assessment of appropriate components, underpinning theoretical foundation, all to consider in future software designs and implementations of pedagogical agents in immersive environments.

In parallel to the solution approach activities, practical and technological experimentation was necessary to add to the feasibility of the approach dimension. Technological investigations included practical immersive environments exemplified by virtual worlds. Another investigation is finding a practical method to develop AI functions, especially in relation to methods for learning support survey and requirements. An evaluation of a practical intelligent agent framework adds to the solution approach through selection and integration to the virtual world. However, incorporating the different components to shape a prototype was a challenge, especially in answering the question of how the pedagogical agent can interact in relation to its artificial nature, the environment characteristics, and the user expectations. A solution was formed to simulate the elements of the learner, the pedagogical agent, and the environment components in the selected intelligent agent framework. Not only it provided a proof concept of how to utilize the agent approach for learning support, but also provided details of the interaction pattern in a target prototype in the virtual world. In another thread, the intelligent agent approach in relation to particular implementation, and the Belief-Desire-Intention (BDI) model of agent reasoning was studied to show how the pedagogical agent can pursue pedagogical goals in environment and subject to the solution approach.

Thus prototype development was targeted to materialize different requirement aspects and pre-implementation findings to give a proof of concept and particular implementation details for learning support solutions. The proof of concept gives the necessary elements of communication and learner-centered supporting scenarios with input to show particular interactions and solutions in the virtual world environment. Prototype elements and the resulting learning scenarios are used accordingly to obtain assessment and input about its effect on the learning experience and to provide input for new and further research.

This thesis proceeds as follows: Part A provides a theoretical foundation phase for the work comprising literature reviews on different aspects and Part B provides the solution approach that also includes a qualitative evaluation process and results for the prototype. Figure 1 illustrates the thesis layout and structure. Part A proceeds on Chapter 2 by discussing relevant topics to learning theories in general and with ICT tools in particular. The challenges and opportunities for learning with ICT tools are relevant to consider and are discussed in the same Chapter. Then, Chapter 3 discusses the focused immersive environment investigating its characteristics and researching why it is appealing for utilization in learning. Such utilization forms properties, when identified can provide an input to the strategy of pedagogical agent mission in those environments. It is assumed, throughout the thesis that pedagogical agents operate with no isolation of the context, in which the environment forms an important factor of it. Chapter 4 focuses on the roots and properties of pedagogical agents such as characters, bots and discussing the constituents of them. An important constituent found is the intelligent learning support component, which is left to Chapter 5 for discussion in further details. Consequently Chapter 5 identifies intelligent methods that can equip pedagogical agents with intelligence in particular for learning support.

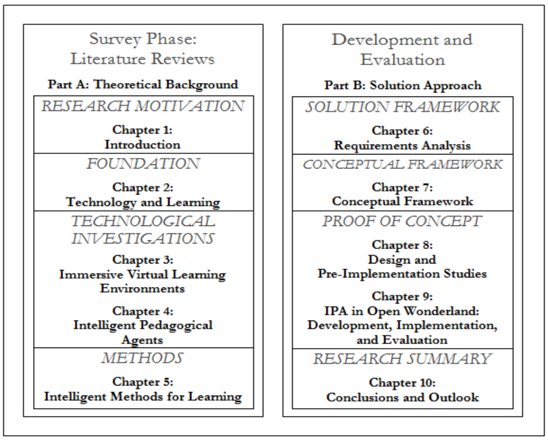

Figure 1: Thesis layout and structure.

Proceeding to Part B, the theoretical background study of Part A, which covered the aspects of learning, the pedagogical agent, the environment, and the supporting methods provide an input to shape the solution approach. The requirements, as discussed in Chapter 6 provide an input to the methodology in proceeding to further steps with several of the activities are performed in parallel. An important aspect of the solution approach is obtaining a conceptual view of pedagogical agents in the immersive environment identifying what is available in research literature, how to utilize them, and how to be complemented and utilized to form and establish a view. Chapter 7 discusses the conceptual model in detail along with elements found to be necessary and supporting the pedagogical agent in the immersive environment. The strategy of the approach requires inspecting the conceptual view to providing a proof of concept specific investigations and a closer look. Chapter 8 provides implementation specific studies and design to realization of concepts. It gives architecture and investigation of Open Wonderland virtual world, a two step evaluation process and the results for selection of practical intelligent agent platform and method. With this selection, learning scenario simulation was enabled leading to results reported in Soliman and Guetl (2012, 2013b) and discussed in the same Chapter. While experimentation in the virtual world environment worked in parallel with other research activities, the simulation enabled putting a prototype with realizing the interaction methods in a better form. Chapter 9 illustrates the architecture and the elements of the prototype. Those elements form variations of learning possibilities or scenarios with the pedagogical agent in the Open Wonderland virtual world environment. Those learning scenarios are not only explained, but are also assessed in relation to the solution approach and been used as an apparatus for a study experiment that is described with results in the same Chapter. Finally, Chapter 10 summarizes, outlines answers to research questions, and provides an outlook in relation to the work done and obtained findings.

1.4. Contributions

Reporting of progress has been submitted to various international conferences and journals during the various stages. Those publications are incorporated at different sections and stated in the thesis Chapters accordingly.

A: Literature Reviews & Theoretical Background

Literature reviews contributed foundational background for the research as the following:

- Soliman and Guetl (2010a) provides a literature review on intelligent agent support to collaborative learning. The survey resulted in answering the question of how intelligent agents can support collaborative learning with aspects reported.

- Soliman and Guetl (2010b) provides a literature review, historical developments, different projects in the use of intelligent pedagogical agents, and an initial investigation at their adoption in immersive virtual learning environments.

- Soliman and Guetl (2010c) provides investigation and review of the learning objects and the virtual world representations that provide support to learning.

- Soliman and Guetl (2011c) is a comprehensive review of intelligent methods for learning support (see Chapter 5).

B: Technological Studies and Proof of Concept Implementation

Investigations for technological solutions that satisfy properties found in literature reviews and methods study are required. The investigations led to experiences and findings are reported and helped to form a proof of concept simulation approach before implementation.

- Soliman and Guetl (2011a,b) reports an investigation to discover an appropriate tool and method to implement the agent by evaluating several platforms through a two stages selection process. Details are discussed in Chapter 8.

- Soliman and Guetl (2012) reports initial results of a simulation of learning scenarios and experiences with intelligent agent platforms.

- Soliman and Guetl (2013b) reports simulating interactive learning scenarios with intelligent pedagogical agents in a virtual world through BDI-based agents as a method to relax implementation challenges and provide a proof-of-concept prior to an implementation.

C: Proof of Concept User Prototype Development and Evaluation

According to requirements study and solution approach, a prototype is realized and evaluated as:

- Soliman and Guetl (2013a) reports prototype of learning scenario implementation as a proof-of-concept and experimentation with pedagogical agents in Open Wonderland (see Chapter 9).

- Soliman and Guetl (2014) reports the results of an evaluation study in relation to the process and results discussed in Section 9.4.

Part A: Theoretical Background

Comprises

Technology & Learning
Immersive Virtual Learning Environments
Intelligent Pedagogical Agents
Intelligent Methods for Learning Support

2. Technology and Learning

Learning is a fundamental pillar to human and society development. In targeting learning, there have always been questions about how learning occurs in the human mind. Understanding learning has been a motive for researchers over decades. That led to learning science that is vast with a distinct research discipline by itself that also works to find the methods that improve learning. These efforts, in the recent few decades also considered employing technology for learning with the phenomena of proliferation of technology, connectivity, and the availability of learning support tools. More utilization of those tools in enhancing and supporting education can rather be supported by better understanding how learning occurs with methods to provide efficient learning support. While on the other hand such understanding can provide the innovator of technology with insights of better ways to utilize technology to server learning better. Learning and how it occurs to step forward to better utilization of technology to serve learning needs and find new possibilities. This Chapter provides background about relevant learning theories with potential impact on learning in virtual learning environments and attempts to clarify the meaning of the learning process and the meanings of relevant terminologies in learning science.

This Chapter is organized as follows: Section 2.1 targets learning theories shedding light into understanding the objectives of learning, how they occur and understanding the learning process and relevant models. Section 2.2 discusses how can different forms of technology support learning from different aspects and the challenges with using technological tools for learning. Section 2.3 is a conclusion.

2.1. Learning and Learning Theories

In the objective of utilization of technology to foster learning, one discovers the need to understand what is learning, how to describe it, and why it is needed. How to reach the goals of learning and what are the settings that involve learning? Exploring learning has been investigated for centuries with several theories and models of learning found in the literature. This Section introduces relevant topics to learning and learning theories to help understand the process as a pre-requisite to applying technological innovations to contribute to it.

2.1.1. The Objectives of Learning

What is learning? Why is it important? And why learning takes place? For example, without learning to speak, one cannot conduct conversation with others. Without the ability to write, there would have been no books or written communication. It is retrieved from earlier civilizations inscriptions on walls which document earlier society and life activities. Those old civilizations learned writing with different languages to achieve several of their objectives.

Therefore, learning is a process, occurs throughout the lifetime, aimed at obtaining abilities that enable one to achieve an objective, either to serve at the individual objective scale or for the community at large.

A commonly relevant and used term is *pedagogy* which should be distinguished from learning. *Pedagogy* refers to the art and science of teaching. Alexander (2004) defines pedagogy as *"the act of teaching and its attendant discourse"*. While it focuses on the teacher as the provider of instruction for learner development, it has a strand of focus in education research that investigates its different aspects.

Then, what are the objectives of learning? Bloom's hierarchy of learning objectives provides a blue print for educators to know about the learning goals and its classification (Bloom, 1956). It has three domains: *cognitive domain*, *affective domain*, and *psychomotor domain*. Originally it started with the cognitive domain while the other domains where added in later publications. Six levels are identified in the cognitive domain and published in Bloom et al. (1956). The original taxonomy included six dimensions: *knowledge, comprehension, application, analysis, synthesis, and evaluation* to show what the student is expected to learn. The revised Bloom's taxonomy is based on two dimensions: the cognitive process dimension, and the knowledge dimension. There are six dependent levels of educational objectives in the cognitive process dimension, from lower to upper levels are: 1) *Remember* 2) *Understand* 3) *Apply* 4) *Analyze* 5) *Evaluate* 6) *Create*. Those action verbs describe abilities of the learner from simplest to more complex. Table 1 depicts the structure for the cognitive domain.

Table 1: Structure of the cognitive process (Krathwohl, 2002).

1.0 Remember - Retrieving relevant knowledge from long-term memory.
1.1 Recognizing
1.2 Recalling
2.0 Understand - Determining the meaning of instructional messages, including oral, written, and graphic communication.
2.1 Interpreting
2.2 Exemplifying
2.3 Classifying
2.4 Summarizing

2.5 Inferring
2.6 Comparing
2.7 Explaining

3.0 Apply - Carrying out or using a procedure in a given situation.
3.1 Executing
3.2 Implementing

4.0 Analyze - Breaking material into its constituent parts and detecting how the parts relate to one another and to an overall structure or purpose.
4.1 Differentiating
4.2 Organizing
4.3 Attributing

5.0 Evaluate - Making judgments based on criteria and standards.
5.1 Checking
5.2 Critiquing

6.0 Create - Putting elements together to form a novel, coherent whole or make an original product.
6.1 Generating
6.2 Planning
6.3 Producing

Furthermore, in the revised taxonomy, Krathwohl (2002) describes the knowledge domain structure consisting of four types of knowledge acquisition as objectives for learning: *factual, conceptual, procedural,* and *cognitive knowledge.* Thus the learning objective will be a matching between dimensions, cognitive process and knowledge domain, for example to *Create Conceptual Knowledge* (Krathwohl, 2002).

The affective domain of Bloom's taxonomy motivates objectives for growth in emotions and feeling towards others involved as objectives of learning. The Psychomotor domain is relevant to the physical manipulation of instruments. Bloom's taxonomy of educational objectives suggests handling all domains and levels in instruction design.

2.1.2. How Learning Occurs: Learning Theories

In investigating and understanding learning, researchers depicted learning theories and models that conceptualize the learning process. The science of learning attempts to understand how learning occurs in the human mind, puts models for effective learning, and decides what activities and processes can contribute to it. Three main models refer to three main schools of thoughts are distinguished: *behaviorism, cognitivism*, and *constructivism*.

Behaviorism is based on the work by Skinner (1904-1990) who suggests that learning occurs as a result of stimuli and response. Behaviorism does not fully consider the thought processes of the learner mind. Several education researchers such as Pavlov, Watson, Thorndike, Skinner, and Gagne promoted and experimented with stimulus and responses in the behaviorism (Soliman & Shaban, 2009).

Cognitivism stresses the importance of understanding the operation of the mind and its processes. In contrast to behaviorism, the importance of inner workings of the mind has put this theory in favor to replace behaviorism. Dewey, Piaget, Vygotsky, and Gagne are of those theorists associated with cognitivism (Soliman & Shaban, 2009).

Constructivism (Piaget, 1964) rather proposes that learners construct new knowledge in relation to prior knowledge. When faced with new knowledge, the human mind will to try to relate it to prior knowledge in search for a logical explanation. Once an explanation is found, it becomes more established in the mind at a point referred as the *equilibrium*. Therefore, teaching content, in instruction, is to be carefully selected and put reasonably to students based on their prior experiences. Intentionally creating *disequilibrium* leads to the search for logical explanations and thus learning. Constructivism theory is referred to Jean Piaget pioneering work. *Social constructivism* (Laurillard, 2008) is a special type of constructivism that relates to the fact that individuals learn as a result of social interactions and considers it within the group of learners.

2.1.3. Learner Differences

Understanding learners and their differences is fundamental to instructional activities. Learners differ in several aspects. First, they vary in their background. Based on constructivism, new constructed knowledge is based on prior knowledge. Since learners differ in prior knowledge, provided knowledge for learning should be the one that gives best constructivism. Second, variation in motivation among different students exists. For example, a low performing student, due to motivational factors, should be handled differently in encouragement than a high performing learner if motivation to learn is cause of such low performance. In addition, Gardner (1983) suggested the *theory of multiple intelligences* that proposes differences in learner intelligence due to environmental and experiential reasons. Even in the same class or lecture room, learners not only have different abilities but also prefer to learn with different methods. Those methods provide better results with them than the others. Educators are thus advised to vary the learning methods as possible, supported by the theory of learning styles (Felder & Silverman, 2002). For effective learning, understanding the learner from different perspectives is needed. The learning style concept does not mandate that the learning process uses one method, but rather a combination of learning methods to suit the different learning styles. Felder and Silverman (2002) give five dimesnions of learning styles. Table 2 suggests the student participation teaching style for an active learning style[1] for example.

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[1] In support to learning with IPA in virtual world since it has the characteristic of active learning style.

Table 2: Preferred learning styles with the corresponding teaching style (Felder and Silverman, 2002).

Preferred Learning Style		*Corresponding Teaching Style*	
sensory intuitive	perception	concrete abstract	content
visual auditory	input	visual verbal	presentation
inductive deductive	organization	inductive deductive	organization
active reflective	processing	active passive	student participation
sequential global	understanding	sequential global	perspective

Differences in learners, given the above mentioned dimensions, support tailoring of instruction to the learner (based on learning styles) thus providing input to adaptation methods that are based on the individual learner rather than a group. Soliman and Shaban (2009) tie effective learning in an e-learning system to its ability to be adaptive to individual learning needs. Generally, an e-learning tool does not necessarily handle all learner styles or consider the multiple intelligences given its instruction delivery and in the class room understanding the learner is hard especially for large number of traditional classes.

2.1.4. Motivation and Learning

Motivation is an important factor to consider in the learning process as it is relevant to learning goals attainment. Motivation has been significantly investigated by educational theorists. Maslow (1943) developed a fundamental theory of motivation proposing the needs to form the *hierarchy of needs*. Maslow's motivation theory presents that human actions are directed towards goal attainment. And behavior could satisfy different functions simultaneously forming a hierarchy. Maslow's hierarchy of needs is represented by a five layer hierarchy. The levels from the bottom layer are: physiological, safety, belongingness, esteem, and self-actualization[1]. The theory suggests that seeking fulfilling lower level needs in the hierarchy before higher order ones influence behavior. The four low order needs are physiological needs while the top one is a growth need.

Several theories exist to explain motivation in relation to learning. One of which is the *expectancy-value* theory. As cited by Svinicki (2010), the *expectancy-value* theory suggests that learners have higher motivation if they believe they can be

[1] Self-fulfillment

successful in doing the task. Self-efficacy refers to this belief in one's own ability to succeed. Learners can also have higher motivation if they believe the task is worth doing. If any of these is missing, motivation is lowered. Therefore, with this theory, educators should keep that in mind in both designing affordable activities, scaffolding them, and providing assessments. In technological-based environments, this factor should also be considered to give the motivation to complete the task.

Self-determination is another theory of interest as it adds one more dimension (Svinicki, 2010). When learners have choice and control over their actions, they are to select doable activities thus increasing their motivation. With the three factors affecting motivation: the task, beliefs about the outcome control, and self-efficacy, Svinicki (2010) relates several motivation theories (see Figure 2).

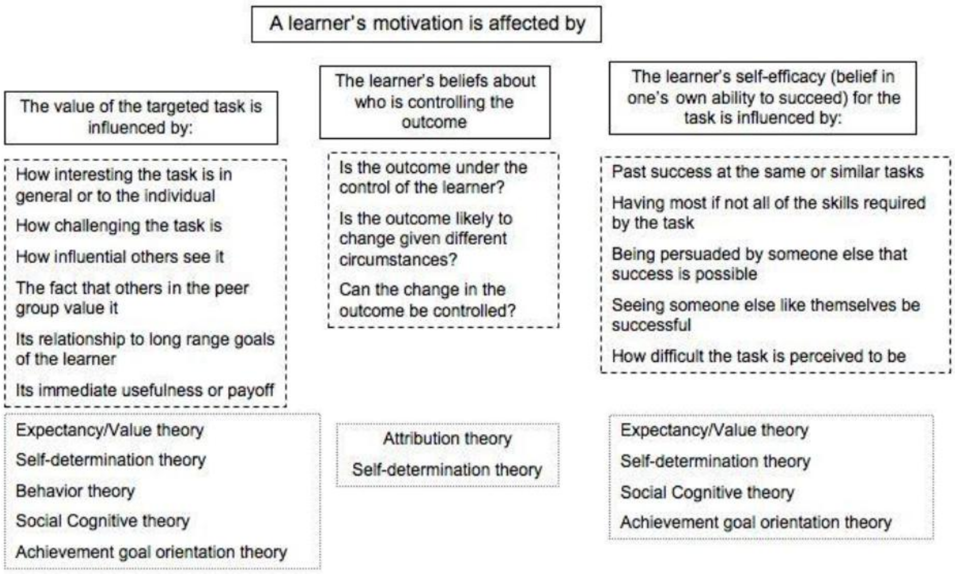

Figure 2: A combined motivation theory (Svinicki, 2010).

Therefore, inclusion of motivational aspects of learning has influence on completion of tasks and learning results and is also important in the design of learning systems. Soliman and Shaban (2009) suggest that an e-learning system that considers motivation in its design objective is preferred than the one who does not. Al-Smadi and Guetl (2012) integrated motivation in e-assessment systems. While in traditional learning, the educator plays a central role in enhancing learner motivation, in electronic learning environments and in lack of human instructors, motivation, and how it is delivered becomes a challenging task.

2.1.5. Learning by Doing

Learning by doing influences learner motivation based on his/her control over the outcomes and the *self-efficacy* impact of task completion (see Section 2.1.4).

Several learning theories dealt with learning by doing investigating its support for learning outcomes. The *experiential learning theory* (ELT) (Kolb, 1984) is based on learning from direct experience (see Figure 3). Experiential learning theory is strongly tied to learning by doing as the theory suggests the importance of experience taken from its name.

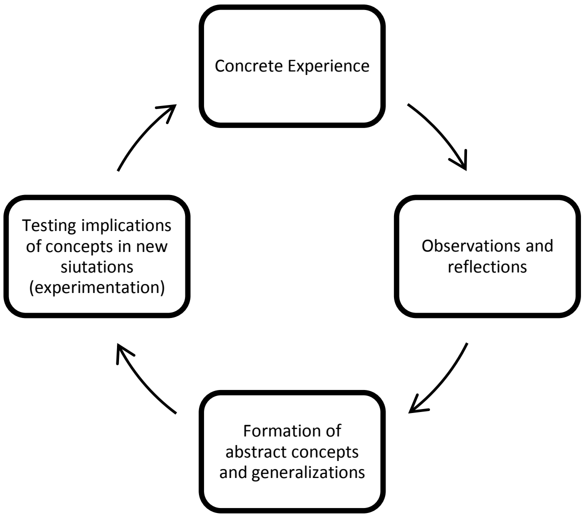

Figure 3: Experiential learning (Kolb, 1984).

While training can have individual learning activities, it usually involves a trainer whose objective is different from a general educator. Usually the trainer has the skills relevant to how to instruct and communicate effectively with knowledge about the learners. His objective is to have the trainees master the skills.

Active Learning (Bonwell & Eison, 1991) is an important learning concept that promotes learning by doing. Active learning suggests that students learn more by not being passive. Students participate in the learning process in a way that they are not just recipients of information but by making activities such as writing, reading, discussing, or reflecting. Thus active learning makes the learner more in charge and control of the learning process that shifts the learning from being instructor-led to learner-led education.

The *cognitive apprenticeship* learning theory (Collins, 2006) further lays foundations for learning by doing in a way to promote acquiring skills or expertise not only from the perspectives of the learner, educator, or adopted methods, but also from the environment settings perspectives. Collins (2006) discusses the principles of the theory with four dimensions: the learning content that is taken to acquire skills or expertise, the methods to promote the development, sequencing importance for the learning activities, and the environmental social characteristics. The principles are explained in Table 3. With traditional instructor-led learning-by-doing settings, knowledge about its concepts, taking its strategies, and setting the environment should lead to better development and learning results. However, it requires small teacher-to-learner count ratio, and therefore it becomes difficult in traditional settings to achieve while potential ICT tools can fulfill this requirement given its scalability. It is questionable, in recent e–education tools whether those foundations are considered in the design of the tools. In other words, virtual environments should seriously consider those principles as design objectives.

Table 3: Principles for designing cognitive apprenticeship environments. Taken from Collins (2006).

Content	Types of knowledge required for expertise	
	Domain knowledge	subject matter specific concepts, facts, and procedures
	Heuristic strategies	generally applicable techniques for accomplishing tasks
	Control strategies	general approaches for directing one's solution process
	Learning strategies	knowledge about how to learn new concepts, facts, and procedures
Method	Ways to promote the development of expertise	
	Modeling	teacher Performs a task so students can observe
	Coaching	teacher observes and facilitates while students perform a task
	Scaffolding	teacher provides supports to help the student perform a task
	Articulation	teacher encourages students to verbalize their knowledge and thinking
	Reflection	teacher enables students to compare their performance with others
	Exploration	teacher invites students to pose and solve their own problems
Sequencing	Keys to ordering learning activities	
	Increasing complexity	meaningful tasks gradually increasing in difficulty
	Increasing diversity	practice in a variety of situations to emphasize broad application
	Global to local skills	focus on conceptualizing the whole task before executing the parts
Sociology	Social characteristics of learning environments	
	Situated learning	students learn in the context of working on realistic tasks
	Community of practice	communication about different ways to accomplish meaningful tasks
	Intrinsic motivation	students set personal goals to seek skills and solutions
	Cooperation	students work together to accomplish their goals

2.1.6. Collaborative Learning

There have been much attention and demand for collaborative learning in educational institutions worldwide. Educators have discovered the importance of group learning against traditional learning. An apparent example comes from the fact that one learns upon teaching. So when students teach peers, they learn twice (Whitman, 1988). Another factor is the social benefits of learning in groups[1].

Collaboration has several forms in the classroom. For example it can be group project work, collaborative writing, and more. Intuitively, the production of knowledge, in proper settings, as a result of group learning, does not mandate that the sum of knowledge is equal or more than the total of the individuals learning result, but leads to better established knowledge. Therefore, guided group discussions contribute to learning by the construction of knowledge. Brainstorming suggests that knowledge produced by the group is better than one or summed of individuals. In group project work, learners divide their tasks then reflect on them to the group and integrate the activities towards the common objective. This setting allows not only learning the individual task but also reflecting on it, communicating it, and learning from others as well. Thus, this procedure of learning in groups to reach better knowledge or decisions is very healthy to learning as it improves learners' soft-skills of communication, negotiation skills, and unifying arguments. Furthermore, one can agree on the social benefits gained as a result of group interaction. Of course, many can do much more than one, if the settings are proper and healthy to group learning[1].

Collaborative learning is about two or more learners learning together. This concept is referred back to the work by George Jardine (1742-1827) in developing a peer-review process. Gaillet (1994) further provides historical perspectives in collaborative learning. Nowadays, there is a common agreement among educators on the importance of collaborative learning to the health of learning compared to individual learning. Student learning by teaching peers is emphasized by Lev Vygotsky who laid foundations for collaborative learning based on the social nature of learning. He developed the *Zone of Proximal Development (ZPD)* as a measure of what the learner can do without help and with help in collaboration with peers (Vygotsky, 1978). The co-construction of knowledge as a result of group learning while social interaction takes place is related to the *social constructivism* education theory (Laurillard, 2008). Social interactions increase in the context of collaborative learning leading to creating much higher possibilities of gain compared to one educator teaching the whole group[1].

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[1] This paragraph is adopted from Soliman and Guetl (2010b).

2.1.7. Emotions, Gestures, and Learning

Emotions play a significant role in learning effectiveness. No wonder why educators pay attention to the well-being of the emotional state of the learner (Fried, 2011). Emotion in education is tied to motivation and the desire to learn. Emotional *suppressors* and *depressors* work to reinforce learning or training and lead to retention. When one recalls a learning session where the educator provides gestures, will definitely relate it to the knowledge or skill subject of education. Consequently, Valenzenoa, Alibalib, and Klatzkya (2003) report, with study results, that gestures may play an important role in instructional communication. In addition to the emotional state of the educator, the emotional state of the learner has been of interest to educational researchers for a long time. In early stages of learning, a positive emotional state of the learner results in positive attitude towards learning, better learning results, and definitely less drop rates for youngsters. No wonder educators are not to ignore the ergonomic factors of the design of the learning environment striving to provide a cheerful one to learners, selecting comfortable lecture rooms, adequate lighting, specific colors, and cafeterias. They believe on the level of comfort that will reward back with better education on that environment (Graetz, 2006). The emotional state of the learner also relates to better learner engagement as an essential element for learning effectiveness. In electronic learning environments, better engagement in the learning environment as an objective, leads also to the continuity of learning towards better learning results.

While emotional implications on learning results are evident, its influence and realization in computerized environment becomes apparent given machines rather than humans interaction.

2.1.8. The Role of the Teacher

Classical models of formal instruction put the teacher as a main influential part in the learning process. In a formal classroom setting, students attend a class with a teacher who follows an instructional design method. The teacher provides lessons or lectures, conducts individual or group learning activities, assesses learning results, and provides help to students. The teacher motivates students, scaffolds activities, and ensures progress towards learning enhancement.

For instructional effectiveness, several characteristics to the teacher suggest his or her competencies of different areas. Shulman (1987) categorizes the teacher knowledge areas to include knowledge in the subject matter content knowledge, pedagogical knowledge, knowledge about the learners, and more. The abilities of the teacher to understand the learning process, tailor the activities and methods to deal with learner differences, and adopt best strategies are roles of the teacher based on the knowledge areas of Shulman (1987).

However, pragmatic difficulties can hinder the teacher ability to apply educational strategies with the variation of learning settings. For example, how teachers deal with multi-cultural differences, how to tailor instruction at a fine level given a big number in class, and how to provide one-to-one and face-to-face support for individuals for large number of students, all remain to be challenging factors. As constructivism suggests the importance of prior knowledge to best construction of new knowledge (Piaget, 1964), the teacher ability to understand the knowledge levels of all students become impossible. Moreover, students always need help and support in the learning for varying reasons and times. Unfortunately, teachers can rarely become available immediately when a student needs help and off course not anywhere.

With technological changes and the entry of technology for education, the role of the teacher is changing from coping with technology to exploitation and utilizing it for learning activities. And furthermore, technology can support the teaching with facilities that are difficult for the teacher such as in personalization.

2.2. ICT in Education

With proliferation of computers and the increase of the availability and speed of the Internet, and pervasiveness of computing resources, better utilization of those resources for learning becomes evident. Researchers have been working to utilize new inventions for learning, especially considering attractiveness of ICT functionalities and power.

Researchers in e-education have been attempting to utilize attractive features of technology. The digitization of learning resources such as text and video enables the reusability to make them available several times anytime and anywhere. This also enables the use of resources at the pace rate of the learner and go through the resources, such as videos several times on a mobile device.

Technology nowadays has added *convenience* to its users. Connectivity can help access systems not only remotely but also available 24 hours a day and 7 days a week. Users do not have to commute to distant places saving transportation effort, cost, and time. Even at several situations, such as in rural areas, access to learning is difficult.

The economic aspect of education and the need for resources to support learning should not be neglected. *Economy of scale* plays a central role in the success and potential for ICT in education. As a simple example, once a Web page is developed and delivered on the Internet, millions of users can visit it and browse through the information presented. The *scalability* of Internet resources plays a significant role in the economy of scale of such tools. While education institutions can take this aspect into consideration, it also lessens the costs incurred in buildings and classroom using the virtual class or the virtual university. However, consideration is moved towards administrative and support cost to e-learners who do not receive face-to-face interactions.

On the other hand, it is obvious that it replaces the human-to-human interaction toward human-to-environment interaction or human-to-human indirectly (asynchronous learning). Adding a none-human medium of communication brings a *virtual distance* between the learner and the educator (see Figure 4). Unfortunately, it removes important human aspects needed for learning; such as emotions and gesture effects. That is in addition to the intelligence of the human educator compared to an artificially intelligent software component. That led to the idea of combining the advantages of both through *blended learning* settings that e-learning should be complemented with human educators support. However, new interesting features are yet evolving that brings new learning scenarios that were not possible in traditional learning settings.

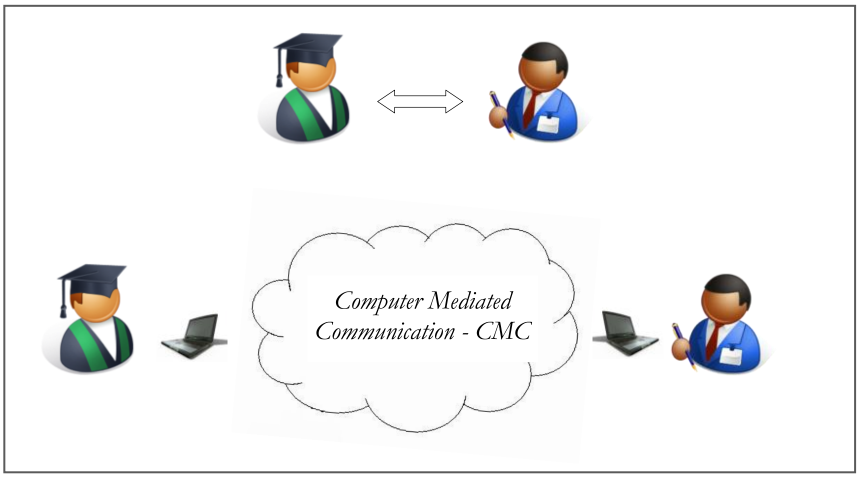

Figure 4: The virtual distance between the instructor and the e-learner.

2.2.1. Forms of Learner-Centered Tools

With evolvement of technological solutions for education, several forms of supporting tools are considered for solutions. Several of which considered understanding the learner as a central element. Table 4 gives examples of learner-centered tools and their supporting learning theories.

Table 4: Several forms of ICT tools for adaptive learning based on learning theories (modified from Soliman & Shaban, 2009)

Personalized Learning Environments (PLE)	PLE systems try to capture information about the learner as a form of profile and present the suitable material to the learner	This complies with different learning theories based on understanding the learner.
Intelligent Tutoring Systems (ITS)	ITS's requires no human intervention. These systems are intelligent and try to capture information about the status of learning result and change the sequence to suit the learner	These systems assume the importance of understanding the learner needs in the subjects but not the learning styles. The use of cognitive tutors that try to establish a learner cognitive models make it eligible of use of congitivism-based theories.
Learning Objects and Web Services	Tries to use useful IT disciplines of learning objects and services to create on-the-fly compositions. Having those variations helps in establishing variations of learning methods.	Pedagogical-aware learning objects
e-Portfolios	Are collections and records about learner activities in an electronic format	The use of e-portfolios improve learners' motivations of esteem and self-actualization
Social Collaboration & Social Software	The use of social web, folksonomies, etc	Social constructivism
Adaptive Hypermedia	In user interfaces. Only the presentation of content.	Theory of multiple intelligences

2.2.2. Technological Support to Collaborative Learning

Different technological solutions have evolved to support collaborative learning. The growth and availability of the Web has made it an interesting medium for aiding instruction. Tools for group learning support include the use of emails, instant-messaging, and others to facilitate communication in either standalone domains or within course management systems. Supporting the production of knowledge by groups has become available recently as the evolution of the Social Web (Web 2.0). Most of the success of Web 2.0 is attributed to the social nature that encourages group work by Blogs, Wikis, and group tagging. Other e-learning methods have evolved to support instruction. Unfortunately, pedagogy as a design factor is sometimes ignored or sometimes has the view of e-learning paradigms replacing conventional methods. E-learning should support the learning process in a way that complements rather than replaces other settings thus improving learning effectives; and it always depends on the environment settings. Then e-learning support for groups has to be investigated in way that complements, rather than replaces other methods by seriously considering learning pedagogical objectives[1].

Computer support aiding group human activities takes different forms, and dates back even to the early stages of the creation of computers. Computer

[1] Paragraph is adopted from Soliman and Guetl (2010b).

Supported Cooperative Work (CSCW) evolved as a multi-disciplinary research including computer science, social psychology, and education (Grudin, 1994). It involves how people work and do things together by means of computer support. Computer Supported Collaborative Learning (CSCL), instead, adds the dimension of learning in addition to collaborative task achievement. CSCL involves learners who are separated by distance or time. Then the key distinction aspect between Computer Supported Collaborative Learning and CSCW is the learning focus. This means further pedagogical support is needed. And CSCL environments should have further support and richer capabilities than CSCW since CSCL involves group work to achieve a task in addition to learning requirements. While both fields are multi-disciplinary, CSCW started by technologists to learn from different fields including social psychologists and educators (Grudin, 1994). Conversely, CSCL are crucially expected to be pedagogical-aware[1].

2.2.3. Virtual Learning Environments

Given that learning occurs in environments and in conjunction to interaction with others, researchers investigated the environment impact towards creating virtual learning environments. What is a virtual learning environment (VLE)? What are its characteristics? And what distinguishes it from other environments? A good view of VLEs that clarifies it and provides insights into its design is found in the work by Dillenbourg (2000). Dillenbourg (2000) identified seven characteristics to the virtual learning environment listed in Table 5.

Table 5: Seven characteristics specific to virtual learning environments by Dillenbourg (2000).

1.	**Information space realization:** "*The information space has been designed*"
2.	**Turning spaces into places:** *"Educational interactions occur in the environment, turning spaces into places"*
3.	**Social space representation:** *"The information/social space is explicitly represented. The representation varies from text to 3D immersive worlds"*
4.	**Students are actors:** *"Students are not only active, but also actors. They co-construct the virtual space"*
5.	**VLE complements classroom:** *"Virtual learning environments are not restricted to distance education. They also enrich classroom activities"*
6.	**Technologies and pedagogic approaches integration:** *"Virtual learning environments integrate heterogeneous technologies and multiple pedagogical approaches"*
7.	**VLE overlaps with physical environment:** *"Most virtual environments overlap with physical environments"*

In order to further assess added pedagogical values of virtual learning environments, one can consider it in comparison with Intelligent Tutoring Systems (ITS). ITS's characteristic is the removal of human intervention by the use of artificial intelligence methods. While intelligent tutoring systems intended

[1] Paragraph is adopted from Soliman and Guetl (2010b).

to provide pedagogical functions through personalization, sequencing of instruction, and more, their direct benefits were a focus on individual uses as direct consequences of the removal of the human tutor. But so far, they lacked the rich 3D visualization aspects that are available in recent 3D virtual learning environments. Furthermore, VLE provides more collaboration and exploration-based learning opportunities and can be much more open and flexible than the individualistic ITS. An intelligent agent can roam across several domains to search for resources, collaborate with other peers, or learn from others' experiences. This was not a design factor in an individual ITS.

In the virtual environment, the learner user has more control on his/her experiences and is more of an actor. Therefore, it is more directed towards learner-centered learning, and hence greater need for individualization services towards learners as actors is expected.

2.2.4. Challenges for Learning with Technology

Students face challenges in using electronic environments for learning due to interaction with machines rather than the human. The human aspects in learning cannot be found in virtual environments. Even with a remote teacher in asynchronous learning environments, the virtual distance still exists that hinder for example face-to-face passion that teachers use to support students in the traditional classroom.

With the scalability and availability of learning environments, it becomes difficult to provide 24/7 remote support to learners. Furthermore, with the explosive growth of learning resources available, it becomes questionable of how a teacher can guide learners to navigate through those resources. In individual learning in those environments, the engagement of the learner should be taken into consideration; otherwise, learners will become discouraged from completing activities on time.

Furthermore, the role of the teacher should change with new ICT-based learning activities and environments. Online learners are faced with challenges in the environment as a result of lack of human guidance in those environment and interaction with machines. Challenging questions arise such as how to motivate and engage learners in virtual environments? Developments in adopting innovative methods should target those challenges. The use of *artificial intelligence in education* is an example attempt to target such problems.

Education occurs in relation to real-life situations, such as in experiential learning and situated learning theories. The visual component of the situation has an effect on occurred learning. Learning with two dimensional resources such as photos or videos does not provide a complete representation of reality. Learners' ability to interact with visualizations should foster learning preferably if there are three dimensions rather than images or video content that will be considered in the subsequent Chapter.

2.3. Conclusion

While learning is a process that technology can support, there are windows of opportunities with automation support availability. There is importance to answer questions about the meaning of learning towards effective ICT-based instructional design. Learning theories answer questions of what is learning, how it occurs, and highlight the importance of understanding the learner differences, motivation, and the meaning of effective learning and training activities.

With that understanding, it becomes evident to understand the learner and the situation of the learning, and more in order to take effective strategies for developing new tools for learning support. There are different forms of virtual education tools evolving with the phenomena of innovations in IT. Virtual learning environments that are context-aware, learner-aware, promote active and social learning provide new generation of effective learning tools. Those environments should be focused on the learner.

Furthermore, collaborative learning has strong reward for ICT based learning that is reflected in further investigations in virtual learning environments to mediate the challenges of the created virtual distance and motivate for substitution to lack of face-to-face interactions. The design of recent virtual learning environments promotes new tools supporting virtual collaboration.

While technology created new possibilities for learning support, it created factors that either change the role of the teacher or mandate new forms of support. This is to cope with explosive growth of available knowledge, ability to have numerous learning resources. The adaptation needed is to provide intelligent and technology-aware methods to provide pedagogical guidance to digital learners and motivate them for enhanced effective learning results.

3. Immersive Virtual Learning Environments

While the virtual learning environment provides the contextual aspect for situated learning support and objectives, there are inherent benefits to extend the virtual environment to 3D. Recent innovations in immersive technologies bring new possibilities and potential additions to learning with technology. The characteristics of those environments along with the potential additions to learning are discussed in this Chapter.

This Chapter is organized as follows: Section 3.1 discusses immersive virtual environments providing an example practical implementation of virtual worlds. Section 3.2 discusses how immersive environments can be used for educational purposes summarizing benefits found in research literature. Section 3.3 is a conclusion. The Chapter adopts published work in Soliman and Guetl (2010a, c).

3.1. Immersive Virtual Environments and Virtual Worlds

3D immersive virtual environments add 3D visualization and the ability of the user to navigate 3D virtual spaces, in comparison to 2D environments. The user immerses into the 3D virtual environment being represented as an avatar. Other users are represented as avatars as well. It is possible to meet other people or educators from distant locations online, collaborate with them, discover new places instantaneously, or even play games. A distinctive characteristic of immersive environments is visual collaboration abilities supported by multi-modal communication (Dalgarno & Lee, 2010; Schmeil, Eppler, & Gubler, 2009). As per example, remote users communicate via text or voice chat while they share the changes in the 3D scene. This visual characteristic has an important impact on collaboration tasks given the sharing of the visual scene dynamics. Schmeil et al. (2009) demonstrate, with experimental evidence that 3D virtual environments bring a real value to collaboration. The research confirmed evidence on improvement of retention in collaboration in those environments in comparison to a pure text-chat only environment (Schmeil et al., 2009).

The visualization of the space, and interacting with other avatars who can be learners, give new possibilities of computer-aided learning scenarios not existed before in a game-like environment. That opens the doors of creativity and imagination to the user.

In immersive 3D virtual environments, the user immerses into the 3D environment where he/she will be able to visualize experiences, attend events, or interact with 3D objects alone or in collaboration with others. The user will identify other potential collaborators of the virtual environment with a representation, a virtual character for example named an *avatar*. In contrary to ITS where a character is assigned to a tutor only, immersive environments give each participant an actor identity, contributing to vision of Dillenbourg (2000, point 4 of Table 5).

Immersive virtual environments inherit properties form *a Virtual Reality* (VR), as Oxford Dictionary defines VR as: *"the computer-generated simulation of a three-dimensional image or environment that can be interacted with in a seemingly real or physical way by a person using special electronic equipment, such as a helmet with a screen inside or gloves fitted with sensors"* [1]. Burdea and Coiffet (2003) indicate that the virtual reality is immersive and define it as *"a high-end user-computer interface that involves real-time simulation and interactions through multiple sensorial channels. These sensorial modalities are visual, auditory, tactile, smell, and taste. "* (Burdea & Coiffet, 2003, page 3). Thus generally VR assumes the senses through various devices such as Head Mounted Display (HMD) units or attached sensors to the human body. Lee and Wong (2008) rather argue that the immersion level of a VR could be varying depending on number of engaged user senses. For example a fully immersive VR assumes attachment of all the senses through various sensors and devices for the full immersion of the user (Lee & Wong, 2008; Carter, 2012). In contrary, in none full immersive environments, the 3D display and control could be given by a regular screen unit and regular computer control devices such as the keyboard and the mouse.

A *virtual world* attempts to resemble real world with possible virtual additions or abilities that also include the immersion in the environment through the term avatar. While the avatar represents visual user actions in the 3D environment such as walking, running, and providing several gestures, it can provide imaginary functions not possible in reality such as flying, violating rules of gravity, and teleportation. The avatar is not the only concept that characterizes a virtual world from other environments such gaming ones. While different definitions for a virtual world are attempted in literature, Bell (2008) combines those definitions to form it as *"a synchronous, persistent network of people, represented as avatars, facilitated by networked computers."* Thus, virtual worlds are not necessarily designed for learning purposes. But rather, several of which evolved from Massive Multi-Player Online

[1] See http://www.oxforddictionaries.com/definition/virtual-reality

Games (MMOG) taking implementation lessons or utilizing their gaming and 3D animation engines. Virtual worlds depict a real software implementation as a product that works with networked computers. In other words, it is viewed that virtual worlds utilize available technologies and standards to realize immersive environment concepts. Example virtual world implementations are Open Wonderland (2012) and Second Life (2013). Figure 5 shows a 3D scene from the Open Wonderland environment where the display is in 3D and each user is represented in the environment by an avatar.

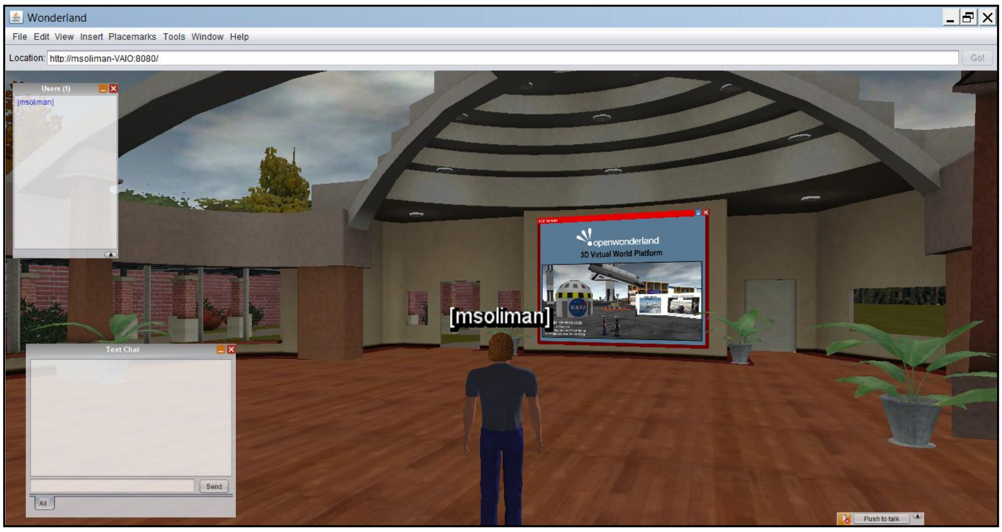

Figure 5: A 3D scene in the virtual world of Open Wonderland. Users are represented with avatars, such as "msoliman" user. They can communicate through voice or text chat while performing activities in the 3D space.

Research has highlighted motivational factors from games, visualization and Human-Computer-Interaction aspects that can greatly motivate the nowadays' digital native who likes games, Prensky (2001). This is exemplified in a 3D visual learning environment that utilizes virtual world gaming environments. Those environments give the abilities to other parties to build their own places and therefore they evolved as virtual worlds. Taking the example of Second Life, participants have the ability to build new models by themselves forming new possibilities and scenarios. As long as it is a guided built by the crowd, the environment is scalable and has great potential for adding new educational services day after day. Several educational bodies and education researchers have recognized this importance for education and are seriously considering them for learning.

3.1.1. Avatar Impact

Users of immersive environments have a distinct characteristic compared to other environments as the representation of their existence with *avatars*. The avatar purpose is for embodiment and representation of the *user identity* (Boberg, Pippo, & Ollila, 2008). The user has control over the avatar shape and movement in the immersive environment. Other users can obtain information based on what they see of other avatars. Information obtained about other users can include the location of the avatar, the activity the user is doing, and perceptions about the personality based on gender, shape, dress colors, etc. It further gives the sense of others' presence in the environment thus providing opportunities of multi-modal communication with other users regardless of their physical location (Hamilton, 2009). That sense of presence adds to the social aspects of the environment, through *co-presence*, to increase and enrich possibilities of activities and increase its utility towards better user engagement (Hamilton, 2009). In contrary, the feel of an uninhabited environment discourages users to be engaged in its activities. With avatars, there are two possibilities. The user can control the avatar if he/she is online. Also the avatar may provide offline functions. The user has the option to create multiple identities. Thus avatar-to-avatar interactions might occur based on the different modes and situations.

The avatar is a representation of existence of the user in the virtual world. Therefore its appearance reflects actual user desired changes. For example, upon conversation with another remote user, the avatar shape reflects speaking. The virtual world tool implements a set of possible animations to reflect such changes such as walking, talking, flying, etc (Open Wonderland, 2012; Second Life, 2013).

The use of avatars in such environments provides a form of personalization from different perspectives. First, the user has choice on the appearance of the avatar in terms of embodiment, clothing, skin color, and more. Second, the view of the virtual world, the user experiences is from the avatar perspective, in contrary to a Web site for example that is static to all users. In the search for environments that put the user as a first class entity, it is found that Virtual Worlds are strong candidates, given the changes of the 3D scene upon user interactions and the user-oriented surrounding services.

3.1.2. Evidence of Immersion Impact on User Behavior

The *Proteus* effect (Yee & Bailenson, 2007) states that: *the behavior of the user in a virtual environment changes in accordance to its digital representation*. For example, in a firefighting training scenario in a virtual world, firefighter avatars should have a compatible costume that represents them in the environment. And similarly the available avatars to educators should be limited to educationally compatible ones. No wonder why companies make policies for employee dress codes in virtual worlds.

In relation, negative cognitive effects of virtual environments also exist. Jorge, Jeffrey, and Nicholas (2009) report that *"avatars with negative connotations affect* *users' cognition in line with the associations they raise"* and *"aggressive connotations can negatively affect users' cognition*". This mandates the need for a control of the environment specially when being used for learning so that it improves learning results and attitude towards learning.

In another effort of obtaining evidence on behavior effects, Christopher (2011) reports that immersive virtual environments create behavior change in the physical world resulted by research at Stanford University (Ahn & Bailenson, 2012). Users were asked to cut a tree in an immersive environment forest that resulted in difference in behavior compared to non-immersive environment users. The one(s) who participated in cutting the virtual tree seeing it falls down felt more accountable for the occurred damage. Furthermore, Gardner, Gánem-Gutiérrez, Scott, Horan, and Callaghan (2011) reported that the use of avatars increased opportunity for participation by shy students and allowed to explore new identities.

With those characteristics mentioned above and the increase in popularity, and attention especially for new generations of users, immersive environments have benefits and new possibilities for virtual learning.

3.2. Immersive Virtual Environments for Learning

With the advent of utilizing advancements in ICT and Internet in education, experiments can be conducted remotely. And with the previously mentioned characteristics of immersive virtual environments, they are further considered for such utilization in education. This gives the opportunity for remote users to obtain chances of learning and experimentation with expensive or remote settings. Thus it is to take advantage of *scalability*, *cost-effectiveness*, *availability* of the resources 24 hours, and more that give the rise for their utilization for education with such needed characteristics.

Benefits of immersive virtual learning environments to learning include the flexibility relevant to removing time and distance barriers to collaborate with others visually. For example, a physics experiment can be conducted with visualization and simulation of equipment and with participants who are remotely located but are interacting synchronously or asynchronously with the aid of the immersion in the VLE (Scheucher, Bailey, Guetl, & Harward, 2009; see Figure 6). An added value to remote experimentation is the *rich visualization* that enables visualizing the elements, the control of the experiment, and even adds computerized visualization of the result. An example is visualizing a magnetic field which is not possible in reality. Therefore, the use of 3D immersive environments for education in performing remote experimentation is seen as an added value as it gives 3D visualization, collaboration support, and the potential for adding contextualization (Machet, Lowe, & Guetl, 2012). Lila project (Lila: Library of Labs, 2011, December) is an example of online labs effort that adopts Open Wonderland as a virtual world. Lila is a library of virtual and remote labs as a consortium of eight universities and three companies[1].

Immersive Virtual Learning Environments provide a step ahead for engaging learners electronically. In addition to the virtual reality benefits for learning, they offer the *sense of presence* to the learner and put the social learning principles in context. They improve collaborative functions and support *active exploration* and *authentic learning* experiences.

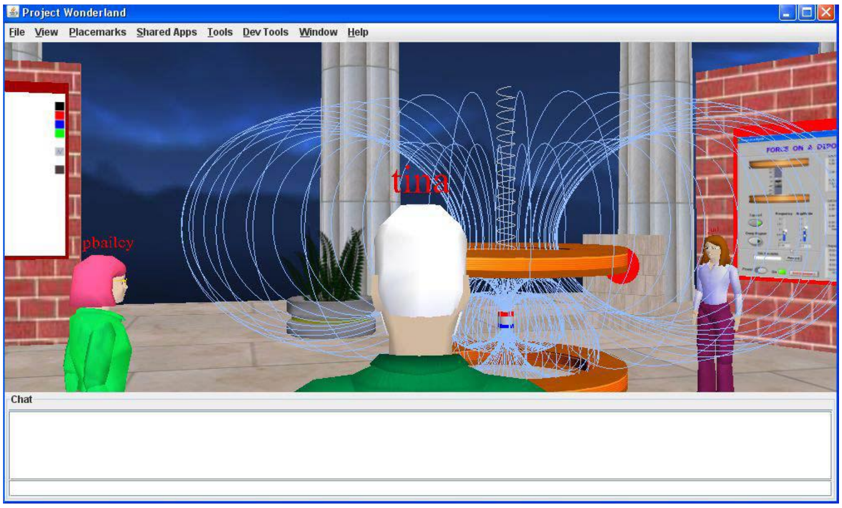

Figure 6: Force on a dipole experiment in Wonderland (Scheucher, Bailey, Guetl, & Harward, 2009).

Another strong value, according to Salmon (2009), is the ability through the rich visualization to provide *authentic learning* experiences that focus on the real world. Those experiences are not easily available in learning institutions or can be very expensive or dangerous to create, a nuclear reactor for example. As virtual environments are simulation places, they provide both imaginary scenarios and simulations of real world scenarios that are rare, simulating what to do in an earthquake or in a battle, for example. Both scenarios are valuable to the learning and training processes. The social aspects of learning can also be improved with immersive virtual environments. Since the learner immerses into the environment meeting other people, the immersive VLE can outperform ITS in terms of collaborative learning which has significant importance nowadays. 3D virtual worlds such as Second Life, Open Wonderland, and EDUSIM have been used for educational purposes as VLE (Kluge & Riley, 2008). And therefore, they provide examples of benefits of innovative collaborative learning scenarios

[1] Paragraph is adopted from Soliman and Guetl (2010a, 2013a).

(Chang, Guetl, Kopeinik, & Williams, 2009; Guetl, Chang, Kopeinik, & Williams, 2009)[1].

Universities have been also trying to adopt new learning experiences by existing in virtual worlds. For example, Harvard Law School conducts lectures in the Berkman's island of Second Life. Another example is the *River City* project of Harvard University that is for scientific inquiry in virtual worlds (River City Project, 2007). According to Clarke and Dede (2009), over 250 teachers and 15,000 students participated in the River City curriculum. Figure 7 shows an avatar of a student talking to a River City resident. Guetl and Pirker (2011) rather utilize the collaborative abilities of the Open Wonderland virtual world environment to support entrepreneurs in a virtual incubator world. Science, Technology, Engineering, and Mathematics (STEM) education has current attempts to adopt virtual worlds for learning in several educational institutions (Immersive Education, n.a.). This gives the opportunity for online labs and engineering education extension. Efforts reported in (Scheucher, Bailey, Guetl, & Harward, 2009; Guetl et al., 2012; Guetl & Pirker, 2011) adopt Open Wonderland virtual world environment to extend physics experiments to virtual world environments thus allowing collaborative abilities and more.

Figure 7: Avatar of a student talking to a River City resident (Clarke & Dede, 2009).

Immersive VLEs rely on the co-existence of learners in the environment and therefore are supported by *social-constructivism* for learning. Constructing an immersive 3D learning environment and giving avatar abilities give the sense of immersion and create the immersion pedagogy to improve learning, but several pedagogical services are still needed. Further potential learning scenarios can be developed on top of the available virtual world. Another contributing factor is the potential scale of the virtual world and the volume of possible undiscovered learning resources given the millions of contributing users to those environments. Also, Immersive Virtual Learning Environments provide learning opportunities that rely on *active exploration*. A major design factor for virtual worlds such as second life is the scalability of resources and users. This implies a potential for massive learning resources to exist and to be explored by the learner supporting *active learning* principles. In other words, the immersive VLE can enhance learning experiences with just in time learning is exploited. This represents a major design factor.

3.2.1. Technological Perspectives with Learning Objects

The 3D visual appearance of immersive VLEs create an opportunity for providing visual simulation for learning that puts a learning object as an important entity in the world. This allows the learning for example to run a 3D simulation, not only individually but also in collaboration with remote peers. This allows simulating an experiment in 3D with possible connections to a physical device (see Figure 8). The TealSim module which is a part of MIT's Technology Enabled Active Learning (TEAL) project is an example (TEAL, 2013). The use of virtual worlds for education was utilized in this project to transfer a simulation of the capacitor function shown in to a 3D virtual world of Open Wonderland utilizing Java3D in both implementations. Instructional support can be added through an instructor avatar.

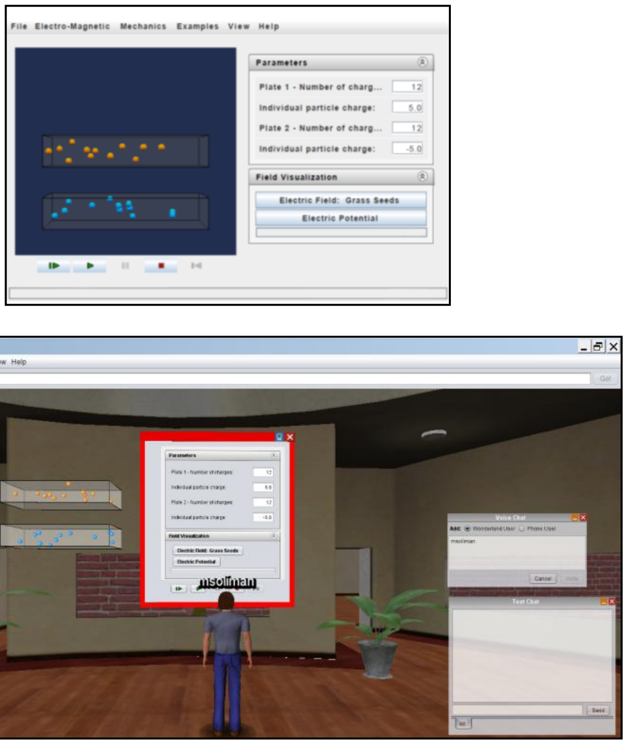

Figure 8: Capacitor simulation in the TealSim module and its implementation in Open Wonderland. Once deployed, it does not only give 3D immersion but also offer visual collaboration. Verbal and non-verbal communication abilities are possible in a virtual world.

Implementation technologies of the virtual world are of important consideration to realize further learning functions in 3D. In observing implementations, Second Life as a virtual world uses Linden Scripting Language (LSL) that is C like to create 3D interactive content. LSL describes objects in the virtual world and it is event-driven meaning that an object event will trigger execution of an LSL script. In contrary, Open Wonderland is a client server pure Java-based environment and hence it is convenient for being Java3D enabled. On a note, Wonderland allows importing 3D models to create the scene of the environment. Different technologies and standards contribute to the design. Wonderland considers the X3D standard objects (Web 3D Consortium, 2013; X3D, n.a.). X3D is an XML like format for representing 3D objects. It is used to create objects in those virtual worlds such as Second Life and project Open Wonderland. The use of the object format promotes reuse of objects and help in the scalability of the virtual world. The self-describing ability of those objects, if well utilized, can support learning functions and thus can also promote active learning through exploration. Another relevant technology standard is the Virtual Reality Modeling Language, VRML (Web 3D Consortium, 2013). 3D representations in Virtual worlds are adopted by the use of a scalable object model using VRML. VRML supports URLs meaning that the user can select a part of the 3D object to navigate to a website. It supports environment objects' construction as well as their animation.

3.2.2. Learning Affordances of Immersive Virtual Learning Environments

Effects in using a 3D VLE are categorized by Dalgarno and Lee (2010) to be: *construction of identity*, *sense of presence*, and *co-presence* (see Figure 9). In order to describe the benefits of 3D virtual environments given to a learner, Dalgarno and Lee (2010) use the concept of *affordances*. An *affordance* is first established by Gibson (1986, pages 127-143) as a utility of an object or environment, not in an absolute form but in relation to an observer. The learning affordances by Dalgarno and Lee (2010) of a 3D learning environment are summarized to be: *spatial knowledge representation*, *experiential learning, engagement, contextual learning*, and *collaborative learning.*

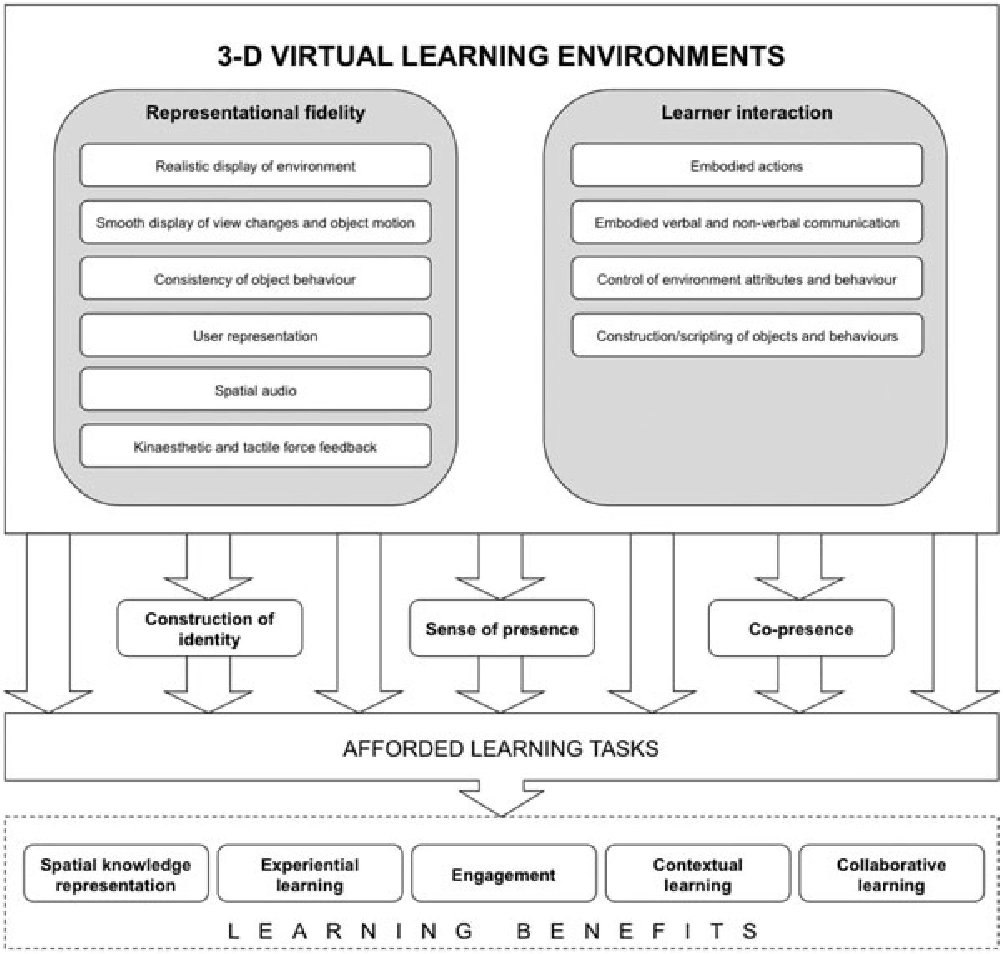

Figure 9: Model of learning affordances in 3D virtual learning environments (Dalgarno & Lee, 2010).

Spatial knowledge representation is relevant to the learner ability to experience changes in the visual scene within time. As discussed above, it contributes to increasing retention and enhancing a learning activity. With different theoretical learning models, the research suggests the *experiential learning* benefits of a virtual word. It places the virtual world as a delivery environment for *learning by doing* settings that offer the constituents of the experiential learning model discussed in Chapter 2. *Engagement* of learners as a result of the sense of presence is very important concept to educators that ensure continuity of the learning process and thus it makes the environment very appealing for consideration in learning deployment. However, engagement is not absolute and can be hindered in situations that negatively affect the learner such as the inability to find peers in discussions or failure to complete a task.

In contrary to 2D environments, *contextual learning* is enhanced in virtual worlds to improve transfer acquired knowledge and skills to real world situations in relation to authentic learning concept discussed above. This ability has evidence in the implementation of contextualized remote labs presented by

Machet, Lowe, and Guetl (2012). With the availability of multi-modal communication functions, the *collaboration* affordance is evident.

3.2.3. Pedagogical Limitations of Virtual Worlds

A major characteristic in virtual worlds is related to their orientation of evolution from online games. While gaming environments makes learning more fun with serious games, they lack disciplined pedagogical design orientation. They can be further set for other application purposes such as marketing, in the case of Second Life. Pedagogical design consideration can improve virtual world offerings to learning.

When the virtual environment becomes increasingly bigger with abundance of available places to visit and learn from, pedagogical scenarios are pervasive. Guidance is needed to aid the learner to find places, learning resources, or peers relevant to the educational goals and need to follow a disciplined and pedagogical-aware learning activity. Given the potential number of collaborators in the virtual learning environment, and with the possible individualization abilities for pedagogical objectives (Scheucher, Bailey, Guetl, & Harward, 2009), support is needed to automatically finding effective peers to collaborate with. This support can be given in way that understands the learner abilities and the associated learning goals. As it will be described subsequently, effective group formation considers the background of learners. Intelligent Tutoring Systems (ITSs) considered *personalization* methods to improve Web-based learning by creating adaptive learning environments based on individual learning needs and properties. Evidently, understanding the learner is crucial to effective learning in virtual worlds as well. Several personalization tactics can improve the active explorations and collaborations in virtual worlds as well if the learner is well modeled in the environment and if such representation can be safely discovered and used.

There is a need for autonomous learning support in virtual worlds. For example, for learners who do not get peers find themselves alone with lack of guidance. Unless there are educator avatars available for support, learners do not get enough support and suffer from lack of expert guidance. Another problem is the need to feel that the environment is being inhabited. Otherwise, the learner feels bored and reluctant to learn. Furthermore, similar to pedagogical tactics that ask for more engagement in the classroom, there should also be ones in the virtual world so as to motivate and engage learners to complete learning tasks. In general, it is achieved by adopting methods for managing the environment towards immersive and autonomous learning support.

Learning by doing is suggested in a virtual world with experiential learning theory is one of its affordances. Support to task completion is required so as to improve learner motivation in accordance to the self-efficacy theory discussed in Chapter 2. What is the best way to improve these aspects given ways to track learning progress and scaffolding learning or training?

What if the learner is offline, are there services in immersive environments that can give learner support as well? For example, it is to capture interesting educational events or exchange resources. Learners may interact with others who are offline if their agent representations have intelligence capabilities, for example as a virtual tutor if the instructor of the virtual university is away or as a student collaborator otherwise.

Narrative and dialogue functions provide increased engagement in the environment and promote better learner motivation. While narration has proved to improve the sense of presence in the environment (McQuiggan, Rowe, & Lester, 2008), an uninhabited environment is less engaging.

In summary, immersive VLEs are in need of improvement to have the following characteristics:

- A 24/7 available and automated learning support.
- A one-to-one interactivity with an educator.
- Means to obtain intelligent navigation support.
- Utilize the affordances of the 3D environment and personalize it for the learner.
- Motivation functions.
- Methods for increasing engagement in the learning session.
- Ability to monitor progress, scaffold, and provide assessments.
- Intelligent support to collaborative learning functions.
- A peer like entity with narrative and dialogue functions.
- Intelligent navigation in the environment for pedagogical objectives.
- Pedagogical awareness in general.

3.3. Conclusion

The unique characteristics of immersive virtual environments in providing rich visualizations, sense of immersion, and multi-modal communication abilities encouraged educators and educational institutions for their deployment in education. Immersive environments create the *sense of presence* and the context that adds to learning by doing in forms of experiential learning affordances. An important aspect of the environment is the user representation of an avatar that influences the user behavior that can contribute to learning in those environments. The affordances of learning in immersive environments include *spatial knowledge representation, experiential learning, engagement, contextual learning,* and *collaborative learning.* Thus it encouraged utilization of virtual worlds for learning in several institutions worldwide, as discussed in the Chapter. The utilization efforts included different subject matters including physics education and ability to even take labs to become online.

With those affordances, immersive environments such as virtual worlds provide a very promising medium to deliver innovate learning methods. However, there are problems relevant to the need for smarter and learner-centered education methods. In immersive environments, learners' motivation is required; support of engagement should be available 24/7. They require intelligent methods for learning support towards creating lower educator-to-learner ratio. The possibility of creating autonomous software and intelligent pedagogical support can fill this gap and enhance the learning offering of immersive virtual environments.

4. Intelligent Pedagogical Agents

There is a need, as discussed in the previous Chapters, for automated learning support in immersive virtual learning environments. One major concern with e-learning systems over traditional methods is the lack of face-to-face interactions, and consequently motivational concerns occur. However, other forms to increase interaction with the learner could be sought. The inability to provide 24/7 support to a wide range of learners can make an educator unable to fulfill all the needs. An educator avatar is not enough in giving one-to-one learning support in those environments. Instead of an avatar directed by a user, a pedagogical pro-active and autonomous approach is needed to assist in pedagogical undertakings and act with or on behalf of the learner in the environment. Research has shown that adding a human or a creature shape to the interface in a virtual learning environment can improve interaction with the computer and fill pedagogical gaps in the learning environment. Adding conversation and animation abilities give to the potential for increased interaction and engagement. Furthermore, computerized and intelligent functions can be further investigated from a pedagogical value perspective, as discussed later in Chapter 5. Those mentioned characteristics contribute to the construction in research of what is so called Intelligent Pedagogical Agents (IPA). This Chapter discusses IPA characteristics and its potential for providing smart learning function in the potential environment. In order to achieve this objective, a literature review is provided in this Chapter that adopts published work in Soliman and Guetl (2010a; 2010c) while further intelligent functions that can be associated to pedagogical agents are the main focus of Chapter 5.

This Chapter is organized as follows: Section 4.1 discusses early forms of pedagogical agents with different forms. Section 4.2 discusses affective aspects of pedagogical agents and how can the learner perceive them. Section 4.3 discusses aspects relevant to the realization of intelligent pedagogical agents. Section 4.5 is a conclusion.

4.1. Pedagogical Agents with Various Forms

The concept of IPA has evolved from different character forms in those environments. From its name, the concept of an Intelligent Pedagogical Agent (IPA) is characterized as[1]:

Agent: The agent is a software component that can act by itself in the environment based on a goal (Jennings & Wooldridge, 2000; Wooldridge, 2002).

Intelligent: An intelligent agent applies AI methods to achieve goals (Russel & Norvig, 1995). The intelligence ability of the pedagogical agent adds power to learning support functions. Intelligence can be characterized by the agent ability to learn from the environment and adapt behavior accordingly to achieve the design goals.

Pedagogical*:* It possesses pedagogical awareness and abilities to make learning more effective. As Alexander (2004) defined pedagogy as *"the act of teaching and its attendant discourse"* (see Section 2.1.1), IPA pedagogical abilities can include tutorials, feedback, answering questions, and providing assessment functions. Each agent will act and interact with the environment based on pedagogical goals.

In order to support pedagogical functions, the use of virtual characters in an ITS has been suggested as an effective method to compensate for the lack of face-to-face interaction (Lester et al., 1997). The Microsoft office assistant is a simple example where the user asks questions and the assistant, shaped as a virtual character searches for answers or recommends tutorials. The learner can choose a character that can provide facial expressions. Animated virtual characters that can guide the learner are sometimes named guide bots. Table 6 gives examples of commonly used agent characters in literature.

Table 6: Popular pedagogical agents with character in research.

Character	Nature	Source
Herman the Bug	Virtual character that teaches student biology	(Lester et al., 1997)
Steve	Intelligent Pedagogical Agent, can demonstrate tasks, offer advice, and answer questions.	(Johnson, 2001)
Adele	A Case-based reasoning agent	(Johnson, 2001)
Peddy	Virtual animated character agent that can teach, has tools for speech recognition and synthesis	(Peddy, Online)

Examples of those characters of famous pedagogical agents are the Soar Training Expert for Virtual Environments (Steve) and Adele. Steve is an

[1] Several paragraphs of this section are adopted from Soliman and Guetl (2010a).

intelligent pedagogical agent that can demonstrate tasks, offer advice, and answer questions. Adele is also a pedagogical agent that provides pedagogical support to medical students. Steve and Adele are shown in Figure 10.

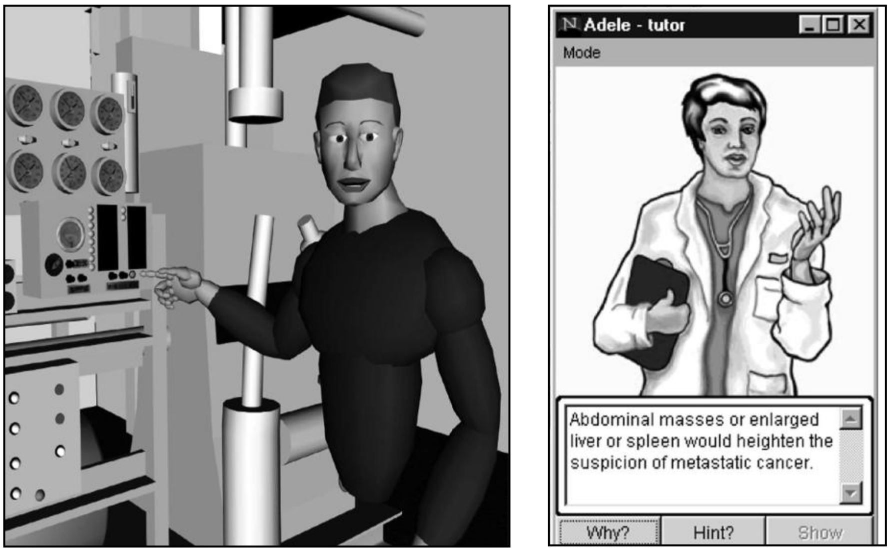

Figure 10: Steve and Adele pedagogical agents (Johnson, 2001).

The development of further capabilities in virtual characters leading to smarter ones with human-like appearance has led to the notion of embodied agents. Table 7 gives the meaning and characteristics of relevant used terms to show how the concept has been used in various forms but for similar goals. Common to all those categories is the character objective of improving affection to compensate for the lack of face-to-face interaction in dealing with the machine by expressing feedback emotions in gestures or through verbal dialogues with the learner. Research has shown the effectiveness of characters in improving this aspect of learning (Lester et al., 1997; Wang et al., 2008). Wang et al. (2008) investigated this aspect to show that an agent that exhibits a polite behavior provides a significant improvement on the learning result compared to other ones.

Table 7: Examples, meanings, and characteristics of relevant terms used in conjunction with intelligent pedagogical agents.

Term	Examples	Meaning and Characteristics
Agent		Autonomous entity with goal.
Virtual Character	Herman the bug, Steve	Has character. An animated form is named animated virtual character, an HCI term.
Embodied Agent	Microsoft Agent	Has physical body, stresses the visual appearance Embodied Conversational Agents have conversation abilities. An Artificial Intelligence Term.

Pedagogical Agent	Adele	Stresses pedagogical functions.
Intelligent Agent		Stresses AI intelligence abilities.
Guidebots	Steve (Johnson, 2001)	Stresses guidance functions to stimulate and encourage learning.
Avatar	Second Life & Open Wonderland Avatars	Incarnation of the user in the virtual environment. User selected appearance. Mainly used in 3D virtual environments to emphasize personal preferences. Guided by user.
Intelligent Pedagogical Agents	(Wang et al., 2008)	Combines different abilities including intelligence and pedagogical orientation. Autonomous and not directly guided by user.

In literature, the concept of Intelligent Pedagogical Agents (IPA) provides more advanced forms than just characters. In the research work of Qu, Wang, and Johnson (2004), a pedagogical agent has been used to detect and interact with the learner in suitable times such as confusion and indecision to resolve difficulties and increase motivation. The learner eye gaze has been used as input for a Bayesian network for reasoning. In a related aspect in increasing interaction with the learner, the work by Johnson (2003) targets improving the interactions between the computer and the learner by means of animated pedagogical agents. This work tries to solve the problem of interaction expectation with the pedagogical agent by means of social intelligence tactics. In addition to intelligence addition for an individual setting, group intelligence support methods are discussed later in Section 5.5 stressing the social significance. With the proven potential of learning support of pedagogical agents in social settings, Kim and Baylor (2006), in a related work, formalize the constituents of pedagogical agents as learning companions in relation to supporting social learning theories (see Figure 11). The constituents of the pedagogical agents, provided by Kim and Baylor (2006), are: *competency, interaction type, gender, affect, ethnicity, multiplicity,* and *feedback type*. Common to the model, is stressing the social component of interaction. Furthermore, the model signifies the discussed properties of pedagogical agents when they can act as learning companions proposing pedagogical agent value to multiple learners in social settings as well.

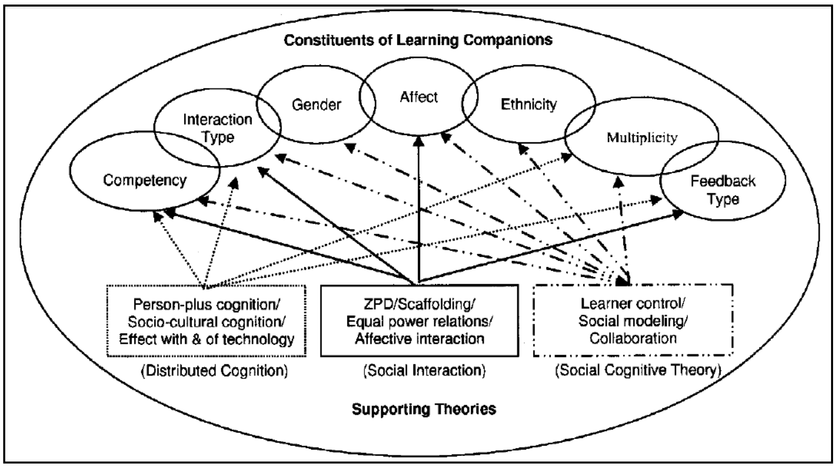

Figure 11: Constituents of pedagogical agents as learning companions (Kim & Baylor, 2006).

IPA can have a significant impact on increasing the learner motivation. This is suggested in an early study conducted on an early IPA; *Herman the bug* (Lester et al., 1997) on 100 middle school students. The study concluded that: *"Well crafted lifelike agents have an exceptionally positive impact on students. Students perceived the agents as being very helpful, credible, and entertaining."* (Lester et al., 1997).

One important theme of research in computer-aided learning is the role of personalization based on building and capturing user models. Pedagogical agents have been also used for user-models based personalization. The research work by Ashoori et al. (2009) supports *personalization* in virtual learning environments in general through the use of intelligent pedagogical agents. In this work, agents extend prior human-like characters to provide personalized learning services such as the mentor-agent and the guide-agent (Ashoori et al., 2009). The pedagogical agent obtains information of the learner qualifications, interests, and activities through interaction and by reading the user model and act upon the learner based on those models. Chapter 2 discussed the importance of personalization in understanding the learner and his interaction and providing learning support accordingly.

In relation, Intelligent Tutoring Systems (ITS) tried to exploit machine intelligence to support the learner in a personalized way (Qu, Wang, & Johnson, 2004). Since ITSs assume that the learner uses computerized support instead of the human instructor, virtual characters have been developed to improve interactivity (Devedzic, 2004), trying to compensate for the lack of the human aspects in that form. But it resulted in discussions of whether e-learning is better than classical methods and that led to the blended learning approaches. In studying the reason for such a debate, the problem of the lack of face-to-face interaction had consequences in motivational aspects. The particular methods of intelligence support are discussed in Chapter 5.

Another aspect of improving learner interaction with the learning environment is through creating dialogues with the learner to improve learning situations, provide guidance, resolve difficulties, and improve motivation. This can improve learning results with handling the different type of learning styles such as verbal-linguistic learners as suggested by the theory of multiple intelligences (Gardner, 1983; Soliman & Shaban, 2009). Pedagogical agents gain can provide narrations or adapt conversations with the learner. In an early publication in 1999, Mott et al. (1999) provided insights into *narrative-centered learning environments* by the use of IPA from *narrative intelligence* of AI. The research outlines what computer generated narration, by IPA can contribute to effective learning. Subsequently, several research efforts added narrative functions to learning environments, by the aid of agent intelligence. For example, Jones and Warren (2010) suggest simple personalized and directed instructional narratives to the learner to provide instructional value and save class time. This is accomplished by the use of scripted IPA. In that work, different narratives are stored in a database and contextually retrieved on demand during the learning discourse.

4.2. Emotion, Affection, and Believability of Pedagogical Agents[1]

Emotions play a significant role in learning. For example, learner motivation is highly affected by the emotional state and can lead to higher learning results. Human emotions are complex to understand and have its own theme of research. Gratch and Marsella (2004) reported that emotions have effects on human decision making ability in learning. The authors showed that traditional AI capabilities can be extended by artificial emotion research and hence it took its share in AI research. *Affective computing* became an established research theme of artificial intelligence that works with finding computational emotion models. There have been several steps taken in integrating emotions in pedagogical agents to improve HCI with the learner. Providing gestures and animations of the pedagogical agent or providing conversations with the learner are of interest to the researchers in the field, as will be shown later. Emotions add believability to personification aspect thus enhances learner engagement.

Traditionally another evidence of the importance of emotions in learning is found in the famous model of Bloom's taxonomy for educational objectives as it includes the affective domain. Emotional modeling tries to understand emotions and build a computational model with the emotion states and their triggers. The OCC model of emotions, by Ortony, Clore, and Collins (1998) is found to be

[1] Several paragraphs of this section are adopted from Soliman and Guetl (2011c).

widely used among researches in relevant topics. The OCC model provides an organization of emotional states and how they are triggered (see Figure 12). The OCC model classifies 22 emotion types. The emotions are generated as of valenced reactions in consequence to events, actions by agents or characteristics of the surrounding objects in like or hate. With this model that includes agents and objects, it found its suitability as a standard for utilization in artificial characters such as in Bartneck (2002).

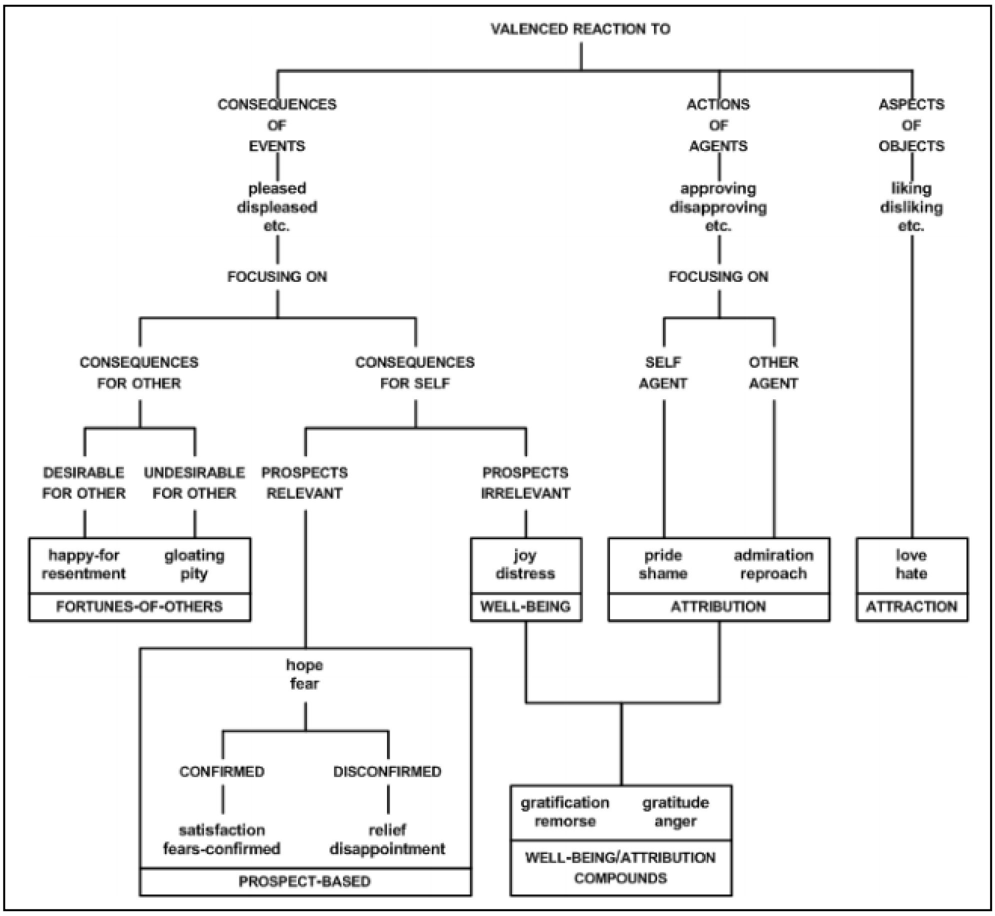

Figure 12: Global structure of emotion types (Ortony, Clore, & Collins, 1998).

Ailiya, Shen, and Miao (2010) use OCC rules to implement emotions by involving Fuzzy Cognitive Map, FCM. The research gives details of the rule-based emotion elicitation that considers the emotions' causations of events, agents, and objects. Alternatively, Ochs, Sadek, and Pelachaud (2010) represent emotions in agents as mental states of beliefs, uncertainties, and intentions. The research focuses on the empathy aspect of emotions and defines it as an important factor for learning with the ability of the agent to feel or put itself in the emotional state the learner. For example, the agent feels sorry for the learner failing to answer a question. That research effort also provides the definition of artificial empathy and empathic virtual agents in good detail. It categorizes the empathetic agents found as of only two categories: *Happy-for* and *sorry-for* agents as a result of goal attainment or not by the learner. And therefore it dictates the need for more. It also states the different emotion interaction patterns:

- Learner empathy towards the agent.
- Agent empathy towards the learner.
- Among agents themselves. Example: Agent behavior and emotional state change in mine discovery game as a result of events.

Empathy is an example of an emotional strong mutual reaction that occurs in social interactions. De-Melo, Carnevale, and Gratch (2010) studied social effects of emotional pedagogical agents on learning, in general and on decision making, in particular. The research considered five emotional states appeared in facial expressions of an agent: *neutral, joy, sadness, shame*, and *anger*. It also studied the effects of agent emotion dynamics according to the environment situation and its effects on the cooperation and interaction with the human. The study showed that "*participants are sensitive to differences in the facial displays and cooperate significantly more with the cooperative agent*" (De-Melo et al., 2010). The conclusion is that emotions influence the HCI interaction as it adds a new channel to listening or viewing. People can infer information looking onto facial expressions. It is worthwhile noting that the agent is a central concept to include emotions in virtual learning environments as it is the only possible representation to emotions to it. Studies with the *persona effect* have shown that learners are engaged more with agents that express emotions (De-Melo et al., 2010).

Research with *politeness* of the facial expressions of the pedagogical agent supports the impact of emotion presentation on the learner, in general and its relation to the *persona effect* in particular. Wang et al. (2008) and Jaques and Viccari (2004) discussed the politeness theory based on Brown and Levinson (1987) in social intelligence within the scope of pedagogical agents. The Brown and Levinson theory of politeness (Brown & Levinson, 1987) as cited by Wang et al. (2008) differentiates between the positive and negative face threats on learners. Wang et al. (2008) regard the *politeness effect* as a major motivational drive for the learner and report higher learning outcomes with polite pedagogical agents compared to non-polite ones. The same research stresses the significance of the *politeness effect* of the pedagogical agent when compared to the *persona effect*.

Determining the emotional state has two sides: the emotional state of the pedagogical agent and the emotional state of the learner. The emotional state of the pedagogical agent changes according to the emotional state of the learner, with empathy for example, or according to events occurring in the environment. Change in the emotional state is referred to emotional elicitation and it occurs due to a change event in the environment, belief or intentions (Ochs et al., 2010). It is possible to infer about the learner emotional state through pattern recognition after capturing the face picture since it is evident that emotions change facial expressions. It can be done also by the means of specialized sensing and measuring devices attached to the human body in a form of wearable devices, or inferred from user beliefs or intentions. Jaques and Viccari (2004) summarized methods to infer user emotion states (see Figure 13). The determination of the learner emotional state, if used properly as an input to pedagogical agents' affection, can improve learner interaction, learner attitude towards learning and lead to better learning results. The research work by Jaques and Viccari (2004) contribute affective tactics of agents based on the Belief-Desire-Intention model, BDI of agents that will be discussed in a later Chapter. Those tactics are based on events occurring in the environment. Jaques and Viccari (2004) analyze those tactics according in intrinsic or extrinsic motivation toward learning and their resultant behavior. The choice in this research of the BDI is based on the possibility of cognitive understanding of emotions. This choice can be fortunate as the BDI model is implemented in intelligent agents and can be integrated with other cognitive skills.

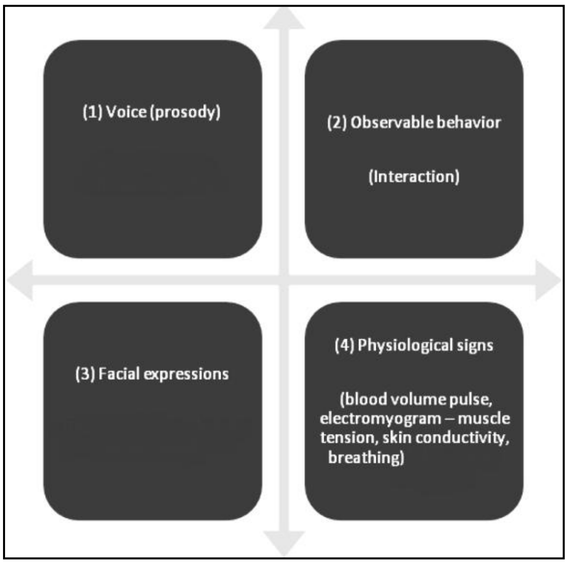

Figure 13: Four methods of capturing user emotional states (Jaques & Viccari, 2004).

When working with emotions becomes possible and automated, pedagogical agents are needed for:

- Increasing believability within the learning environment.
- Engaging the learner and capturing attention.
- Elevating emotional state. That can be achieved through removing frustration caused with difficulties or failure in a task using empathy-affective tactics.
- Alleviating negative emotional states and creating positive learning situations.

- Determinations of emotional states and learning moments that can negatively impact learning.
- Improving motivation: providing appraisal and suppressors for learning.

4.3. Issues on Realizing Intelligent Pedagogical Agents

The realization of an IPA involves creating a virtual character and incorporating lifelike features including human-like animation, emotion elicitation, and dialogue. Pedagogical functions are to be added to the human-like character as well. With the lack of better behavior and intelligence, believability of the agent is lower thus leading to lower learning engagement.

In the literature review, it is found that an AI component of the pedagogical agent is important to provide adaptive and smart functions to the learner as well as realizing the above mentioned pedagogical agent characteristics. This is to provide reasoning functions and adapt the behavior to be aware of the environment and the learner. Furthermore, a significant component of the IPA discussed in the Chapter is the social component that suggests the importance of distributed intelligence abilities.

The artificial intelligence support for the pedagogical agent can take various forms with different methods for adding intelligence support. For example, the work by Quirino, Paraguaçu, and Jacinto (2009) employs case-based reasoning techniques to tutoring. An IPA in this research work reads from a database of cases and adapts prior cases to reuse them in tutoring medical students. The IPA in the same work (Quirino, Paraguaçu, & Jacinto, 2009) had the following properties: *domain-specific knowledge*, *autonomy*, *communicability*, *learning*, *reactivity*, and *pro-activity*, *social skills*, *customization*, and *learning abilities*. Those functions are realized by means of AI methods. A particular model of interest discussed is the intelligent agent model. It is required to answer how in particular the intelligent agent model or other relevant models, can realize sought characteristics in pedagogical agents.

Yet, research of pedagogical agents has not exploited the full potential of the use of Distributed Artificial Intelligence (DAI) since pedagogical agents can be multiple and intelligence can be distributed in a virtual learning environment. Most of the work on pedagogical agents focused on the visual appearance and interface with the learner as a character. However, there are lots of potential of intelligent agents capabilities, especially of AI, social abilities, intelligent resource location, negotiation, and social abilities that can bring several useful learning scenarios for collaboration in the virtual learning environment. Common to the intelligent agent model is the ability of the agent to act autonomously which is a desired characteristic in attempts to imitate human behavior. The intelligent agent, as a method of learning support, is discussed in Chapter 5.

It is also important to mention challenging aspects for the IPA that might provide negative impact on learning. Learning from a pedagogical agent is obviously from a non-human to raise issues for research while the interest in this thesis is to fill gaps relevant to the need for them. For example, while an association of a human-like character as a tutor, younger children can confuse between a real person avatar and the pedagogical agent in comparison to reality. Revealing a false emotion can also result in negative result. It is well known that too many and unnecessary animations lead to negative results as well. Cognitive research can reveal the impact of the character shape or *persona* differences on that aspect while it is not in the scope of this thesis to differentiate between characters. However, relevant aspects are considered in the suitability of the selection of gestures and the selection of the IPA shape.

In an immersive virtual learning environment, it is expected that the learner will have flexibility and control over numerous active explorative learning resources. The learner requires intelligent support and guidance with those vast resources. Newer pedagogical scenarios with new innovation possibilities can also be added as a result of the new forms of immersive education. The IPA can act as a teacher, learning facilitator, or even a student peer in collaborative settings. The IPA will guide the learner in the immersive virtual environment, explain topics, ask questions, give feedback, and help the learner collaborate with others. It provides personalized learning support and acts on behalf of the learner in different times in virtual places. It is particularly vital that the agent acts pedagogically in the immersive environment. Realizing IPAs in the 3D VLE is not an easy task as it considers several factors including pedagogy, learning environment constraints - current and future functions, architectures, technologies and more. But it helps in the road map for effective learning in the environment. The purpose is seeking the best model that suits elevating educational functions of the immersive VLE to the learner by the means of IPAs working in this special environment. The pedagogical strategy the agent will undertake should be compliant with the properties the immersive environment will provide, as discussed in Chapter 3. An example is taking the approach of experiential learning by doing.

The immersive VLE is also expected to be scalable with numerous learning resources as discussed before. This provides advantages if the content is personalized to the learner depending on his needs and abilities. I.e. it is to have controlled active explorations in the environment rather than random ones. If the environment is scalable encouraging users' contributions with learning resources, intelligent navigation guidance and learning support among those resources are highly needed. Considering reliability of the learning content, having compatibility of learning resources, language, and cultural issues are examples. Adding constraints to the design elements of the VLE does not solve those problems but can complicate and then hinder the environment scalability. The use of intelligent agents rather can overcome those obstacles to discover and present reliable, consistent, and cultural-safe resources and scenarios in those environments. Other agents or the same ones can be working in the background to support group communication and learning, which is one of the major advantages of the VLE that brings distant learners closer. Agents can support this as well in the environment (Soliman & Guetl, 2010b).

Furthermore, design of the IPA should consider several aspects including interactivity, dialogues with the learner in different forms, emotions, pedagogy, and collaborative functions (Soliman & Guetl, 2010b). Irrespective of the VLE aspects, intelligent pedagogical agents have the following aspects of design considerations:

- *Learner-IPA interaction elements:* IPA provides a smart user interface. As shown in Soliman and Guetl (2010a), IPA can be a character that can provide smart gestures to attract attention and speak to the learner. IPAs are considered then effective to improve the sense of presence in the immersive VLE and hence motivation. Several works include dialogue abilities as well.

- *Agent design aspects:* For the IPA to interact with the learner in the environment, knowledge about the learner is considered. For example, the ability to interact with a learner profile. Pedagogical goals are given to the agent.

- *Multi-agent design:* Pedagogical agents are socio-cognitive entities. Providing smart pedagogical functions in the social context are needed in the environment. An intelligent agent-oriented approach gives distributed intelligence abilities. This function facilitates smart collaborative learning support (see Section 5.5).

- *Interaction with the environment objects.* It is the ability of the agent to interact with learning objects in the environment to understand and to control them for demonstration to the learner.

Interaction with the environment objects approach mandates technological consideration. For example, an IPA can read a 3D object in the environment, understand it, present it, and follow up on the relevant learning goals. With the reusability requirement of a learning object a standard like X3D is possible. The pedagogical agent can play a major educational role by interacting with self-describing 3D objects to aid learning, extending the avatar roles in Paredes et al. (2009). While this provides scalability gains in creating learning resources, pedagogical agents are needed to help in providing intelligent navigation and guidance support to learners in those environments. With this approach, just-in-time learning can be accomplished in such scalable environments.

Intelligent pedagogical agents thus can be viewed as autonomous and intelligent software entities that act on behalf or with the learner for a pedagogical objective. That resonates with intelligence capabilities taken from distributed AI (Soliman & Guetl, 2010b) and thus can complement the VLE for effective learning experience. In research, IPAs took various forms from simple characters to embodied agents and avatars. The use of such agents have been used for the purpose of improving learner interactivity and engagement by providing several functions such as expressing emotions, conducting dialogues with the learner, tracking learner actions and states, and providing learning feedback. Those functions should be integrated in an intelligent method.

4.4. Conclusion

This Chapter presented a literature review relevant to pedagogical agents with different forms. Those forms included characters, virtual humans, guide-bots, and more. It is found in research that a positive impact on learning and change in motivation of the learner occurs as a result upon interaction with a pedagogical agent. Different learning functions of pedagogical agents, presented, shed light into what can exist as supporting functions to deploy with pedagogical agents. Common to these functions is the resulting increased interaction and engagement potential that pedagogical agents can provide. That is in addition to the one-to-one interactivity property. Pedagogical agents take strategies and perform learning support functions such as tutorials, monitoring, and more.

The emotion elicitation component of pedagogical agents is an important component that impacts it associated believability and consequently the interest to work with it. There are two sides explored of emotions: capturing user emotions, and eliciting emotions by the pedagogical agent. With these properties, sympathy with the learner can be achieved.

While the pedagogical agent is found to play several roles, it is viewed to be also a close learning companion to the learner who needs pedagogical and motivation support. In such a case, it is suggested that the pedagogical agent be the central point of interaction between the learner and the learning environment. With that, the pedagogical agent conducts activities that are adapted to the learner who is working with. Embodiment of the pedagogical agent hence is needed so as to provide a representation in the environment. Associated to embodiment is the *persona* effect that has shown to provide positive results in learner attention and engagement.

Towards the objective of realizing pedagogical agents, intelligent behavior is needed. Intelligent tactics are sought to support pedagogical agents to act and interact with the learners smartly, be able to reason about its state such as emotions, to infer the learner emotional state, and to set the character to act intelligently given the human-like embodiment. An example approach is the use of intelligent agents that will discussed along with relevant other methods in the next Chapter.

5. Intelligent Methods for Learning Support

This Chapter discusses methods relevant to the realization of intelligent pedagogical agents focusing on the intelligence component in general, for different pedagogical aspects. Those aspects include how intelligent agents are used in realizing *personalization*, the use of intelligence for *cognitive support*, *self-regulated learning,* and *group learning* support. A special aspect is how an intelligent agent becomes *teachable* by the learner. Intelligent methods to be used in the realization include the use of *Bayesian Networks*, *Hidden Markov Models*, the *Belief-Desire-Intention* model of intelligent agents, and other *cognitive* models. How they are relevant to realizing human learning functions with intelligent agents is discussed from an educational perspective. The Chapter further provides a review of how intelligence support is given to collaborative learning and team training.

The Chapter is organized as follows: Section 5.1 provides an introduction about AI in education. Section 5.2 reviews the topic of agent-based personalization which took other forms presented in other sections. Section 5.3 is focused on cognitive and meta-cognitive components in learning, what research has been done, and how it supports the learning process from different aspects. Section 5.4 discusses a special case that improves the learning which is the ability to teach a pedagogical agent and its method of implementation. Section 5.5 discusses the research when agents are used for team training and discusses relevant issues. Section 5.6 is concerned with surveying pedagogical functions as a result of interaction among different agents and support for collaborative learning. Section 5.7 provides summary and conclusion in preparation for steps taken to select methods of realization. This Chapter adopts work published in Soliman and Guetl (2010b; 2011c).

5.1. ICT, AI, and Pedagogy

The current use of technology in education has proved to offer benefits to distant learners. While there is the proliferation of the tools to education, still there are very promising areas to improve specially in considering teaching effectiveness as a goal and considering implementation of pedagogical strategies. Tools for collaborative learning, adaptive and personalized instruction, automated and semi-automated assessment provisioning, visualization, pedagogical guidance, and more all are possible but not yet fully utilized given their potential and value for instruction. There are particular values to the use of new advancements of ICT: scalability, reachability, convenience, and cost-effectiveness can make such tools wonderful to be utilized for teaching. However, the use of machines for learning cannot substitute an experienced teacher. And therefore, the use of ICT in education has been done in ways that do not replace teachers, such as blended learning. But in the quest for using ICT for education purposes, researchers found great windows of opportunities in employing the machine to aid learning in an intelligent way as by utilizing AI in education. The use of the Artificial Intelligence (AI) models can contribute with new functions to serve those objectives.

For human learning, investigating the pedagogical foundation of learning scenarios with technology is a necessity. For example, what makes collaborative learning very effective? How to guide learners digitally? How to motivate learners? How to provide healthy and productive digital learning experiences? With those questions in mind, one can highly contribute to learning given the scalability, intelligence, automation, and availability of computing nowadays anywhere and anytime. One may also discover that there are new possibilities that were not possible in a classroom before.

Considering AI to support learning is an extension to those ICT utilizations. AI has been considered in Intelligent Tutoring Systems over decades to provide smart learning support. While there are several AI methods, a model of interest is the intelligent agent model to realize suggested pedagogical functions. Intelligent agents are multiple active software entities that can have pedagogical design purposes. Those agents are goal-oriented, are acting upon or with the learners towards those goals by being equipped with intelligence abilities. Those entities can also interact and negotiate learning objectives. In this case, the goals are pedagogical. In investigating new AI methods, the human mind has been also considered to study and understand. This Chapter considers investigating how the human mind think and learn and how learning can be supported by intelligent pedagogical agents. With artificial intelligence capabilities, Intelligent Pedagogical Agents (IPAs) can support learning functions, and provide new possible learning scenarios when equipped with AI functions. While this Chapter discusses different methods of AI-based pedagogical functions, the intelligent agent model is a common denominator among those functions with possibilities of extensions by implementing the functions in the intelligent agent itself. It is found and discussed below that the intelligent agent paradigm provides a “suitable” paradigm for supporting intelligent pedagogical agent realization. And therefore surveys focused on that model.

Why Intelligent Agents for Education?

According to Jennings and Wooldridge (2000), an agent is a proactive and autonomous software entity. An agent has a sensing mechanism to respond to environment events. Agents proactively act in the environment based on goals. The environment of inhabiting agents is named a *society of agents*. Since there are multiple agent goals, and with the autonomy of the agent behavior, the multi-agent model is a distributed computing paradigm. With that, agents may have different conflicting goals which give closer model to reality. Agents negotiate to resolve conflicts in order to achieve those goals or coordinate to achieve a collective task by coalition of different agent intelligence abilities. Agents can also play a significant role in data fusion and delivery in a distributed environment, not only for learning but also for different application domains such as in (Wang, Chen, Kwon, & Chao, 2011). In the virtual learning environment, learners are interacting with the environment and with back-end tools, or software entities, that can automate goals or provide learning services as possible to learning. The goals can be individual learning goals or organizational learning goals. The agents can be viewed as dynamic gluing mechanisms to those goals with their autonomous and proactive nature not existing in other paradigms. The use of agents is an excellent model for a distributed learning environment that provides a balance and solution between individual learning goals and the environment facilities and constraints. And therefore it is needed for a new generation of learning environments that is different from a single learner-to-environment interaction model. This will be demonstrated among different research efforts found in literature.

In summary, intelligent agents have the following characteristics:

- Act autonomously towards a goal, without direct control. A group of agents can act and interact autonomously in the system to reach a goal.
- An autonomous agent can act as a common interface with the learner.
- Decentralized intelligence: Help to take decisions by considering other resources.
- Balance individual goals against common goals.
- Negotiate and cooperate of information, intentions, and goals.
- Perform tasks not possible by individual software or user by working with the environment and other event generators.

Based on these properties, several research efforts attempted utilizing them to improve learning or training. The objective of this literature review is to reveal this topic in particular to include better utilization of pedagogical agents in electronic learning environments.

5.2. Agent Based Personalization[1]

Education theories and practice support understanding and treating the learners individually according to their specific differences. In electronic environments, *personalization* provides effective learning (Soliman, 2006). Furthermore, learning occurs by building associations based on prior knowledge and abilities. Evidently, prior knowledge is different from one learner to another, depending on the environment the learner was exposed to and according to several factors as presented in the theory of multiple intelligences, learning styles, and further aspects discussed in Section 2.1.3. Online environments considered personalization as a learner-centered approach giving different forms discussed in Section 2.2.1. An Intelligent Tutoring Systems (ITS) is an example paradigm that seriously considers the personalization value in computer supported learning environments (see Sections 2.2.1, 2.2.3). Selection of courses and sequencing based on learner assessment results are forms of personalization in ITS. Distinctive aspects of pedagogical agent-based personalization are of major interest. The use of the agent model further supports personalization as the pedagogical agent is regarded as a focal point of interaction between the individual learner and the environment.

Sun, Joy, and Griffiths (2005) built a system of multiple interacting intelligent agents based on the Java Agent Development Environment (JADE) to support *adaptation* based on learning styles. The system is composed of five different interacting agents: *student agent*, *record agent*, *evaluation agent*, *learning object agent*, and a *modeling agent*. All have a common general goal of *personalization*. The system provides a segregation of agent duties in the agent design as an agent-based design goal. The student agent, as an example, is responsible for communicating with the learner through a communication layer. The evaluation agent is responsible for ensuring an individual and adaptive learning path. However, the system did not provide embodiment of the agent that acts as an interface with the learner. The *personalization* function is also provided by Lee, Chen, and Chen (2005) through an interface agent that interacts with another agent that implements Item-Response-Theory (IRT) agent. IRT is an assessment mechanism that provides and estimates the learner abilities through learner feedback. This research is an example of how a pedagogical agent can provide personalization by interacting with supporting mechanisms through agent technology. Aseere, Millard, and Gerding (2010) argue that agent systems provide

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[1] Several paragraphs of this section are adopted from Soliman and Guetl (2011c).

ultra-personalization of the learning process in a decentralized way. The basis for the argument is that agents can represent the requirements of the learner in a virtual learning environment and hence it can negotiate to achieve those requirements in a decentralized fashion.

5.3. Cognitive and Meta-Cognitive Agents[1]

Cognition refers to the process of human thought. It involves understanding how the mind works. In research, there were significant efforts in cognition research shaping different education theories. On the aspect of technology, there were several efforts to build cognitive models with agents. Scholars such as Allan Newell laid the foundation to unified cognition theories that have been used later with agents creating SOAR architecture. Steve, the pedagogical agent (see Section 4.1) was created based on SOAR. Another popular cognitive system is the ACT-R architecture developed at Carnegie Mellon University. Dubois, Nkambou, Quintal, and Savard (2010) provide an introduction, history, and review of cognitive architectures with inspiration of their biological roots. Dubois et al. (2010) argue on the rationale and the necessity of understanding human cognition to provide effective tutoring systems. Not only understanding the human cognition can lead to better learning, but also to building artificially intelligent entities that simulate the human brain as possible, such as the case of Steve with SOAR stated above. In this case, it becomes possible to teach an artificial agent harvesting benefits of learning by teaching[2]. However, fully understanding human cognition and building a complete model is far from reaching. Yet, researchers are working to find better representing models day after day.

Cognitive models can further help in achieving co-cognition between the pedagogical agent and the learner. Dubois, Nkambou, Quintal, and Savard (2010) point the challenges researchers face with this understanding. Researchers further attempted employing cognitive architectures to also consider emotions, as discussed later in this Chapter. Cognitive tutors are agents with cognitive architectures mainly adopted in Intelligent Tutoring Systems. ACT-R is an example cognitive tutor agent that is based on the ACT-R cognitive theory.

Furthermore, researchers have pointed the importance of building architecture of cognitions rather than a single entity. Franklin and Graesser (2001) indicated that the agent model is a suitable model for building a cognitive architecture, and hence provided the Intelligent Distribution Agent (IDA) based

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[1] Several paragraphs of this section are adopted from Soliman and Guetl (2011c).

[2] It is found in research that it is possible to teach an agent by the exchange of a concept map. Teachable agents are discussed later in this Chapter.

on the so called the Global Workspace cognitive architecture (GW)[1]. Thus the cognition based approach gives also a rise to intelligent agents. Dubois, Nkambou, Quintal, and Savard (2010) propose the following definition of an ideal artificial cognitive tutoring agent: "*an agent built on an architecture that offers structures, features and functioning comparable to the human model so that it is similarly capable of adaptation, learning, generalization within and across domains, and action in complex situations encountered in tutoring learners*."

Understanding how knowledge is constructed will lead to designing effective teaching methods. Relating to prior knowledge by a schema of prior concepts has an influence on adaptive systems that present tailored instruction. The critical thinking methods compliant with cognitive theories can lead to agent design methods with an agent providing contradictions stimulating thinking and leading to better established knowledge. Thus it is also important to consider cognitive disequilibrium as well.

Conceptual Change Agents

Conceptual change is an important and evolving learning approach especially to science education. Conceptual change involves deep changes of one's knowledge. And therefore concepts and their relationships change over time. It can involve being exposed to contradictions and critical thinking to reach cognitive equilibrium according to Jean Piaget constructivism theories. This equilibrium can be exposed to new set of conflicts through conceptual change leading to a new cognitive equilibrium that is a better established knowledge.

Ting and Chong (2003) propose the integration of conceptual change in animated pedagogical agents. Learners perform experiments and are given an opportunity to generalize or model the experiment by linking graph nodes of concepts thus creating hypotheses. The pedagogical agent will foster conflicts and thus stimulate the conceptual change for the learners. The intelligent agent also has the function of changing its conceptualization by the so called *belief revision* functions in the Belief-Desire-Intention (BDI) model that will be discussed later.

While learning is a social activity, social interactions have a learning component. I.e., one may learn by social interactions with others by influencing each other concepts, possibly discussions and arguments are triggers for concept change leading to a new equilibrium. Distributed cognition vs. collective cognition looks at surrounding objects and group of individuals rather than individualized learning ones. Study of this model is relevant to multi-agents and the social virtual environment.

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[1]The GW theory focuses on consciousness and unconsciousness in learning.

5.3.1. Bayesian Networks for Agent Learning

Bayesian Networks (BN) is a common probabilistic AI method. It is common to be referred also as Belief Network (Russel & Norvig, 1995). A BN is represented as a directed acyclic graph with each node represents a belief or hypothesis as a random variable while edges represent conditional dependences between them. The BN learning problem is inferring the structure of the graph from data, which is not a trivial problem. Consequently, BNs are used for inferences as a method for inferring about learner abilities to provide tailored adaptive instruction consequently. The main interest is the machine learning application and issues relevant to understanding the learners and their cognition and dynamically dealing with it through time. A Decision Network (DN) is an extension to the Bayesian Network by adding *utility* and *decision nodes* to enable solving decision problems under uncertainty (Russel & Norvig, 1995, pages 471, 484). To handle evolution of the state of the environment over time, Dynamic Belief Networks (DBN) and Dynamic Decision Networks (DDNs) are devised as variations to BN and DN accordingly to enable further representation changes and solve complex decisions problems (Russel & Norvig, 1995, pages 514, 516).

The Dynamic Bayesian Network (DBN) model has been used by Conati and Zhao (2004) to enable a learner model through a pedagogical agent. The choice of the pedagogical agent was due to an evidence of increased learner engagement and improved learning as discussed in Chapter 4. The learner model by Conati and Zhao (2004) considers cognitive, meta-cognitive abilities, and emotions. Upon constructing the DBN, reasoning about learner knowledge levels is done and used by the pedagogical agent to provide guidance to the learner. By having more information through this model about the affective state of the learner, the purpose of that study is to have better informed pedagogical agent interventions. The work by Conati and Zhano (2004) provides relevant details such as: what DBN to keep, short term, long term student models, and an evaluation of the results. Ting and Chong (2006) equip pedagogical agents within the scientific inquiry learning environments (INQPRO) with DBNs. In this model, a probabilistic BN model is used to model learner properties as it changes through time due to learning or conceptual change mentioned above. Learners interact with the learning lesson as a computer simulation by the aid of a pedagogical agent. At this stage, a mental model is constructed. Then a discrepancy is presented through the simulation. The pedagogical agent monitors the subsequent interactions through this process of conceptual change leading to conflict resolution stage. In this work, the probabilistic nature of capturing mental states is tackled by the use of Bayesian Networks and the conceptual change mandated it to be of a dynamic nature. Ting and Chong (2006) did not consider emotions nor checked for the accuracy of what is captured in the above mentioned work.

The DDN concept has been used in several tutoring systems for predicting learning abilities such as knowledge, focus of attention, affective states, and actions taken. The purpose of the DDN according to the research by Ting and Phon-Amnuaisuk (2010) is to support scientific inquiry by reasoning about learners abilities and provide learning support. A special feature of the DDN is its ability to deal with the temporal aspects captured during interaction with the system (Ting & Phon-Amnuaisuk, 2010). Peedy, the pedagogical agent (see Table 6), uses DDN in the INQPRO learning environment.

Common to the above mentioned research efforts with BN, DDN, and conceptual change models are trying to capture concepts or cognitive states of the learner by observing the behavior of interaction with the system.

5.3.2. BDI Agents for Human Learning

The Belief-Desire-Intention model (BDI) has been widely adopted in agent-based systems. It originates from AI Agent research (Jennings & Wooldridge, 2000) as it encodes agent behavior though setting goals that determine desires and the intentions. Generally, the agent behavior can result from the BDI model (Weiss, 1999, p. 54). The BDI model is composed of a set of logic rules to form the cognitive encoding of the agent as a core component. The components of the BDI model are explained in Table 8 below.

Table 8: Belief-Desire-Intention (BDI) model (Jaques & Viccari, 2004).

Beliefs *"represent the information about the state of the environment that is updated appropriately after each sensing action."*
Desires *"are the motivational state of the system. They have information about the objectives to be accomplished."*
Intention *"is a desire that was chosen to be executed by a plan, because it can be carried out according to the agent's beliefs (because it is not rational that the agent carries out something that it does not believe). Plans are pre-compiled procedures that depend on a set of conditions for being applicable."*

Hence, the BDI model gives autonomy and goal-directed behavior to the intelligent agent as a main distinction between it and a traditional object. The BDI model is used by agents to create behavior by creating to achieving goals. Those agent types monitor the environment to capture changes and represent them in their beliefs. BDI systems have two main reasoning processes: reasoning about the intentions to undertake and reasoning about the desires and whether they have been reached.

With the reasoning of the BDI model, it can be further useful in the important learning activity of explanation by track changes in the beliefs, desires, and the intentions and showing how reasoning happened. Broekens et al. (2010)

utilize BDI agents for algorithms of explaining the agent behavior to the user. It uses an agent platform, named GOAL[1] that supports the BDI concept for that purpose. This work relates the reasoning chain to a result to show how the agent has reached that state thus achieving an explainable agent for learning or training purpose. This concept is referred as *explainable agents* who can explain and convey their behavior to the learner or to an educator entity.

Bercht and Vicari (2000) extend cognitive encoding in agents to add the emotional dimension of the learner to the learner profile. The affective domain in the learner is explored through mental states of the learner exploited by the use of BDI-based agents. This allowed researchers to model mental states and their complex interactions allowing describing agent complex activities. Reasoning about student current emotional state is very important in the classroom and in electronic environments as well (see Sections 2.1.4, 4.2). The tutor can utilize those states to improve motivation, restrain about stressors and it may provide stressors in specific situations that can improve learning. Jaques and Viccari (2004) also utilize the inference power of BDI to reason about the student emotions given its dynamic nature. The system needs to know events in the environment, the student's goals, and the desirability of the events according to student's goals. Jiang, Vidal, and Huhns (2007) extend the BDI model integrating the emotional dimension to the Emotional BDI (EBDI) architecture. The model describes interactions between beliefs, desires, and intentions with emotions during the reasoning process.

5.3.3. Meta-Cognitive and Self Regulated Learning Agents

Meta-cognition is an important topic to learning. Meta-cognition is relevant to thinking about thinking and is related to learning improvement as it calls for learners' awareness of their cognitive abilities and learning gains. Critical thinking for example is related to meta-cognitive ability. Self Regulated Learning (SRL) is also a meta-cognitive activity. SRL means learning that is guided by meta-cognition with strategic actions, evaluating, and motivation to learn. Zimmerman (1990) provides detailed overview and definitions of self regulated learning, and shows its impact on student achievement. The importance of this subject is for learners to be self-guided and self-directed having learning goals directing them by having self-control of cognitive processes.

Kinnebrew, Biswas, Sulcer, and Taylor (2011) employ self regulated learning aided by Betty's pedagogical agent. Betty's system of SRL is depicted in Figure 14. As shown in the Figure, Betty provides either knowledge construction or

[1] GOAL as a multi-agent realization framework will be discussed in Chapter 8.

monitoring strategies. Information structuring meta-cognitive student activity is communicated to Betty's system through concept maps. Students conduct monitoring meta-cognitive activities with Betty such as asking questions to the pedagogical agent (checking) and probing parts of the concept map with the pedagogical agent (probing). In this research, the pedagogical agent provided meta-cognitive feedback to the learners. While this study provided results showing that students perform better in knowledge construction strategy, it sheds light into the importance of developing monitoring meta-cognitive strategies to improve self-learning. The study reports positive results on learning by teaching a pedagogical agent as well.

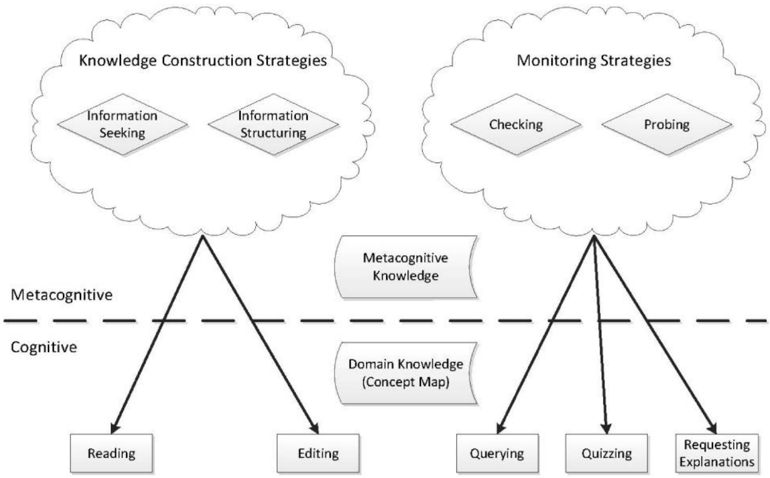

Figure 14: Model of self regulated learning strategies and activities in Betty's Brain agent (Kinnebrew, Biswas, Sulcer, & Taylor, 2011).

Hence, self-guided or self-regulated learning is fundamental to active learning realizations in virtual learning environments that lack of human teacher but being subsidized with artificially intelligent agents. Therefore, one can seek to utilize intelligent agents with SRL and meta-cognition abilities in the realization of pedagogical agents as well to promote self-guided learning in VLE.

5.4. Teachable Pedagogical Agents[1]

Educators agree on benefits of teaching as a tool for learning. Students learn twice when they teach. Psychology studies show why students pay extra attention and effort to teaching others, possibly due to taking responsibility and harvest social benefits (Carberry & Ohland, 2012). A meta-cognitive gain is added to the learner upon teaching others for the effects of reflection and cognitive processes of teaching (Carberry & Ohland, 2012). In electronic environments, an added

[1] Several paragraphs of this section are adopted from Soliman and Guetl (2011c).

meta-cognitive benefit is through teaching an agent. This is due to the ability to know about student's concepts and cognition to aid for assessment of acquired concepts, to improve the current ones, or to know about the learner characteristics and abilities (Chase, Chin, Oppezzo, & Schwartz, 2009). The novelty of this idea also comes from the fact that teaching an agent could be easier to implement than of an agent teaching the user. That is due to human vs. computation abilities. Indeed there are pedagogical benefits for teaching an artificial agent. Schwartz et al. (2009) report two meta-cognitive aspects of learning by teaching: *dual-task demand*[1] of meta-cognition that alleviates burdens of learning by teaching and *teaching responsibility* as an important motive to involve students in meta-cognitive activities.

Personalization research has focused on the aspect of understanding the learner by different methods (see Sections 2.1.3, 2.2.1). Common to the methods is building a learner model that tries to infer learner abilities by monitoring the learner behavior and interaction with the system (Ashoori, Shen, Miao, & Peyton, 2009; Xu & Wang, 2006). Teaching an agent in the environment can give a great opportunity for AI methods to know more about the learner (Conati & Zhao, 2004). Research in teachable agents adds to the aspect of understanding the learner since the teachable agent as a trusted companion who gives the opportunity for the learner to reveal his/her beliefs. The agent side can use AI methods to infer the learner conceptions and misconceptions. These results of understanding the learner upon teaching an agent will be used for further learning strategies undertakings.

Betty's Brain is also a teachable agent (Chase, Chin, Oppezzo, & Schwartz, 2009). Betty uses concept maps as a method of instruction. The student teaches Betty a concept map through a graphical interface. An interesting feature in the system is that the student asks Betty questions, Betty can answer from the given concept map. But Betty's inability to answer questions will trigger and motivate the student to learn more so as to teach it to Betty thereafter.

The teachable agent group at Vanderbilt University conducts research in the area of teachable agents. The group extends the use of Betty for further research including measuring Self Regulated Learning (SRL) results with teachable agents and building Hidden Markov Models, HMM generated from student activity sequences as a result of interaction. HMM is a similar method or a variation to Bayesian Networks. Dubois, Nkambou, Quintal, and Savard (2010) discuss other methods of representing knowledge dealt with agents including several cognitive-based architectures including *semantic networks*.

[1] Dual-task demand refers here to the need to perform two tasks upon meta-cognition: thinking, and thinking about the process of thinking.

Compared to *Bayesian networks*, the use of the deterministic concept map teaching to an agent can solve the problem of reasoning under uncertainty of BN. Since it is not a behavior observation approach, no inference errors occur.

5.5. Intelligent Agents for Collaborative Learning[1]

In considering tool support for collaborative against individualized learning, several questions arise. First, what tools can be given to the group to aid their formation itself? Does this make a difference to the learning result? Second, in order to conduct a group learning activity, learners should agree on the learning goal and have a unification of arguments; can the learning environment provide assistance to unify the learning goals of a group of learners? Can it help in resolving conflicts by aiding negotiation? How to provide intelligence support for group learning? How can distributed artificial intelligence support group learning, given an individual intelligent agent can support a learner as discussed above?

Multi-agent systems are about the group behavior of autonomous and intelligent software entities (Jennings & Wooldridge, 2000). The agent perceives the environment and acts upon it by using intelligence abilities. Intelligent agents might act individually to solve a problem or act in a group by means of coordination methods drawn from distributed artificial intelligence (DAI). Agents take place in agent societies where they interact with other agents to solve a problem if the problem is not solvable by single entity. Since agents have different goals, negotiation occurs. For example, agents negotiate to reach an optimal decision among multiple-objectives (Shi, Lue, & Lin, 2006). An agent has its own goals as it can act on behalf of a user. Since the agent acts and interacts with other agents and the environment, it is influencing and is influenced by the environment.

Properties of intelligent agents are appealing to contribute to learning environments especially for group work that involves individual learning and decisions in addition to group learning activities. This requires strong intellectual interactions and social abilities among peers and from individuals to the environment while having rich and pedagogical-aware support. The Belief-Desire-Intention model (BDI) of an agent resonates with groups' intention formation to achieve a common task. For example, upon a group of learners' common desire to attain a certain design goal, they have to negotiate differences to find a collective intention (Jiang, Vidal, & Huhns, 2007). Several social aspects of group work are evolving such as group wisdom and collective intelligence as the current advancements in the use of technology in group. Collective

[1] Several paragraphs of this section are adopted from Soliman and Guetl (2010b, 2011c).

intelligence is the resulting group intelligence that develops as a result of different means of interaction among many individuals. This resultant intelligence is very appealing if it is the group learning result compared to individualized learning. A related concept in multi-agent systems looks into collective group behavior to solve a problem by many smaller agents, such as ants, is named swarm intelligence (Hinchey, 2007). Therefore, the use of DAI's paradigm of multi-agent systems can act as an association mechanism for different individualistic intelligences, behaviors, and conflicting requirements to provide group learning support. While emotions are important for individualized learning, it becomes more important for group learning as a result of its importance to social interactions. Agent systems can also take a role in improving emotions not only at the single level but also at the group level (Gratch, Mao, & Marsella, 2006). Group work can help engage students in learning. Therefore, one can expect that CSCL environments should outperform individual learning ones in terms of student motivation aspects. Multi-agent systems research has gained roots from modeling social behaviors[1] with roots from social studies. Therefore, these capabilities can be used or extended to model and analyze complex learning-related activities that involve group learning.

The importance of multi-agent systems for complex, yet flexible systems has been exemplified in the evolution of the agent-oriented software engineering (AOSE) approach. As per the view of Jennings and Wooldridge (2000), the AOSE approach is effective in developing complex software environments through a set of autonomous, problem solving intelligent entities named agents. Jennings and Wooldridge (2000) also indicated that "*agents act to achieve objectives on behalf of individuals or companies*" by acting in the environment or interacting among them. In this case, the individual has a learning goal while the group of learners, as a whole, has a collective learning goal or task to achieve. The interactions between autonomous agents and among agent societies are central to AOSE concepts. Modeling interaction among learners has special value to reason about learning and to group-assess learning outcomes. In AOSE paradigms, agents interact in an advanced conversation form of the Agent Communication Language (ACL) taking roots from the speech act theory which is not the case for classical software engineering methods. The Agent Unified Modeling Language (AUML) is associated with AOSE as a modeling language capable of modeling such complex behaviors among agents. This makes multi-agent systems useful as well to model and develop complex and dynamic learning environments supporting group learning in many aspects. Furthermore, an intelligent agent can act as a mediator between the learner and the environment. In the related research, if an agent is used to simulate individual learner cognition, and guide the learner activities, then a multi-agent system is needed to simulate group

[1] A common example is ant colony social behavior research in relation to multi-agent systems.

cognition, to guide the group to a common goal and resolve any conflict by means of negotiation. Furthermore, the distributed nature of learning requires distributed artificial intelligence support.

Several research efforts target employing agents for learning in general and for group learning in particular. Argumentation and negotiation are important for learning as a result of different educator-learner or learner-learner interactions. Baker (1994) highlighted this need and provided a model for argumentation and negotiation based on multi-agent systems. Since argumentation is important for developing critical thinking abilities, this should also be supported in CSCL environments. Collaborative learning involves more than one learner who might have different learning goals, beliefs, and methods of achieving the goals, therefore this issue should be strengthened. Research by Buder and Bodemer (2007) reported that majorities of incorrect opinions may dominate correct minority opinions in the social environment, and therefore they developed an awareness mechanism to overcome this problem.

Another important aspect of CSCL is the knowledge sharing and co-construction among the group of learners. Agent systems can be used to facilitate finding and using related knowledge. In the work by Soller and Busetta (2003), the intelligence capabilities of agents by a *Hidden Markov Model (HMM)* approach have been used to analyze, support, and assess knowledge sharing in a distributed learning environment. And therefore, the method was used to distinguish between effective versus non-effective knowledge sharing interactions in the group. The research study by Moreno (2009) reported that the use of a multi-agent based environment for collaborative botany learning has provided better learning results compared to a non agent-environment as a result of agent support for the co-construction of knowledge. Furthermore, collaborative learning requires social abilities of the learners. And it develops their social abilities as well as a result of the social interactions during the group learning process. Therefore, scaffolding social abilities in group learning should be central to effective collaborative learning. A group facilitator agent should be able to analyze group interaction; agents can also assist learners to increase their motivation to participate in the group (Soller, 2001). Agents can also assist groups socially by social filtering and tagging (Guo, Kreifelts, & Voss, 1997). In this work, social agents were used to extract URLs in specific topics and filter them according to individual users' preferences then collaboratively filter them. Consequently it has two aspects useful for group learning in finding resources; having social tags shared as a result of the group' grounds itself, and the ability to re-use the tags for other groups to help solving the cold start problem indicated by the authors (Guo et al., 1997).

Multi-agent systems also aid in simulating learning activities in groups. A system can be used to analyze group learning behavior and discover communication patterns among the group. This analysis can help to inspect the learning activities to find for example non-functioning peers and patterns that can cause group learning difficulties. Research work by Vizcaíno (2004) embedded a simulated student agent within the group. The function of the student agent was to detect and correct unhealthy situations such as student passivity and off-topic conversations. The choice of a peer agent rather than a tutor agent had a pedagogical basis so as to improve interactions among the group (Vizcaíno, 2004).

In the formation of the learning group itself, what are the ideal settings of work? The group formation process might not be trivial given the differences in background, learning styles, learning abilities, cognitive properties, culture, personalization systems support, and conflicting goals. The study here can answer the question of whether the learning result of an individual can be affected by interacting with an alternate group. If so, further analysis of the dynamics of group learning becomes necessary for understanding success or failure factors to group learning and whether it can be compensated by computer support. Dillenbourg and Schneider (1995) recognize group composition as a condition for the efficiency of group learning. Heterogeneity of groups may lead to success or failure of the group learning result. A group of agents that are able to model, search for suitable peer matches in a large community, and possibly simulate the learning before it occurs by considering individual factors with other peers in conjunction with the environment, are needed to ensure an optimal heterogeneity for effective group result. Soh and Khandaker (2007) recognized this in a multi-agent system for group coalition formation and scaffolding. Once a group is formed, one must assess group learning as a learning outcome for groups while this activity also provides input of what support can aid effective group learning. Law (2005) provides a model in several dimensions and 32 factors for assessing knowledge building outcomes in teams. In order to adopt this model and comparable models, tool support is needed.

Collaborative learning is analogous to CSCW in the dimension of problem solving as in the work by Cossentino, Sabatucci, and Seidita (2009) to aid collaborative software designer activities by means of an intelligent agent-based computer-aided tool. In this work, different agents have separate roles while an activity agent interacts in the meta-level with those agents and the environment providing support on achieving a particular task with an agent-oriented software engineering (AOSE) approach. Similarly, Vicari, and Gluz (2007) used AOSE methodologies to design intelligent tutoring systems while modeling human learners as agents. Sklar and Richards (2006) showed the benefits of mixing interactions between human learners and agents in games, for example, and in virtual environments as well.

5.5.1. Models of Multiple Interacting Pedagogical Agents

It is important to look into the group aspects of pedagogical agents as IPA-IPA interactions, the models supporting them, and what has been done in research. Electronically, a well structured society of pedagogical agents forming a *Multi-Agent System* (MAS) is needed to provide support to agents, set common goals, resolve conflicts, direct to new recourses, and assign agents to learners. Researchers have used a pedagogical agent as a character or as an autonomous software entity. Agents occupy an agent society. One can also look into group aspects of the learning environment such as in the curriculum and learning activity design.

In designing agent-based complex systems, Agent Oriented Software Engineering (AOSE) is considered. Several approaches have been used in research. See for example, the goal-net architecture for project River City. The GAIA MAS system design methodology has been suggested by Zambonelli, Jennings, and Wooldridge (2003). An illustration of the developing levels of MAS by GAIA methodology is depicted in Figure 15.

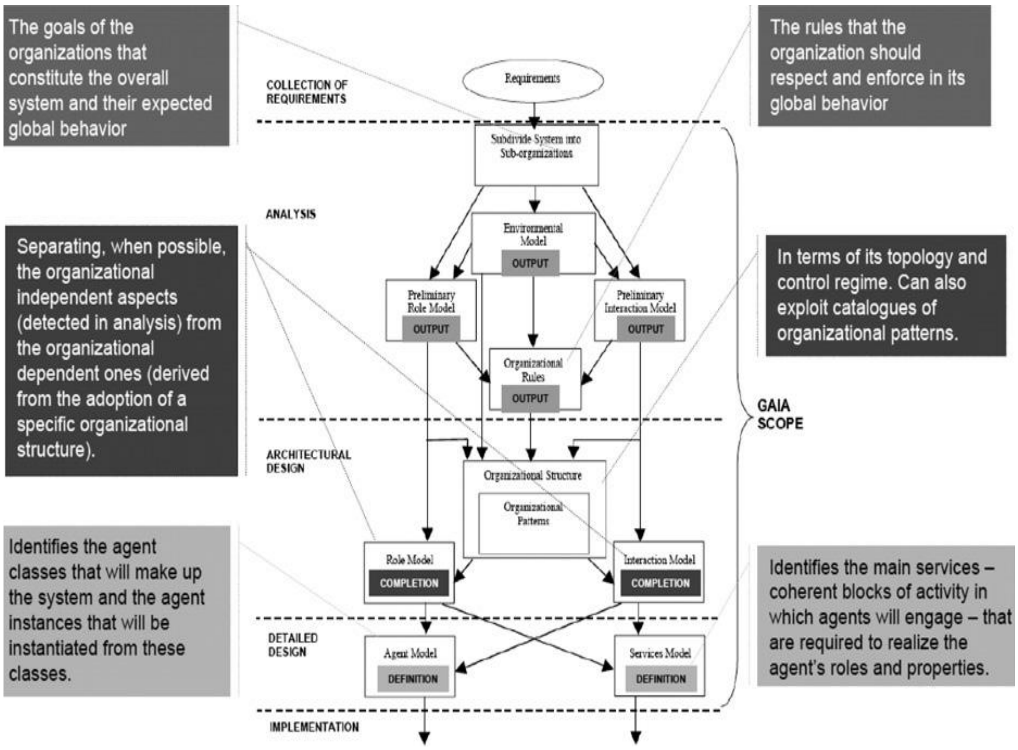

Figure 15: Overview of the GAIA methodology (Castro & Oliveira, 2011).

It starts from global requirements that can be collective pedagogical objectives to the global behavior and working down to individual agents, their coordination, and associated services. Therefore, it is a gluing design mechanism that puts organizational goals first. This model provides an autonomous software organization model that can be suitable for multiple agents. The design of pedagogical MAS including GAIA and others involve definition of different agent roles as described in research surveyed below.

The Gaia Design of Agent-based Online Collaborative Learning Environment (GAOOLE) is a proposed prototype of an agent based tutoring environment based on the GAIA methodology with the Java Agent Development Platform (JADE), (Liu, Joy, & Griffiths, 2009). There are five models described in this research: *environment model*, *roles model, interaction model*, *agent model*, and *services model*. It also contributed to collaborative learning surveyed later. Mendez and Antonio (2005) provide rationale and importance of the Agent Oriented Software Engineering (AOSE) adoption for designing learning environments in the Model for the Application of Intelligent Virtual Environments to Education (MAEVIF). In this research the design of the system incorporates four modules: *expert module* for concepts, *tutoring module*, *student module*, and *communication module*. With agent-oriented deign, four different agent roles are given for each module and an added world agent for interaction with the 3D environment. As recommended with this study, the GAIA methodology was appropriate for the design of the environment according to the requirements mentioned. A resulting model of five agents (Mendez & Antonio, 2005) was formed:

- A communication agent
- A student modeling agent
- A world agent
- An expert agent
- A tutoring agent

5.5.2. Virtual Teams Training with Pedagogical Agents

Diggelen, Muller, and Van den Bosch (2010) propose architecture for training teams by the use of mixed teams of humans and BDI agents. The use of mixed teams means mixing virtual humans and real team players. The objective of this type of research is to enhance team performance to reach a common goal. It looks into both individual roles of team players as well as team common objectives. In this problem domain, agents inhabit a virtual environment; their behavior is controlled individually and according to group objective. Therefore, this is looked as an extension to virtual humans by looking into groups rather than individual ones. And thus it supports decision making in the environment.

Behavior is generated as a result of cognitive model. The ATOM model is identified by Smith-Jentsch, Zeisig, Acton, and McPherson (1998) for high performance team work. This model is used by Sycara and Lewis (2003) to identify where agents can support teams. The ATOM model suggests four dimensions shown in Table 9: 1) Information Exchange, 2) Communication, 3) Supporting Behavior, and 4) Team Initiative/Leadership.

Table 9: ATOM teamwork dimensions (Sycara & Lewis, 2003).

Information Exchange	Communication
▪ Seeking information from all available sources ▪ Passing information to the appropriate persons before being asked ▪ Providing "big picture" situation updates	▪ Using proper phraseology ▪ Providing complete internal and external reports ▪ Avoiding excess chatter ▪ Ensuring communications are audible and ungarbled
Supporting Behavior	**Team Initiative/Leadership**
▪ Correcting team errors ▪ Providing and requesting backup or assistance when needed	▪ Providing guidance or suggestions to team members

According to Sycara and Lewis (2003), the four dimensions are used as guidelines of what agents can do to assist the team and reach the team objective with high performance. For example, agents are integrated with teams to coordinate their efforts, assist the humans on what to do, coordinate with other agents to achieve a common goal, and monitor communication among them. This work employs the *joint intentions* agent model and agent coordination methods to create shared plans. This work demonstrates the importance of the agent role as a communicator of information as a result of events in the environment or conveyed by humans providing *push information*. The use of push events communicated to the learner can improve the believability of the pedagogical agent (see Section 4.2) and improve learner engagement in the virtual environment, such as in games. As this work researches team collective goals, it focuses on team behavior support rather than aiding the team member or the group to learn a complex task online, or co-construct knowledge but rather works in mission actions. For example, this work aims at assisting and adjusting member roles and actions and providing dynamic information for each team player in action.

Given the above reviewed research, it is concluded that agents in MAS can be used for team training. The distributed model with guiding to common goals, autonomy of an agent, ability to interact with the environment and correct beliefs, ability to have a joint-intention and coordinate actions all can lead to train a team to a high performance. Agent-interaction and cognition abilities for group behavior modeling and control can be demonstrated in virtual environments. Similar efforts can direct, for example, training to run an assembly line or a factory, or run a machine by different operators by the use of agents in the virtual environment.

5.5.3. Collaboration Support in Immersive Environments

Immersive virtual learning environments can make an excellent educational tool for mediating collaborative learning by making use of pedagogical-aware multi-agent systems features. While collaborative learning requires flexibility in distance and time, the 3D virtual environment eliminates time and geographic barriers. Collaborative learners need to have increased social communication support. The 3D Virtual environment provides a stimulating environment for collaborative learners by means of a set of visual learning collaboration tools such as the social place, the common media boards, and the recreational areas (Chang, Guetl, Kopeinik, & Williams, 2009). Chang, Guetl, Kopeinik, and Williams (2009) outline several advantages of virtual worlds to collaborative learning including decreased geographical barriers between students and tutors, use of multiple communication channels, awareness of avatars, and learning activities within the virtual environment.

In order to further support collaborative learning in such environments, a player entity can be augmented with intelligence capabilities to provide intelligent learning support. Also, agents as autonomous entities can locate resources, interact with peers, and aid learning in general. For increasing learning effectiveness, agents should take pedagogical objectives into consideration on their interaction behaviors; i.e. to be pedagogical-aware. *Intelligent pedagogical agents* can play those roles in 3D virtual learning environment to guide group of learners interact visually or work autonomously to reach a common goal or to resolve differences. This is because intelligent pedagogical agents have the potential to inherit intelligence from agents in evolution, social behavior, intelligence, autonomy, and change of behavior according to pedagogical properties. They can also make use of the collaborative support mentioned and integrate with the available resources in the environment to increase learning effectiveness by further utilization of group learning potential.

In the research work of Buche, Querrec, De Loor, and Chevaillier (2003), the pedagogical agent is an avatar playing a pedagogical role. Several pedagogical roles that were created as a tutor, companion, or trouble maker facilitated the training scenario in the immersive environment. The pedagogical agent also acted and interacted with a social environment. 3D virtual worlds can also create an environment for simulating learning and providing a study environment to see the effects of learning for newly developed learning methods. A simulation study was done by Jondahl and Mørch (2002) to examine the following working hypothesis: *"Using pedagogical agents in virtual learning environments will have an effect on* *collaboration between the participants in the group "*(Jondahl & Mørch, 2002). The study indicated that *"agents can have an effect on collaboration by making users aware of collaboration patterns"*. They also concluded that agents can create a computationally rich virtual environment.

5.5.4. Summary of Value Addition to Group Learning

Collaborative learning has shown to be an effective and theoretically-supported method of learning. However, it is still not yet fully exploited in classrooms. Computer Supported Collaborative Learning (CSCL) environments, as shown in this Section, provide types of support that the teacher cannot handle and provide new possibilities to learners in a way that was not available in traditional learning. CSCL has special needs of effective team formation, communication, team monitoring, support, and assessment in addition to the individual learning needs. In searching for the best methods for enriching CSCL environments, multi-agent systems have shown special properties of negotiation, autonomy, sociality, and dynamic interaction that makes it ideal tool for supporting group work. Still multi-agent systems have current and promising features that can provide new possibilities of group learning.

Computer supported collaborative learning has several learning, socio-cultural, social, group cognitive dimensions with some challenges and requirements. For better supported learning, intelligent multi-agent systems contribute several abilities including learning behavior, autonomy, and sociality. The intelligence ability of an agent provides abilities to support emotions in learning, modeling behavior and group interactions and in virtual environments, similar to recommender systems, an agent can guide a learner to find best learning experiences or a sequence of them that best suites the learner cognitive model. That agent will roam the different virtual sub-spaces to find support for a group learning task. And therefore, one can conclude the significance of intelligent agents research support for collaborative learning. Having both individualized goals and social and group behavior in intelligent multi-agent systems makes it an appealing area of research for group learning.

Thinking of making use of intelligent multi-agent systems to group learning, research questions arise:

- Collaborative learning provides input to group wisdom. The hype of Web 2.0 is due to its social abilities. Social agents are believed to add further social abilities. Investigations are needed in what social capabilities can expedite the group wisdom results in collaborative learning environments and how to build such tools. What has been done in this regard and what are agents' features?

- How can intelligent agents support group learning activities in an effective way? How can one utilize these interesting features to provide support to fully realize the potential of group learning? What are the conditions that make group learning productive or failure, how can intelligent agents guide group learning to a success by continuous monitoring and assessment of group results? How to assess the *ZPD* in relation to the learning results in group learning?
- Scaffolding is a successful learning method. How can scaffolding be extended to a group of learners by the aid of intelligent agents?

5.6. Conclusion

Because of the inherent distributed nature of intelligence possessed by intelligent agents, they have been utilized for pedagogical functions. It was found that the proactive nature, the goal orientation, and the possible containment of intelligence, agents have been used for that purpose. Intelligent agents were used as cognitive tutors, teachable, and explainable entities. Thanks to the abilities of the agent to capture user interest and act autonomously on his behalf or with him dealing with other agents or other environment intelligence. Thus the agent could act as a companion or more because of the improved interaction that is also possible by adding cognition and emotion abilities. Furthermore, the agent social abilities nature has been used in research for pedagogical purposes. It is found that those natures can provide pedagogical guidance and other significant pedagogical values to learners in distributed environments. An aim is to utilize those features to enrich virtual learning environments pedagogically with agents' intelligence abilities.

It is found in the surveyed research that the intelligent agent paradigm provides realization of several pedagogical functions and was significantly considered. Intelligent agents were used for personalization, team support for a shared mission, collaborative learning in team formation, and negotiation. Intelligence in the intelligent agent requires reasoning and inference about the learner. Methods of inference of the learner included the use of Bayesian Networks, Dynamic Bayesian Networks, Hidden Markov Models, and the Belief-Desire-Intention Model. Cognition is targeted in the agent paradigm through the use of a cognitive architecture. Common Cognitive architectures are SOAR and ACT-R. SOAR was used for Steve pedagogical agent as an example.

The use of the agent model has given rise to different agent roles. In addition for the intelligent agent possibility to create a tutor agent, or a student modeling agent, or forming an agent society, it is found, in research a special type of agent, named teachable agent with sound value to learning

The Belief-Desire-Intention model is commonly used for supporting reasoning in the agent paradigm. The importance is to provide human-mimicking goal-directed and autonomous rational behavior that gives relevance to pedagogical functions. The BDI model is used for decision making with reasoning as well as to provide inference of the learner state including emotion.

A distinction is drawn from the intelligent agent to an intelligent pedagogical agent is the intelligent agent is an autonomous and intelligent entity that does not necessarily provide a user interaction entity. An intelligent pedagogical agent is regarded an embodied entity that is necessarily a mean of interaction with the learner user. The surveyed literature is in support of the relevance of the intelligent agent approach to realization of intelligent pedagogical agents and considers it for the immersive learning environment. The intelligent pedagogical agent hence can obtain intelligence support by an intelligent agent.

Part B: Solution Approach

Comprises

Requirements Analysis
Conceptual Approach
Design and Pre-Implementation Studies
Prototyping & Evaluation Experiment

6. Requirements Analysis

It is found, from prior Chapters, that immersive environments provide strong learning affordances. With the particular form of the proliferating 3D virtual world, immersive learning environments can become great tools for instruction delivery for the new learners' generation. However, it is discussed their need for available and autonomous pedagogical support that is viewed through the use of intelligent pedagogical agents (IPAs). Furthermore, an approach for realizing pedagogically intelligent functions based on various methods is discussed in the previous Chapter. In order to realize an IPA and efficiently adopt it in a virtual world, delving into particular details of its requirements is important in this regard.

This Chapter provides requirements analysis for IPA realizations in the immersive learning environments proceeding as follows: Section 6.1 summarizes and recaps desired characteristics of IPA in general. Section 6.2 discusses challenges and constraints of the view of realizing IPA. Section 6.3 provides the reasoning desired characteristics and gears towards selecting methods for reasoning support. With the input of pedagogical agents and the constraints discussed, a plan for next steps is discussed in Section 6.4 followed by a conclusion in Section 6.5.

6.1. Reflections on Pedagogical Agent Requirements for Immersive Environments

One method of improving the pedagogical support and adding pedagogical intelligence for immersive environments is the adoption of intelligent pedagogical agents (IPAs) who can play the roles of teachers or peers. They can be available 24/7 to provide instructional functions for immersed learners taking advantages of what ICT abilities can bring and utilize it in the service for educating the learners. However, an integrated view of how pedagogical agent functions are realized to provide such pedagogical support is sought, and what should be done towards that target.

Based on the findings in previous Chapters, and above discussions, the requirements for realizing pedagogical agents can be grouped into:

- **Learner to IPA Interaction Types of Requirements.** This requirement is relevant to pedagogical agent abilities to interact with the learner given that the IPA is none human controlled.

- **Autonomy** Agent autonomy and self control are desirable features in 3D virtual words (Aylett & Luck, 2000). Currently characters in virtual worlds are more user-controlled avatars. The property is taken from robotics desired features. Similar to robotics in real world, autonomous avatars in a virtual world will give rise to learning functions in virtual worlds such as interaction and explanations of lessons, 3D scenes or objects.

- **Cognitive and Decision Abilities**: For the pedagogical agent to provide intelligent learning support and to resemble a human, strong cognitive abilities are required.

- **Environment and Context Awareness**: The ability of the agent to be able to know about the virtual world, discovering, constructing or suggesting learning resources, scenarios or scenes that are suitable to learner abilities and goals. Furthermore, the pedagogical agent is better to be aware of other pedagogical agents, interact and cooperate with them accordingly. Distributed intelligence support gives this function.

- **Pedagogical Orientation**. The IPA takes pedagogical strategies to improve learning effectiveness. It employs the above features in provisioning learning services to the learner.

As discussed in Chapter 3, the IPA can provide different pedagogical functions. And with the intelligent agent approach it can inherit intelligent agent functions in pedagogical support. An important dimension that is relevant to a virtual world is to provide pedagogical guidance that has different dimensions:

1) Pedagogical guidance on learning with an object.

2) Guidance on collaborative aspects. I.e. making interaction with other learners has a pedagogical value.

3) Guidance on learning activities that can involve different learning objects that support learning by doing approaches.

Guidance on a particular learning activity involves learning with a pedagogical object that can have a particular learning objective. For example, to perform the capacitor module experiment correctly.

An IPA should also be able to guide a learner to collaborate to learn. For example, the IPA can direct the learner to discuss a topic or perform a task collaboratively with a learner. Collaborative functions are also supported when an intelligent agent approach is taken.

The IPA should have the potential to learn about the resources in the environment and guide the learner towards a learning object that the learner cannot find. That is based on a pedagogical objective the IPA has for that learner. The recommendation of the resource could also be done based on the learner abilities. The IPA awareness of the environment supports such premise. A fundamental idea discussed in the intelligent agent paradigm is the intelligent behavior the agent will do is based on its belief about the environment state. Upon changes in the environment, the BDI model knows about those changes, through an interface to make context aware decisions.

The design of what the pedagogical guidance the IPA can provide to the learner should be tied, in a formal setting, to the possibility of an instructional design approach. Common to the three points is the need for intelligent decision ability of the pedagogical agent in order to give a valuable recommendation to the learner. That recommendation should be from a pedagogical view. In order to provide a better intelligent and pedagogical support in the environment, the interrelation among relevant elements should be inspected. It is recommended to study several systems and device a conceptual approach that supports needed functional realization of the pedagogical agent.

Another factor is the motivation aspect. While an IPA cannot provide exactly what a clever motivating teacher can do, it can provide support towards compensating with automated methods such as personalization and providing one-to-one support. The comparison then can be in absence versus in presence of the pedagogical agent in the immersive environment rather than a pedagogical agent versus the human. In performing motivation support, gestures and providing functions relevant to embodiment, persona effect, with the resulting feeling of presence that can increase engagement as indicated in research in pedagogical agents, as discussed in Chapter 3.

It is viewed that scaffolding learning activities and following up their completion properly lead to improved motivation based on *expectancy-value* theory of task completion (see Chapter 2). In relation to the affordances of a virtual world of learning by doing, the pedagogical agent should leave the control of performing learning activities to the learner for improved *self-determination*. However, it still monitors the interaction to enhance learning through correcting behavior and assessment. Research in Pedagogical agents targeted when to intervene by a pedagogical agent (Qu, Wang, & Johnson, 2004). A relevant concept is the handling of idle time by the learner that can be attributed to different reasons including less motivation. In goal directed pedagogical agents, accomplished learning tasks by the learner should be well known by the IPA so as to support the learner emotionally. Generally and from the name, an IPA is aware of the pedagogical strategies in relation to the situation that gears towards task completion in learning by doing context of virtual worlds.

It is also viewed the IPA, similar to a human teacher should be an expert on the topic of instruction. Therefore a research question is how subject matter knowledge is provided to the pedagogical agent; is it encoded or taught to the pedagogical agent or both. While Chapter 7 answers this question in research, a simplification is provided in the implementation and discussed in Chapter 9. Knowledge about the subject matter is important to answer learner questions correctly. That knowledge is not necessarily abstract but rather procedural knowledge such as in the case of a pedagogical agent tutoring a student on performing a task. As an extension to this work is the possible generalization of available scenarios that form the knowledge base of the pedagogical agent dealing with different situations, each of them are dealt with particular details.

The challenge of resemblance of a human being can be compensated by equipping the pedagogical agent with automated functions. Delivering personalized instructions, having the IPA available all the time, being aware of the environment, or able to update a pedagogical strategy *just-in-time* or other automated methods not possible by the human. When the pedagogical agent is viewed as a central point of interaction between the learner and the environment, it can always be possible to amend it with artificially intelligent and pedagogical functions to support the learner with integrating different innovations in computer supported pedagogy. That should be bound on implementation constraints and putting them into the context of learning.

6.2. Problems and Challenges

Based on the discussion in the prior section, the following challenges exist:

- There is a gap of the lack of support in immersive environments. Autonomous pedagogical support is weak and elements of pedagogical supported interactions with learning objects in virtual worlds are not defined.
- A view of how pedagogical agents can support learning in immersive learning environments is sought.
- Communication with the pedagogical agent as non-human entity. How communication can be achieved to a none-human?
- Resemblance of the human behavior requires embodiment. While the embodiment cannot be perfect. Awareness of the negative impacts is to be taken care of. For example, in educating a child using a character, the child

might get confused with a real teacher. There are two schools of thoughts. The first direction is creating a character that seeks close imitation to the human being. For example, a Turing test is needed to seek if there is a feeling that the pedagogical agent is indistinguishable from a human educator avatar. However, the second school reported problems that a chatbot that is claimed to be human is inappropriate and is better to identify it as a non-human embodiment. It is viewed that the second approach gives rise to pedagogical functions while resolving potential problems reported. Common to both approaches is the focus on learning services provisioning.

- Adding intelligence ability to the pedagogical agent in away to open new possibilities of implementation rather than one function. The intelligent agent approach provides wide range of possibilities with discussions in Chapter 5.
- An integrated framework that shows the view of how pedagogical agents support learning functions, what are the needed components or models that provide a global view of changing the immersive virtual environment to become an intelligent immersive learning environment.
- Inferring and studying details of interaction between the learner and the pedagogical agent. The importance is due to the fact that the pedagogical agent is a non-human entity. Depicting the exact scenario of interactions reveals: *What functions the IPA can provide, intelligence support can be added, and what requirements for the design of the learning objects.* It can also help in improving interactivity, and identify new support functions. It is most important to validate the feasibility of a learning scenario that gives input to learning activity design in virtual worlds. If the scenario components are feasible, it can be implemented with pedagogical agents.
- There is no determination of how pedagogical agents interact with the learner in which situations in relation to a learning object.

Given the mentioned questions, how far an intelligence support to pedagogical agent can contribute to solve them. Furthermore, with the variations of different possible methods, which approach to take? Is this decision influenced by the virtual environment? What are the supporting models to pedagogical agents, and how to depict ones that contribute to approach these challenges and provide new and suitable learning chances?

6.3. Intelligence Support Approach

The cognitive component of the pedagogical agent is found to be important to provide intelligent functions that add value to learning support and new possibilities. The intelligent component of the pedagogical agent is important to:

- Provide a decision ability
- Control the character behavior
- Reason about the environment
- Provide alternatives for the learner
- Enable the IPA in general to act intelligently as possible

Several methods are found to support intelligence addition to the pedagogical agent such as case based reasoning, cognitive architectures, probabilistic reasoning models, neural networks, and more. While those several methods can support reasoning in pedagogical agents, the intelligent agent approach is elaborated for the following reasons:

- The intelligent agent approach provides individual properties to the pedagogical agent of pro-activeness, re-activeness, and reflexive behavior.
- The intelligent agent approach does not isolate an agent but provide methods to support multiple entities. In relation to traditional learning, individualized learning possibilities should not be the only case to assume while ignoring collaboration abilities. An opportunity arises if multiple agents can be depicted. While the research focused on an IPA as an individual entity focusing on the visual behavior of the pedagogical agent of animations and so on. The pedagogical aspects of collaboration worth consideration. With the intelligent agent paradigm, the collaborative learning aspect is extended. The promising utilization of multi-agent system, discussed in Section 5.5., for collaborative learning suggests that IPA can be within a multi-agent system as well.
- The multi-agent system is for a distributed environment. In dynamic, non-deterministic environments, autonomy of agents and dynamic reasoning on the situation suits that nature. The immersive environment is a dynamic non-deterministic environment. Multi-agent systems have been successfully deployed for similar vast distributed environments.
- The multi-agent approach can encapsulate other functions. As it is a distributed model, the component of each agent can represent a function. A constellation of those functions is achieved while maintaining each component desirables of autonomous behavior and non-determinism.
- Models of the intelligent agent to resemble the human think process are available. The Belief-Desire-Intention model of agents is rooted to a human thought process in how intentions and desires a human can take in relation to the beliefs (Bratman, 1987). The model is targeting an action approach that also is desirable for the IPA to act in the environment.

- If the IPA provides action-orientation, this contributes to the presence by the IPA and adds to its believability. An environment is inhabited not only by embodiments, but also by increased interaction and provided support. The actions of the IPA are not only reflexive in relation to learner requests but also should be proactive by nature.

In the research literature surveyed in Chapter 5, intelligent agent systems have been used for human learning purposes either individually as pedagogical agents, collectively in agent societies, or within virtual learning environments. The use of those agents can provide different learning functions (Soliman & Guetl, 2011c). Those agents can be depicted as:

- *Agents for learning personalization.* Those agents promote learning through understanding individual learning abilities and treating the learner accordingly.

- *Agents for emotional support:* Those agents support learning through improving engagement and motivation in the learning environment through considering the learner emotional state and improving it accordingly.

- *Cognitive agents.* Those agents are inspired from cognitive theories of the human mind as well as AI.

- *Meta-cognitive agents.* Those agents are concerned with higher levels of thinking by including meta-cognition supporting methods such as communicating by concept maps.

- *Teachable agents.* Those agents improve learning through giving the human learner the ability to teach an artificial pedagogical agent.

- *Self regulated learning agents.* Apply self-regulated learning theories by agents.

- *Conceptual change agents.* Agents that consider conceptual change learning theories.

- *Explainable agents.* It is discussed in Section 5.3.2 that tracking the reasoning processes of the pedagogical interactions can provide an input to learning. Explaining behavior is possible with the BDI model (Broekens et al., 2010).

- *Multiple agents supporting group learning or training.* It has been shown the benefits of intelligent agents in collaborative learning setting. Thus adopting an intelligent agent approach enables achieving those functions in virtual worlds.

Considering available agent frameworks, it is needed to look into further functional perspectives. The agent based implementation of those functions is taken individually by different research groups. Definitely, adopting most of those functions simultaneously in the virtual environment is desirable with need of considering agent frameworks.

An Agent-based design is a major design decision that has a relation to the environment as well. As the environment is inhabited with various learning resources and immersed learners, several pedagogical agents are required. And hence it should be better assumed that pedagogical agents are not working in isolations. The Multi-Agent System (MAS) model provides an approach for communication between agents at several levels in the virtual world. Research works targeted employing the MAS model in 3D virtual worlds. The work by Panayiotopoulos, Katsirelos, Vosinakis, and Kousidou (1998) provided a proof-of-concept of an agent architecture that works in VRML-based virtual worlds. Benefits of this model include reasoning abilities and the ability of extension to improve collaborative work. In this work the agent is an autonomous avatar that can find his way in a 3D maze. The project of River City in Virtual Singapura (Yu, Shen, & Miao, 2007) recognizes the importance of employing an agent-based model that uses goal-net architecture. A goal-net is a hierarchy of goals that agents need to go through to achieve a bigger goal. In this project the avatar is equipped with goal-net agents (see Figure 16)[1].

Figure 16: Agent controlled 3D avatars in the River City project (Yu, Shen, & Miao 2007).

Furthermore, the work by Canales-Cruz, Sánchez-Arias, Cervantes-Pérez, and Peredo-Valderrama (2009) denoted the importance of employing an MAS model in the VLE for learning architectures to achieve several gains relevant to the sociability nature of the environment. It also denoted its importance for the cooperation in the environment. It coincides with work towards collaborative learning functions in the distributed learning environment by means of intelligent agents. This study suggests a conceptual view of the IPA working in an

[1] Paragraph has partial adoption from Soliman and Guetl (2010c).

immersive VLE to reflect new possible scenarios for learning in the environment and to provide intelligent pedagogical functions in the immersive environment[1].

6.4. Methodology

The discussion in Section 6.2 shows challenging functions for the approach with raised questions. While the intelligence support has shown tendency towards an intelligent agent support for the pedagogical agent, several questions remain unanswered. In particular, what are the wanted properties of the framework, and what methods it supports?

While immersive environments lays the environment aspect, with learning affordances and other characteristics discovered in Chapter 3, it remains how the pedagogical agent can take advantage of it. Furthermore, practicality and pragmatism are important to gear towards actual realizations and deployments. This requirement poses seeking practical frameworks and implementing them. While a theoretical conceptual model can pose a view of the research ideas, validating ideas with proof of concept is also required. While experimentation with a virtual world gives a closer look into what can be utilized and how in particular pedagogical agents can support learning in those environments, experimentation with desired IPA properties are also beneficial and important. Thus delving into details of implementation of the pedagogical agent in an immersive environment give a closer look into what is possible along with the pragmatic aspects that makes them usable. In addition, in order to obtain an opinion on the opportunities, and their learning impact seen with pedagogical agents, the prototype is also required. This is also important given the challenges of the problem discussed in Section 6.2 such as the lifelike behavior in relation to learning focus.

While the conceptual model is an abstract depiction, it requires pragmatic input to validate the concepts taken in the pedagogical agent and the environment aspects given the need to advance and create new functions in relation to pragmatic unknowns. Thus, an iterative approach enables incremental developments to the aspects of incorporating a conceptual model, adopting an immersive environment and learning objects practically, and developing IPA with learning support features. Those activities that are involved in the iterative process include:

1. Researching the literature for conceptual models, compared to requirements, and consequently depicting an appropriate conceptual model. The objective

[1] Paragraph is adopted from Soliman and Guetl (2010c).

is to discover models that support the agent pedagogy in general and in virtual worlds in particular.

2. Targeting an implementation prototype. The prototype is based on evaluation, selection, and implementation of components relevant to the model.

3. Selecting a feasible and practical framework for intelligence support while answering questions relevant to suitable methods.

4. Answers to how interaction occurs with the pedagogical agent, the learner, and the learning objects need resolution.

5. Evaluating the prototype in relation to hypotheses of the IPA learning support features.

Deploying intelligent pedagogical agents require an immersive learning environment. As discussed in Chapter 3, virtual worlds are practical implementations of immersive environments and not necessarily aimed for learning. Hence an approach is to select a virtual world and augment it with learning support from intelligent pedagogical agents for a prototype implementation. After selection of the intelligent agent platform and the virtual world, an approach is required to amend an intelligent pedagogical agent, realize its embodiment and add intelligence support. Hence an interface will be required between the virtual world and the selected intelligent agent platform.

The above requirements are taken into consideration with details in the subsequent Chapters. Chapter 7 resolves challenges on finding the conceptual model and provides input to the prototype realization while creating the view of how a pedagogical agent provides learning services. Chapter 8 takes it to the implementation level by investigating a practical immersive environment. It attempts to answer questions relevant to finding an integratable and practical intelligent agent framework with sought clarifications about reasoning methods through a two step selection process. The interaction pattern with the pedagogical agent is also sought and discovered. Chapter 9 materializes proposed views into learning scenarios that shows the interaction in action, assesses the approach and provides the evaluation. It is important to stress the iterative nature and parallelism in the corresponding depiction, investigations, and implementation aspects in the subsequent Chapters.

6.5. Conclusion

This Chapter worked towards determining the requirements for realizing intelligent pedagogical agents and deploying them in an immersive virtual learning environment. The pedagogical agent in a virtual world requires autonomy, cognitive abilities, learner interactivity, environment awareness, and most importantly, pedagogical aware behavior. The requirements validation for the pedagogical agent include the need for having a global and integrated conceptual model to conceptualize how the IPA is in relation to the environment and what supporting models are. The conceptual model considers how models support learning in virtual worlds by pedagogical agents with stress on the intelligent agent component.

A prototype of implementation in a virtual world can help in reaching the objective and enables investigation of possibilities and facilitating experimentation. As the prototype will require an intelligent agent platform, an inspection into an available and practical intelligent agent platform is required given the inherent benefits of the intelligent agent approach. The prototype targets parts of the requirements and integration with the intelligent agent platform should be sought. Details of interaction between the IPA and the learner in relation to the immersive environment should be more inspected during the implementation.

The following Chapters discuss how to fulfill the requirements through different steps taken towards conceptualizing a solution, investigating a practical agent framework, prototype development, as well as simulating the IPA-learner interaction in relation to the learning objects in the environment.

7. Conceptual Approach

The purpose of this Chapter is to identify the important conceptual elements for applying learning support by IPA in virtual worlds. Based on literature reviews and findings, a conceptual model for IPA in virtual worlds is elaborated and outlined. The conceptual view is for a common understanding, to have guidelines for deeper evaluation of technologies related to the conceptual components and to act as underpinning theoretical foundation for software design and implementation as well as assessment from closer technological viewpoint. This follows an approach of identifying concepts that promote learning with IPAs in general and in virtual learning environments or similar situations such as intelligent tutoring systems that can be enhanced as well. A generality yields identifying architectural elements that bring new educational features into proposed solution model. Relevant architectures, conceptual elements, and models in prior research are surveyed. While there are different relevant aspects with corresponding questions, the focus is targeted towards the elements that enhance IPA support for learning in the environment.

First, relevant research is identified in Section 7.1 looking into conceptual components that have dependent concepts. Section 7.2 provides a reflection and discussion towards creating a conceptual model. The proposed conceptual model is inferred and introduced in Section 7.3 providing an overview of the elements and their dependences while individual conceptual model elements are further detailed in Section 7.4 with a look towards its implementation. Section 7.5 is a conclusion.

7.1. Relevant Conceptual Components and Models in Research

This Section surveys relevant conceptual components and models related to intelligent pedagogical agents in immersive virtual learning environments. First conceptual approaches relevant to pedagogical agents that can provide introductory concepts from research are presented. This is followed by models focusing on the intelligent agent approach as a design principle for pedagogical agents with relevant conceptual models. Subsequently, conceptual architectures and models relevant to virtual learning environments are further elaborated. That paves the road for visiting further conceptual approaches that stresses concepts of employing the IPA in the virtual learning environment.

7.1.1. Models and Architectures for Realizing Intelligent Pedagogical Agents

Incorporating intelligent pedagogical agents in the environment mandate looking at the Intelligent Pedagogical Agent (IPA) as individual entity first, then discovering elements relevant to integrating the IPA in the environment for providing further design concepts. The purpose of this Section is to review conceptual elements relevant to the individual IPA to act as input to further the design. For the intelligent pedagogical agent to act, it is assumed that it has visual appearance and animation behavior in the environment. Communication between the learner and the pedagogical agent can be either verbal or non-verbal. And therefore, both verbal and non-verbal communication methods are considered in the review. Non-verbal communication methods with the learner are associated with the IPA animation behavior. That stimulates affective support to the learner, providing gestures for example, while being realized as a character mandating its animation requirements. One main purpose of the pedagogical agent is to increase engagement and offer support through improving affective functions at the learner side. This Section focuses on the pedagogical agent as a character or humanoid; with animation, verbal or non-verbal communication along with affect processing.

The Virtual Human Architecture (VHA)

Taking the visual appearance of embodiment of the IPA into consideration, and as discussed in Chapter 4, the IPA can take a human-like form. For example, one might seek the IPA to resemble a human teacher in embodiment. In this case, design of virtual humans in VLE provides insights into this aspect of design and how it is influenced by learning needs in relation to the embodiment and its relevant animation behavior. In this aspect, Ieronutti and Chittaro (2007) discuss visual animation of *virtual humans* for 3D educational environments based on the model by Funge, Tu, and Terzopoulos (1999). The authors divide the design problem of the virtual human into five layers: *geometric, kinematic, physical, behavioral*, and *cognitive* (see Figure 17). The *geometric layer* defines the appearance of the virtual human, the *kinematic layer* is concerned with relationship between segments of the body of the virtual human, the *physical layer* applies physics laws to the parts of the body, while the *behavior layer* provides the inherent behavior of the virtual human. The *cognitive layer* therefore manages the virtual human behavior with reasoning based on cognitive modeling.

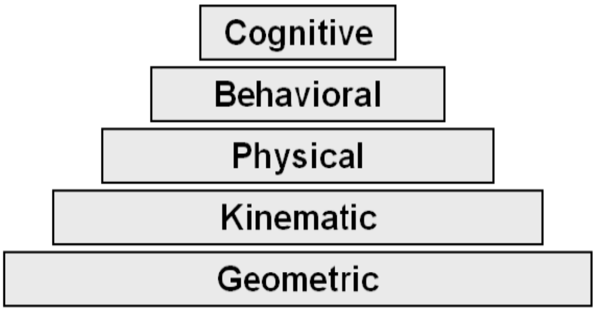

Figure 17: The virtual human modeling hierarchy proposed by Funge, Tu, and Terzopoulos (1999).

In relation to the above mentioned model, Ieronutti and Chittaro (2007) report a limitation of the H-ANIM standard[1] to covering the *geometric layer in X3D/W3D worlds*. And therefore, they propose a model that not only extends the VHA architecture in the several layers but also with the aim to simplify the development, the reuse of virtual humans as tutors, and the integration into a VLE. The components of their proposed virtual human architecture are depicted in Figure 18 consisting of a *behavioral engine, execution engine,* and *presentation module* with a *sense-decide-act* cycle processes. The *behavioral engine* encompasses the behavioral layer the above hierarchy. It manages the "*sense*" and "*decide*" processes. The *execution engine* rather encompasses the *kinematic, physical* and *geometric* layers of the hierarchy. It is responsible for the "*act*" process. The presentation module only presents textual information to the user.

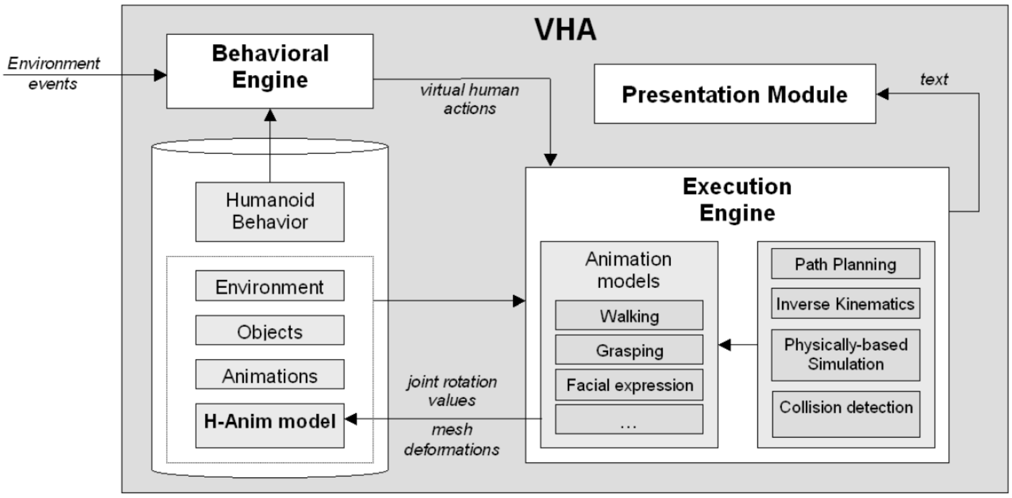

Figure 18: Proposed Virtual Human Architecture (VHA) by Ieronutti and Chittaro (2007).

[1]A standard for creating and animating 3D human figures (H-ANIM, 2004).

Conversation Agents

Kumar and Rose (2009) describe the components of the BASILICA software architecture for building conversational pedagogical agents. This research sheds light into the importance of extending basic dialogue systems with the agent towards enabling contextual and situational awareness as a basis for the conversation. In this work, *situated interaction* is enabled by the capability of the interactive agents to sense and trigger behavior in the environment. In order to achieve context-sensitivity, behavioral components are grouped into *filter* components and *actor* components. *Filter* components observe stimuli from various sources' sensors and *actor* components generate responses accordingly. Example actor functions, offered by the agent are: suggesting help or providing motivational prompts. All components of the architecture communicate through events. The idea of the BASILICA conversation agents, named CycleTalk agent, is to identify situated conversational behavior that is based on reusable separate components (see Figure 19). Weusijana, Kumar, and Rose (2008) further investigated applying the BASILICA architecture to Second Life. In the later work, the conversation agent renders chat behavior to Second Life objects. For example, the prompting actor provokes the user when he/she interacts with the Second Life virtual world relevant interface.

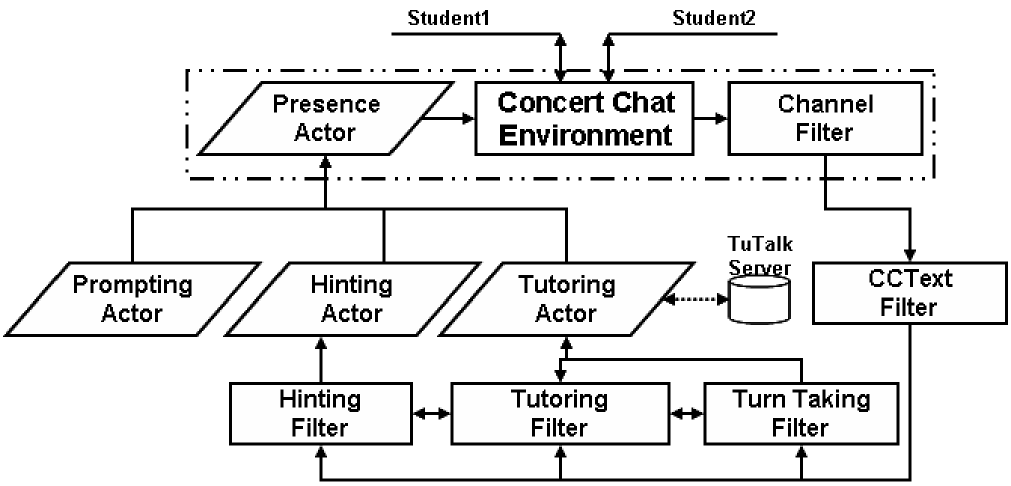

Figure 19: Components of the CycleTalk agent (Kumar & Rose, 2009).

7.1.2. Affect Processing with Pedagogical Agents

Adding affective functions to the IPA has shown evidence to better learner engagement and motivation that contribute to better learning results (see Chapter 4). Therefore, the *affective computing* component is important to the IPA. Affective functions of the pedagogical agent, in relation to learning in the virtual world are discussed in Chapter 4. In relation to this aspect of research, Jaques and Viccari

(2007) observed that affective computing is divided into two main branches: *recognition or expression* of human emotions and *constructing* them. The later is named *emotion synthesis*. Emotion synthesis refers to constructing expressions for the pedagogical agent and linking environment events to the user emotional state[1] (see Figure 20). Jaques and Viccari (2007) indicated that a higher share of the research of affective computing is in the recognition or expression aspect. In relation to this premise, Afzal, and Robinson (2010) surveyed research efforts to automatically recognize and measure emotional experience in learning environments (see Table 10). Table 10 represents the first research branch referred by Jaques and Viccari (2007) being applied to different learning contexts. The information source of affection can be captured through facial expressions, voice, or several interactions by the user and the environment. Afzal and Robinson (2010) also indicate methods of realization. For example, rule based systems, BDI reasoning, rule induction, and more are possibly used for the realization of affect recognition.

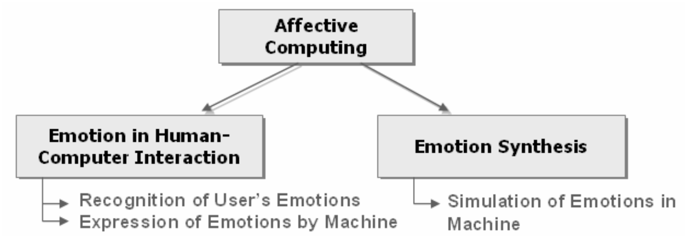

Figure 20: The research branches of the affective computing field (Jaques & Viccari, 2007).

[1] User emotional states can be joy or distress, for example.

Table 10: Automatic affect recognition in learning environments, adopted from Afzal and Robinson (2010).

Affect Concept	Information Source	Learning Context	Method
Difficulty level and speed of content	Facial expressions	Lecture videos	Support Vector Machines and Gabor filters
Positive and negative valence	Facial expressions	Pedagogical agent-based educational environment	Rule-based system
OCC Cognitive Theory of Emotions [27]	User's actions & interaction patterns	Pedagogical agent-based educational environment	Belief-Desire-Intention (BDI) reasoning; appraisal based inference
Flow, Confusion, Boredom, Frustration, Eureka & Neutral	Posture, dialogue and task information	Dialogue based ITS-Auto Tutor	Comparison of multiple classifiers
Pre-frustration & Not pre-frustration	Facial expressions, posture, mouse pressure, skin conductance, task state	Automated Learning Companion	Gaussian process classification; Bayesian inference
Frustration, Confusion, Boredom; Confidence, Interest &Effort	Interaction logs & situational factors	Interactive Learning Environment- WALLIS	Rule induction
Affective reactions to game events	Skin conductance, heart rate, EMG	Educational game-Prime Climb	Unsupervised clustering
Interest, Disinterest, Break-taking behaviour	Facial expressions, posture patterns & task state	Educational Puzzle	Ensemble of classifiers
Scherer's Component Process Model [34]	Facial expressions, task state	Agent-based ITS for nurse education-INES	Appraisal using stimulus evaluation checks
Happiness/Success, Surprise/Happiness, Sadness/Disappointment, Confusion, & Frustration/Anger	Facial expressions	Elementary Maths ITS	Fuzzy-rule based classification
Negative, Neutral & Positive emotions	Acoustic-prosodic cues, discourse markers	Physics Intelligent Tutoring Dialogue System–ITSPOKE	Comparison of multiple classifiers
OCC Cognitive Theory of Emotions [27]	Interaction patterns, personality, goals	Educational game-Prime Climb	Dynamic decision network; Appraisal based inference
Motivation	User actions & interaction patterns; Experience sampling	Japanese numbers ITS-MOODS	Motivation Diagnosis Rules

SCREAM

In relation to the second research branch of Jaques and Viccari (2007) mentioned above of *emotion synthesis* (see Figure 20), Ishizuka and Prendinger (2006) presented Scripting Emotion-based Agent Minds (SCREAM). Figure 21 illustrates the structure of SCREAM as it shows three stages of emotion synthesis with relevant modules: *emotion generation, regulation,* and *expression.* The emotion generation module is composed of three modules: *appraisal, emotion resolution,* and *maintenance.* The *appraisal module* assesses emotional significance based on the OCC[1] model. It infers more than one active emotion that is resolved in the *emotion resolution* module to generate a winning and dominant emotional state rather than several possible emotion states. The purpose of the *maintenance module* is to manage emotions change over time as a result of changes in the situation. The main *regulation module* further manages the resulted emotion from emotion generation. For example, certain emotions may be hidden or presented based on a social distance measure. Therefore, SCREAM not only generates emotions to the agent, but also regulates them within the context of social situation of

1 The OCC model provides an organization of emotional states and how they are triggered (see Chapter 4).

interaction. SCREAM is linked to scripting-based multi-modal communication through an XML based multi-modal presentation language (Ishizuka & Prendinger, 2006).

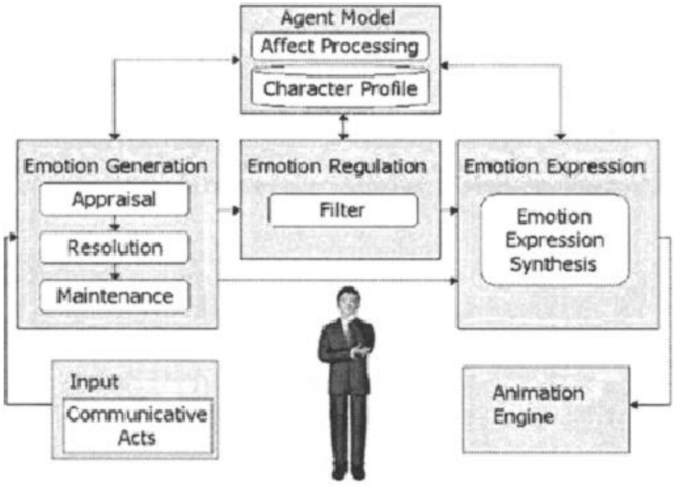

Figure 21: Structure of SCREAM (Ishizuka & Prendinger, 2006).

Summary

Learner interaction with a pedagogical agent support mandates core functions for the design of the pedagogical agent itself. Visited conceptual models reveal fundamental core functions to the pedagogical agent to be: 1) *Appearance* and *Animation* 2) *Observation and Decision* 3) *Conversation*, and 4) *Affection*. The context of learning situation in relation to the environment has shown importance such as in the research of conversation agents (Kumar & Rose, 2009) within *situated interaction* as well as for the *virtual human architecture,* VHA animation within the 3D environment (Ieronutti & Chittaro, 2007). It is also found that affective processing requires two branches of *emotion detection* and *synthesis*. The design of the pedagogical agent, along with the surveyed concepts require IPA *decision* abilities that lead to achieve the mentioned core functions nevertheless to lead the learner to more believability and interaction. As referred in the model of the *virtual human architecture*, the *cognitive* domain provides reasoning abilities to the lower layers. The intelligent agent approach has been found in different designs of pedagogical agents and is investigated in relation to learning functions in the following Section.

7.1.3. Intelligent Agents for Education Support

The cognitive component of the pedagogical agent has shown to be an important part from different aspects discussed in Chapter 4. While different methods can contribute to providing intelligence and reasoning support to the pedagogical agent, there is strong relevance of the intelligent and multi-agent approach that is found in the literature review findings discussed in Chapter 5. The review has shown that the multi-agent approach provide support for the realization of the intelligence component in the pedagogical agent towards achieving different pedagogical support aspects. The objective turns to discover conceptual models and components relevant to intelligent decision behavior and of the cognitive support for the pedagogical agent meant for education support as well by visiting different conceptual architectures.

PVLE

Xu and Wang (2006) present the Personalized Virtual Learning Environment (PVLE) that is based on the intelligent agent approach. They stress the importance of the agent properties of pro-activeness, re-activeness and cooperative behavior to enable a learner-centered approach in virtual environments. PVLE provides different *personalization* functionalities, such as personalized *learning plans*, *learning materials* and tests, and *interaction*s. The PVLE by Xu and Wang (2006) is three-layer architecture composed of: the *learner layer*, the *agent layer*, and the *repository layer* (see Figure 21). The upper layer of PVLE is the *learner layer* which provides adaptive interface services to the learner. The middle layer is the agent layer which provides decision making abilities and is composed of four types of role agents: *learner agent, activity agent, modeling agent,* and *planning agent*. The *activity agent* is in charge of learning activities with the learner such as monitoring tasks, their duration, and test scores and therefore updates the *learner profile* of the *repository layer*. The *modeling agent* abstracts the learner model while the *planning agent* has a goal directed behavior to generate and update learning plans. The *learner agent* provides an adaptive interface. The lower layer is the *repository layer* that is composed of *learner profile*, *learner model*, *learning plan* and *content model* that are used by the agents. In this architecture, the intelligence of the multi-agent approach is utilized for the personalization goal in its different stages of execution. In order to provide learner-centered services, the system has two stages about the learner: *recognition* stage and *reaction* stage. In the recognition stage, the system will utilize agents' autonomous and cooperative behavior to gather information about the learner. At the reaction stage, the proactive and reactive abilities are utilized to match learning activities to the recognized learner model.

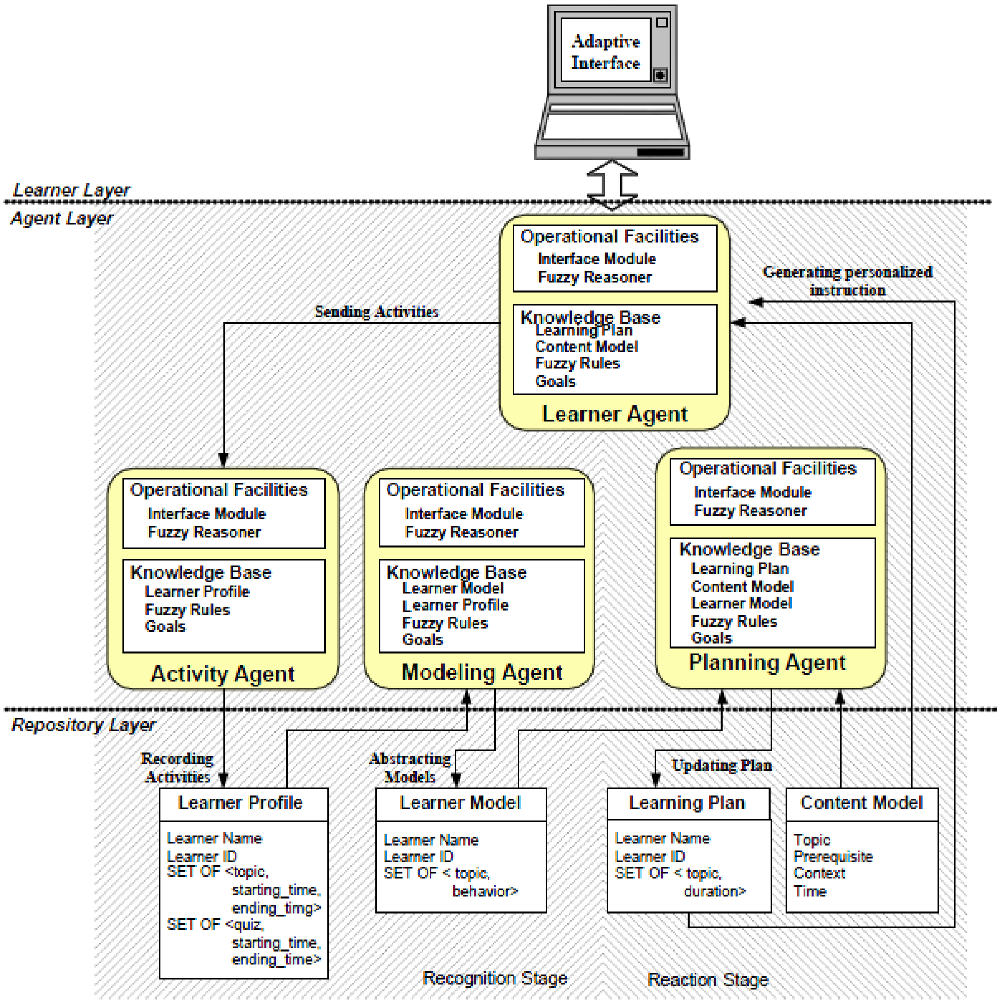

Figure 22: Three layer PVLE architecture (Xu & Wang, 2006).

HABA Based Model

Garces, Quiros, Chiver, and Camahort (2010) investigated implementing virtual agents in a virtual world with the application of chat agents forming the Homogeneous Agents Based Architecture (HABA) as a development process. Agents chat with user avatars in the virtual world to collect and retain data. The virtual agents are implemented by adopting the intelligent agents approach. According to Zambonelli and Omicini (2004) as cited by Garces, Quiros, Chiver, and Camahort (2010), the *multi-agent paradigm* should be a basic conceptual component of software systems. The model of the HABA process is composed of several sub-models in the analysis, design, and implementation parts. The analysis part is composed of *environment model*, *role model*, and *interaction model* (see Figure 23). The *environment model* identifies basic features and resources relevant to the virtual world to the agents. The *role model* defines the generic behavior of the entities as it is composed of activities, permissions, and responsibilities. The *interaction model* defines interaction between components such as between roles and the environment. The design stage of HABA identifies the *social object model*, *role model*, *structural model*, and the *agent model*. This research brings lessons from developing and deploying intelligent agents with the GAIA[1] methodology into the virtual world but with no focus on education as an objective.

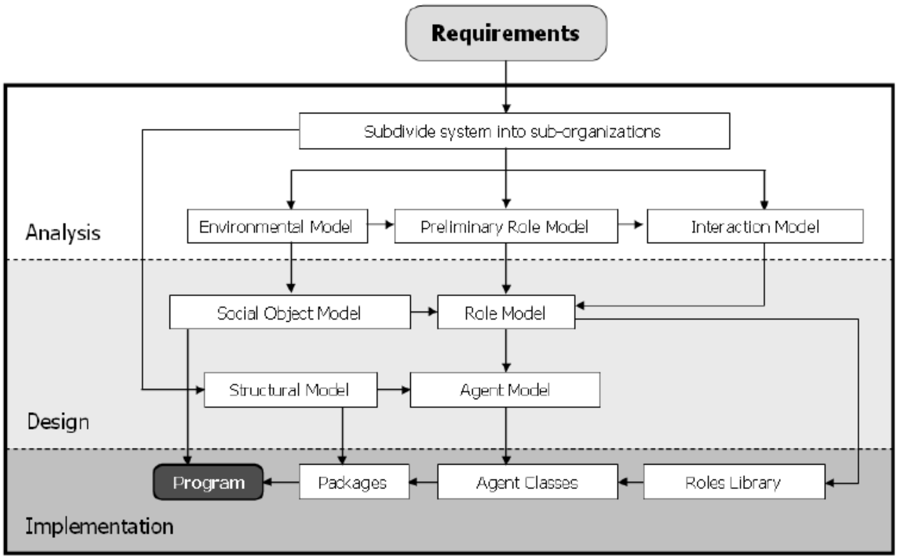

Figure 23: Models in the HABA process (Garces, Quiros, Chover, & Camahort, 2010).

Intelligent Agents in Virtual Worlds for Collaborative Design

Maher, Liew, Gu, and Ding (2005) discuss an *agent-based* support for collaborative design of CAD systems in 3D virtual worlds by a *data-sharing* approach. As data sharing is needed to support multiple designers, updating common models becomes challenging specially within a 3D virtual world. And hence, agents are used to update common data models. Agents exhibit three types of behavior: *reflexive* behavior to respond directly to environment changes, *reactive* behavior that triggers all possible actions in response, or *reflective* behavior to reason about goals before taking decisions. All behaviors are with geometric or non-geometric information. This work can associate agents to objects forming *interface agents*. The purpose of the *interface agent* is to relate the virtual world to the database. An example interface agent is a wall agent. The framework is depicted in Figure 24. In this framework, the agent component receives changes from *sensors* and provides result to *effectors* with virtual world but also with the CAD relevant object database. The reasoning component of the agent provides the knowledge for *perception*, *conception*, *hypothesizer*, and *action*. With the *perception* and

[1] GAIA is a common software engineering methodology for agent oriented analysis and design (Zambonelli, Jennings, & Wooldridge, 2003; Castro & Oliveira, 2011; Liu, Joy, & Griffiths, 2009). GAIA is illustrated in Section 5.5.

conception components, patterns of mismatches of sensed data are found and related to concepts. The *hypothesizer* generates goals with reasoning based on those identified mismatches between the current and desired situation.

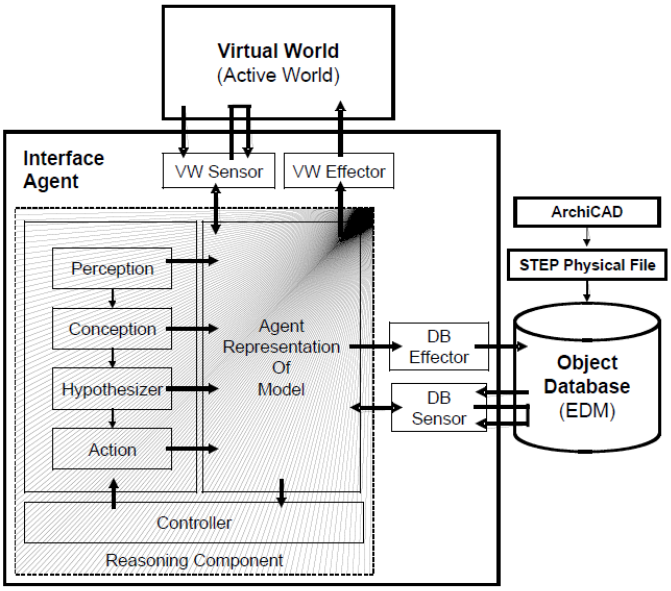

Figure 24: Framework for an agent-centric approach to data sharing in a virtual world (Maher, Liew, Gu, & Ding, 2005).

Intelligent Agents for 3D Electronic Institutions

Bogdanovych, Esteva, Simoff, Sierra, and Berger (2008) propose a methodology for intelligent agent design for interaction in a virtual world by modeling the 3D virtual worlds as an *electronic institution*. They propose the 3D electronic institution as *"Virtual Worlds with normative regulation of interactions"*. *W*ith this methodology, not all actions by avatars are allowed, but rather they are governed by forcing *institutional rules* through the *normative layer* (see Figure 25). While this methodology shifts the focus from role-oriented design of agents towards virtual worlds as an institution, the concept adds features to the VW as a learning environment by enabling rules that govern learner interaction in the 3D environment. That is also applicable to collaborative learning scenarios. This methodology, as indicated by the authors allows efficient collaboration between humans and artificial agents as well.

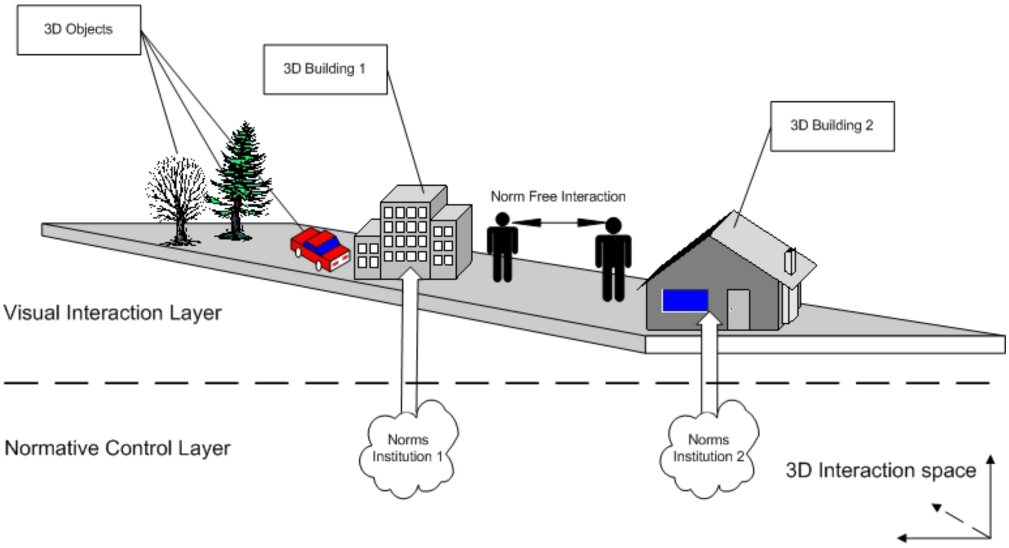

Figure 25: Electronic institution concept (Bogdanovych, Esteva, Simoff, Sierra, & Berger, 2008).

Summary

This Section visited conceptual models, components and relevant methodology for agent-based approach specific to virtual learning environments or virtual worlds. The role model, interaction model, learner model, *activity model* and the *environment model* provide underpinning models for the agent learning functions. From the agent oriented methodology, the *role model* provides a segregation of agent roles in relation to agent goals. The agent obtained knowledge about the learner through the *learner model*, his/her activities through the *activity model*, and interaction aspects through the *interaction model*. To continuously capture such knowledge, the intelligent agent platform requires *sensors* to the environment for *perception* functions. With reasoning, the agent continuously acts in the environment with e*ffectors*. Considering visited research of *collaboration* support in the VLE, the agent had *perception*, *conception*, *hypothesizer*, and *action* functions to provide reasoning support to collaborative design. Interaction in the environment might be guided by a set of *rules* in the virtual environment. In considering the intelligent pedagogical agent acting in the environment, the learning environment should provide supporting conceptual components and models to learning and to pedagogical agents, as focused in the following Section.

7.1.4. The Learning Environment

The IPA is employed in the virtual world in a way that pedagogical services are needed in favor of the learner. In research, the design of the virtual environment is done towards different purposes. The target is to focus on services that lead to better learning support. Elements relevant to the pedagogical aspects of the environment with potential integration of a pedagogical agent are visited in this Section.

PEGASE in Virtual Reality

Buche and Querrec (2011) propose to extend the intelligent tutoring system in VLE to virtual reality with the PEdagocial Generic and Adaptable SystEm (PEGASE). The work focuses on the importance of representation of knowledge of the environment and its use with pedagogical agents to provide instructive assistance in the virtual environment. PEGASE consists of five models, namely: *domain model*, *learner model*, *pedagogical model*, *interface model*, and *error model*. The *domain model* provides semantics needed by the artificial agent *"to be able to construct a representation of the environment and to act together to reach their goals*" (Buche and Querrec, 2011). The *domain model* expresses three types of knowledge: *domain concepts*, *interfacing with the environment*, and *entities behavior*. The *learner model* defines learner personal characteristics and gives the temporal condition of his/her knowledge. The *pedagogical model* provides knowledge for taking teaching decisions with the task to be performed in the environment with knowledge about the pedagogical situation. The *interface model* is concerned with the learner actions in the environment. The error model is used to detect and identify errors of the learner. With the *error model,* distinction is made between observational errors and their causes. Thus it gives rise to the importance of the error cause for the instructional purpose. The system compares learner actions to the expected ones from *domain model* and uses the *error model* to identify errors. The steps from learning interaction to providing pedagogical assistance involving the five models are depicted in Figure 26. The actions of those steps are conducted by different role agents as autonomous entities that infer and share from the models. For example, the *InterfaceAgent* observes learner actions while the *ErrorsAgent* detects and identify errors. The *PedagogicalAgent* offers pedagogical assistance and the *TeacherAgent* selects pedagogical assistance to be displayed by the *InterfaceAgent*.

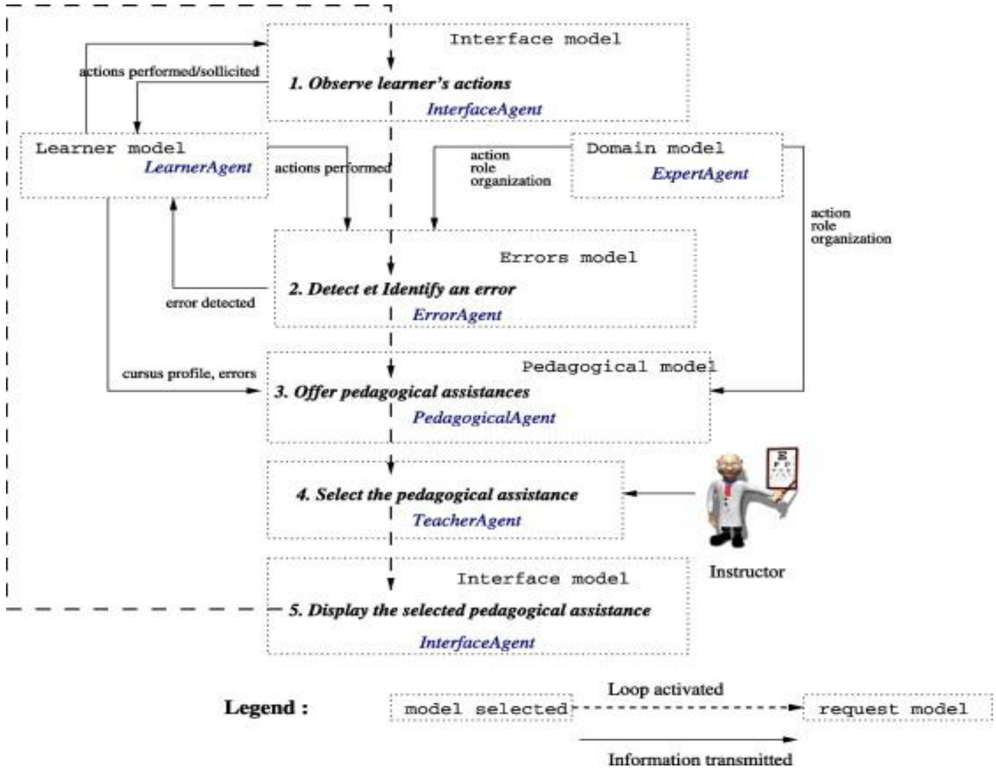

Figure 26: Five models in an instructive process of PEGASE (Buche & Querrec, 2011).

HERA

The Helpful agent for safEty leaRning in virtuAl environment (HERA) is proposed by Amokrane, Lourdeaux, and Burkhardt (2008) to provide learning and training in an ITS based VLE by means of learner tracking. HERA is based on five conceptual model elements: *domain model, learner model, errors model, risks model, and pedagogical model* (see Figure 27). In this approach, the *domain model* provides details about the learning activities. The *learner model* keeps track of learner activities. The *errors model* contains a classification of error types that might occur during learning with causes and consequences of actions committed in the VLE. The *risks model* describes the risks produced by errors. The *risks model* also contains measures used to prevent or limit the effects of such risks. The *pedagogical model* provides the training rules of when, why to intervene, and to explain the learner errors. HERA modules are: *interface module*, *recognition module*, *learner module*, *pedagogical module*, and *risks module*. The *interface module* is an observatory entity that is concerned with observing learner actions and communicating them, in addition to retrieving learner location and the objects in the learner field of vision. The *recognition module* determines what the learner is doing with its ability to infer learner *task plan* by using the intelligent agent tactic of *plan recognition* function. A *task plan* is defined as *"the set of actions carried out by a learner to reach a goal that represents the desired state of the world"*. The *learner module* manages learner task plans. The *risks module* determines the risks produced as of learner errors. It contains the measures used to eliminate, prevent, protect, or limit the effects of risks. An example risk in the 3D virtual environment is not wearing a face mask causing the possibility of inhaling toxic substances. In this case, the *risk module* is triggered by an error with approval from the *pedagogical module*, and sends a message through the interface module with the consequences of the error. The *pedagogical module*, in the context of this research, intervenes to help the learner and provide explanations to errors, or reminds the learner about tasks and in communication with the other modules.

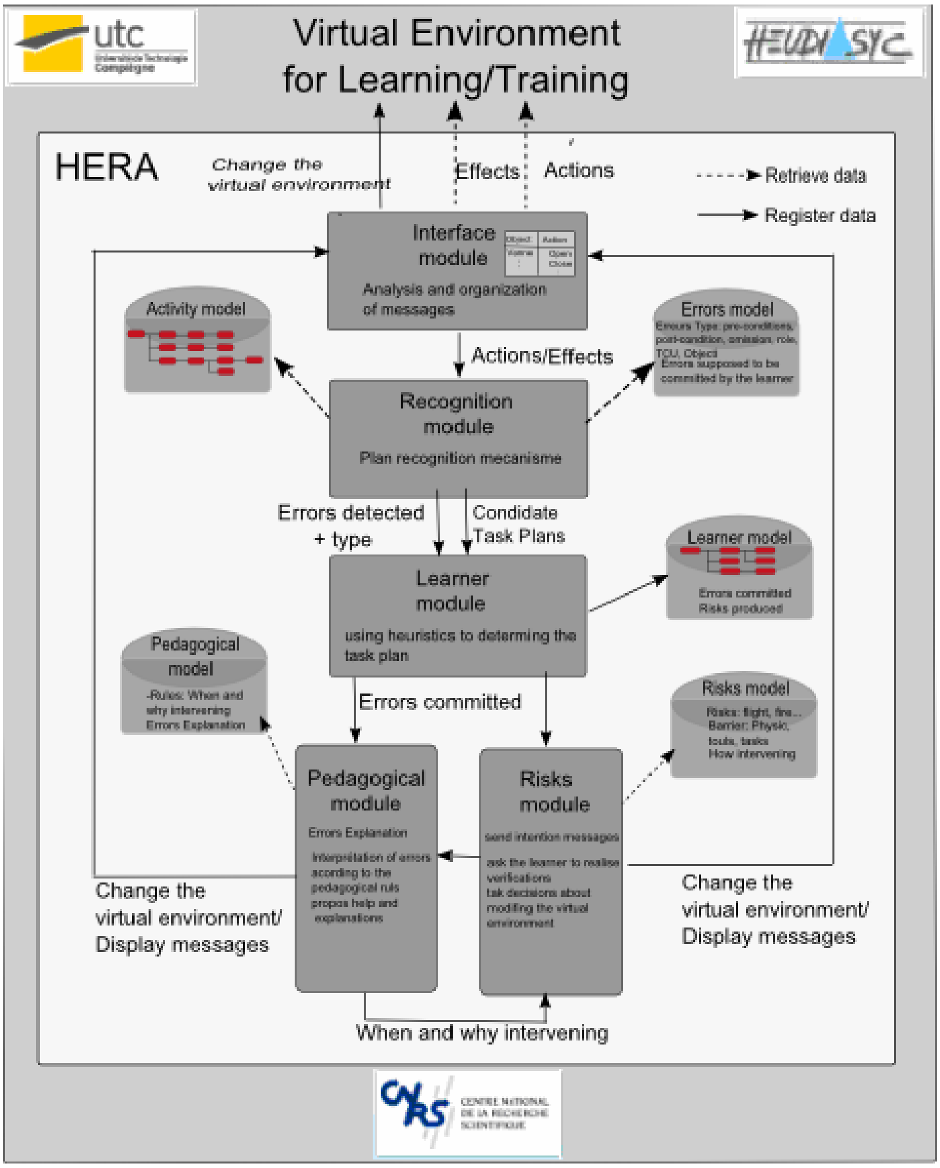

Figure 27: HERA (Amokrane, Lourdeaux, & Burkhardt, 2008).

Model after Sklar and Richards

Sklar and Richards (2006) describe a model in relevance to learning with pedagogical agents. The model is composed of six components: *domain knowledge, teaching component, user interface, student model*, *system adaptivity* model, and *control component*. The *teaching component* is an instructional model that guides the student through the domain knowledge. The *system adaptivity* model is how the system adapts to student behavior. The *control component* manages the pieces together. This model is depicted in Figure 28. This work refers to pedagogical agent to interact with the several components of the model and provide a typology of artificial tutors as *pedagogical agents*, *peer learning agents*, or *demonstrating agents*. Sklar and Richards (2006) stress the importance of the multi-agent model as a control component and discusses its relevant research.

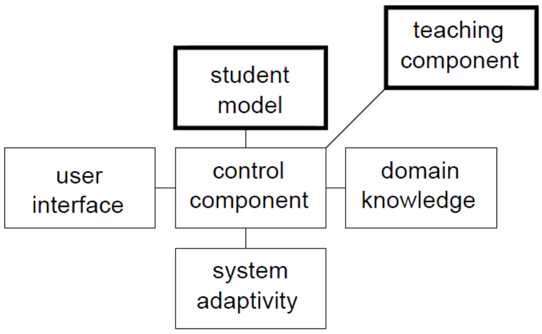

Figure 28: Interactive learning system (Sklar & Richards, 2006).

MASVERP

In the context of safety training in virtual reality for risky situations, Edward, Lourdeaux, Barthès, Lenne, and Burkhardt (2008) propose the Multi-Agent System for Virtual Environment for Risk Prevention (MASVERP) focusing on human decision processes and human-behavior based errors. Three models are used with MASVERP agents: *world model*, *risk model*, and *activity model* (see Figure 29). The *world model* represents the environment objects, their state, and position while the COLOMBO module is in charge of managing changes in the *environment state* or an object state. The risk model is mainly composed of decision rules. The activity model helps the agent in the task of planning. The MASVERP agent is based on the BDI model (see Section 5.3.2). MASVERP is equipped with a *planner,* using an agent planning algorithm for selecting actions based on the agent goals, the environment, and to the individual characteristics of the agents.

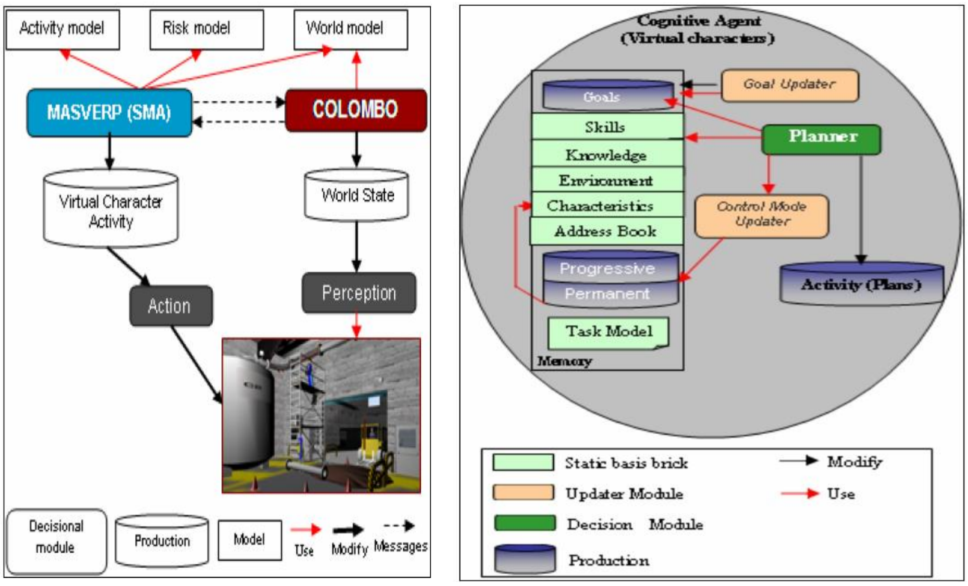

Figure 29: Overall architecture and agent of MASVERP (Edward, Lourdeaux, Barthès, Lenne, & Burkhardt, 2008).

MASCARET

MASCARET stands for Multi Agent System for Collaborative, Adaptive and Realistic Environments for Training (Buche, Querrec, Loor, & Chevaillier, 2003). MASCRET builds on the previously discussed PEGASE component as a multi-agent tutoring system in Figure 26. Chevaillier et al. (2011) further build on MASCARET by utilizing a *semantic modeling* approach to provide basic knowledge about the environment and the system. It covers the different aspects: 1) structure and behavior of the *world*; 2) i*nteractions and tasks* that users and agents perform in the environment; 3) *knowledge items* for the use by agents. The conceptual overview of the main components of the *semantic* MASCARET is depicted in Figure 30. In describing the framework, MATS is a multi-agent based tutoring system for tutoring that refers back to PEGASE described above. VEHA is a meta-model of virtual environment entities. HAVE is a meta-model that describes interactions and activities of users and artificial agents. BEHAVE is a description of the activities that agents can support. Further investigation of this work yields details of the influence of objects or artifacts as well as the environment on the agent behavior. However, no enough details about the pedagogical model are provided in relation to the semantic enhancement.

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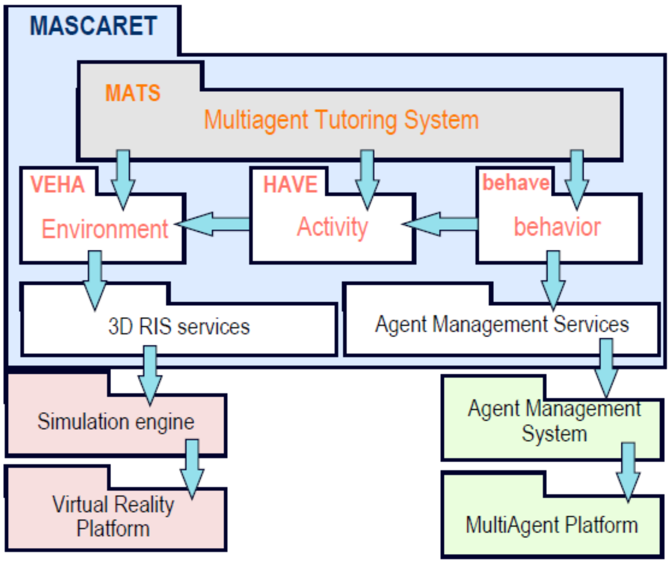

Figure 30: Conceptual overview of the MASCARET framework (Chevaillier et al., 2011).

Framework for Virtual Embodied Collaboration

The framework proposed by Schmeil and Eppler (2009) can be considered a blueprint for collaborative learning in virtual worlds (see Figure 31). While this model does not consider the inclusion of artificial agents, it is helpful to identify learning collaboration elements that the pedagogical agent should deal with in an immersive virtual learning environment. The model has evolved from the authors' effort to formalize the elements in the visual collaboration of a virtual world as well as identifying and incorporating collaboration patterns in the environment. This work identifies three dimensions, namely: *syntactic dimension, semantic dimension, and pragmatic dimension*. The *syntactic dimension* represents visible elements of collaboration. The *semantic dimension* is the alignment with desired objectives. The *pragmatic dimension* represents intentions supported by other layers. The model provides a typology of each of the level elements such as typology of objects such as static, automated, or interactive as well as actions such as communicative, navigation, and object-related actions. The *pragmatic dimension* identifies three categories: *collaborate, learn*, and *play*. The learn category is depicted according to goals of *Bloom's Taxonomy*. While this model provides a blueprint towards formalizing collaboration in virtual worlds, it does not provide indications of the added value of the used collaboration pattern as reported by the authors (Schmeil & Eppler, 2009).

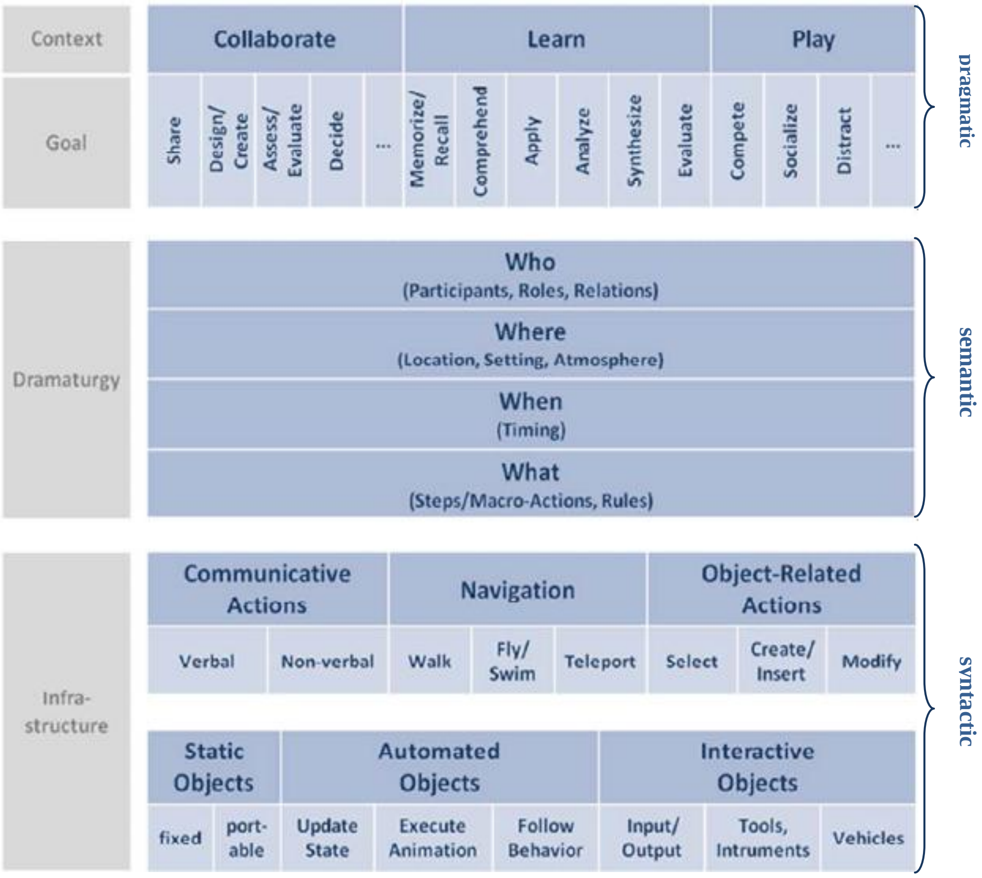

Figure 31: Framework for virtual embodied collaboration by Schmeil and Eppler (2009).

IMA for Complex Learning Resources

Providing assessment is central to the learning process. And therefore, adopting an e-assessment method in the virtual learning environments is also central. A relevant work in e-assessment is found in Wesiak, Al-Smadi, and Guetl (2012) who provide the Integrated Model for e-Assessment (IMA), (see Figure 32) in both the domains of knowledge and skills assessment. The model addresses enriched learning experiences with based on Complex Learning Resources[1] (CLR) and integrated assessment methods. The model includes a core methodology of four components: 1) *Learning objectives*, 2) *Complex learning resources*, 3) *New forms of assessment*, and 4) *Evaluation and validation*. *Educational, psychological, technical aspects* as well as *standards and specifications* are included in this model. Adaptivity components include a *didactic model*, *knowledge model, and learner model.*

The IMA model also includes a *quality assurance* component that aims at ensuring high quality standard in learning activities including best practices and

[1] Collaborative and social learning, storytelling, simulation, and serious games (Wesiak, Al-Smadi, & Guetl, 2012).

standards in delivery and managing ethical aspects such as data protection and plagiarism prevention.

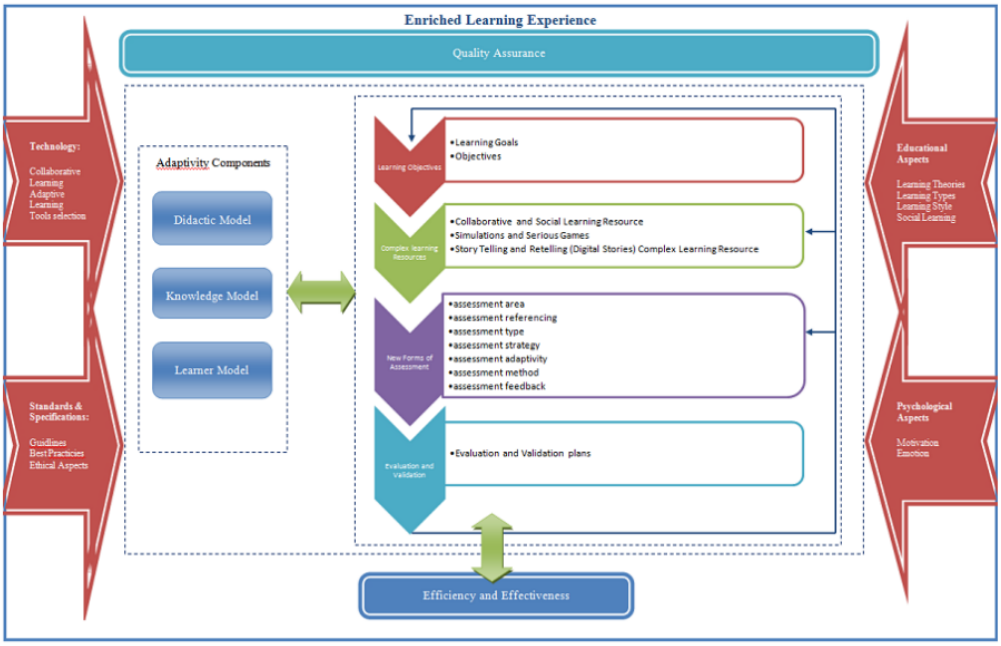

Figure 32: Integrated Model for e-Assessment (IMA) by Wesiak, Al-Smadi, and Guetl (2012).

3D Adaptive Presentation and Navigation

Adapting the visual presentation in an immersive VLE brings positive learning experiences and should not be neglected. Generally changes in the scenes of a virtual word interface occur as a result of change in location. Few studies are performed on visual adaptation in virtual worlds and its consequences on learning and engagement experiences. Visual adaptation for learner personalization has been depicted by a model of Chittaro and Ranon (2007). This research also reports the lack of investigation on the effects of adaptation. Chittaro and Ranon (2007) suggest careful adaptation as it can also yield negative experience, if not done properly. The model is based on the Adaptive Hyper Media Architecture (AHA) by De Bra, Aerts, Berden, de Lange, and Rousseau (2003). With the model by Chittaro and Ranon (2007), the system provides navigation support to guide the learner to suitable VE objects and navigated places while updates to the user model also takes place based on the learner interaction style and with the 3D object and movements in the environment. The system architecture is depicted in Figure 33. The authors describe the system as follows: *"The usage data sensing component sends relevant usage data to a usage data analysis component, which turns the data into user model update and content requests for AHA!, which sends the personalized content through a content transformer component before it's passed to the user's browser. Dotted boxes represent optional transformers that can be added in specific domain or application scenarios."* (Chittaro & Ranon, 2007).

Usage data can be user position, orientation, or actions. AHA interacts with three components, namely: *domain/adaptation model, user model*, and *application content* (see Figure 33). The *domain/adaptation model* represents educational application adaptation rules and conceptual structure. While adaptation in AHA can provide *adaptive presentation* and *adaptive navigation* (see Figure 34) through rules, this model provides a generalization through the *content transformer component*. The model does not consider pedagogical agents and their possible roles in adaptation as well as interaction with other components.

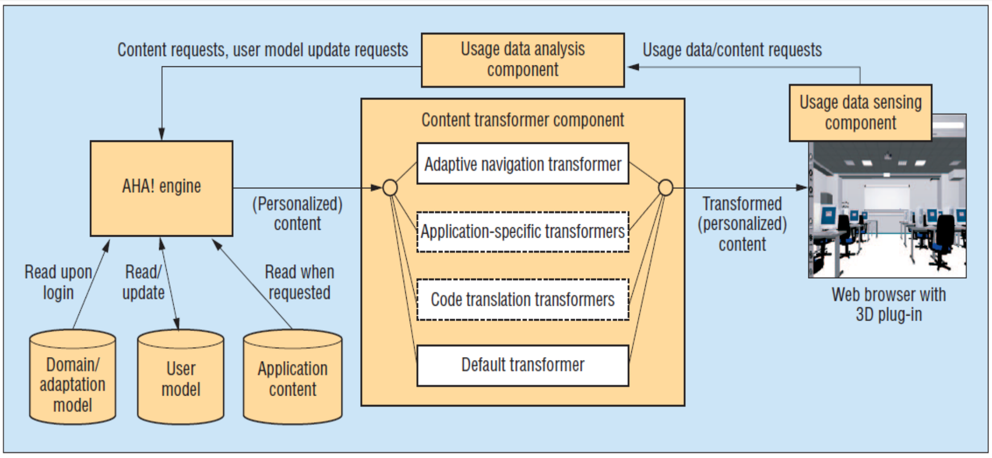

Figure 33: The system architecture proposed by Chittaro and Ranon (2007) for adaptive hypermedia in a virtual learning environment.

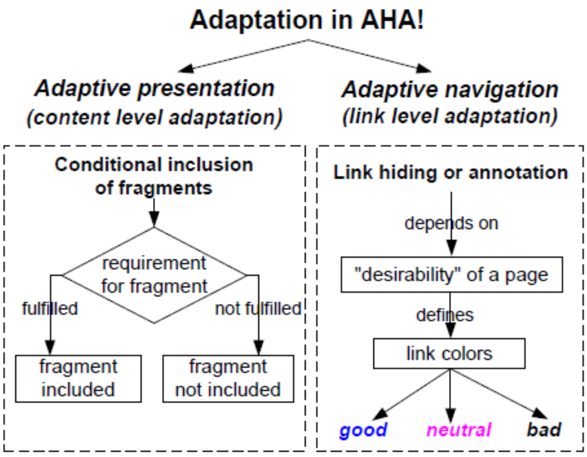

Figure 34: Adaptive techniques in AHA (De Bra, Aerts, Berden, de Lange, & Rousseau, 2003).

Summary

In the visited work, it is found that the environment impacts and provides supporting conceptual models to learning with intelligent agents. Several works visited are in the way to formalize the design of the environments to be both pedagogical aware and supporting the agent approaches. Conceptual frameworks such as PEGASE, HERA, MASVERP, MASCARET, and AHA provide supporting conceptual frameworks to learning in VLE. Several of which extend on intelligent tutoring systems concepts in 2D towards 3D virtual worlds with IPA support. The visited frameworks help identifying the following conceptual models: *pedagogical model, domain model*, *error model*, and *risk model.* The importance of prior identified models, including: *learner model, domain model, task and activity models* are also stressed in this study. The two identified models of *error* and the *risk* have special importance to manage learner errors and extraneous learner behavior in the environment that both have pedagogical values.

With the importance of collaborative learning activities, and the potential offering of virtual worlds, formalizing it by a *collaboration model* is highly desirable. The model by Schmeil and Eppler (2009) can act as a reference model for virtual embodied collaboration in virtual worlds, and therefore its components are relevant in formalizing an IPA model in a virtual world that considers collaborative learning. Another relevant and important aspect to learning in recent virtual environments is the need for a formalized an *assessment model.* And therefore, the IMA model (Wesiak, Al-Smadi, & Guetl, 2012) provides a reference to this need from an integrated and up to date perspective. The pedagogical agent aspects are not necessarily relevant to cognitive and decision abilities. The following Section sheds light into further aspects by visiting further frameworks that has particular support for intelligent pedagogical agents and their integration in an environment.

7.1.5. Employing IPA in the VLE

This Section further visits conceptual models and components that are with focus on integrating intelligent pedagogical agents in the virtual learning environment. The purpose is to discover further conceptual elements and visit other models that support the integration of IPA to complement its function in the environment.

Framework for PVLE after Ashoori et al. (2009)

Ashoori, Shen, Miao, and Peyton (2009) present an agent-based framework for personalized virtual environments that has been applied in the project *Virtual Singapura*. The framework is depicted in Figure 35. The framework consists of *agent model*, *user model*, *interaction model.* The *agent model* consists of *belief model* and *goal model* that follow agent-oriented concepts. The *interaction model* defines protocols and mechanisms for interaction between agents and learners and among agents as well. The *interaction model* purpose is to personalize learner interaction increasing believability. Thus it can be used to update the *user model.* The framework includes a mentor agent who monitors learner activities and updates the learner model as well as acting as a coordinator with other agents as guide agents. With the framework of Ashoori, Shen, Miao, and Peyton (2009), two important properties are achieved: 1) better belief update and fusion, 2) providing *credits* to pedagogical agents who communicate efficiently with learners through a *credit assignment* algorithm. Thus the mentor agent can direct the learner to a better pedagogical agent.

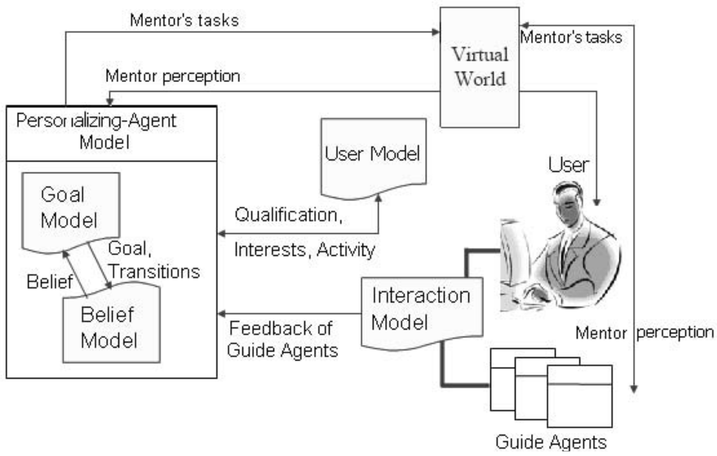

Figure 35: Pedagogical agent personalization framework in VLE (Ashoori, Shen, Miao, & Peyton, 2009).

Steve

Steve, the famous pedagogical agent also acts in a Virtual Environment for Training (VET) to demonstrate tasks, offer advice, and answer questions (Johnson, Rickel, Stiles, & Munro, 1998; Johnson, 2001). There are three "thrusts" in this system: the environment, called VISTA, the VRIDES system that simulate 3D object behavior in the environment, and Steve. VRIDES is a 3D extension to RIDES which is an authoring system for 2D simulations (Johnson, Rickel, Stiles, & Munro, 1998). It controls the behavior of the objects and also acts as a framework for creating structured lessons.

Steve's conceptual architecture is depicted in Figure 36 as it is composed of a *cognitive component*, a *perceptual component*, and a *motor component*. The *cognitive component* is based on SOAR agent cognitive architecture (see Chapter 5) adding *pedagogical functions* as well as *domain knowledge* model. Steve interacts in the environment receiving perceptions and providing actions in the learning environment by the *motor component*. Steve interacts with different components of the VET: VRIDES as an object simulator, VISTA as a visual interface between the user and the virtual world, and Trishtalk for *speech synthesis*. The VET architecture is also shown in Figure 26.

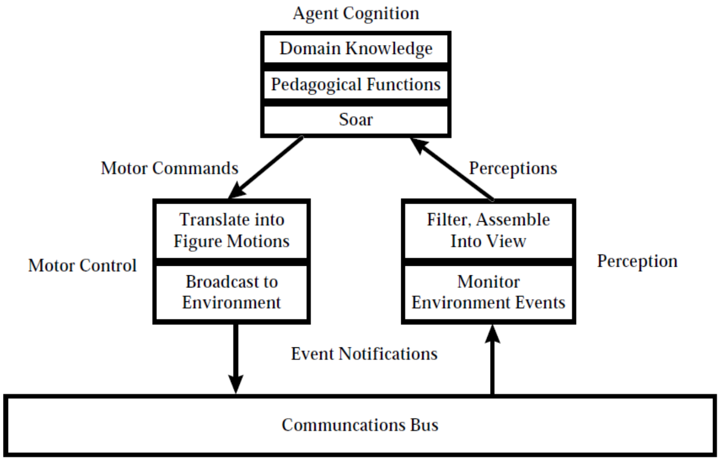

Figure 36: Steve receives perceptions and provides actions to the environment through a communication bus (Johnson, Rickel, Stiles, & Munro, 1998).

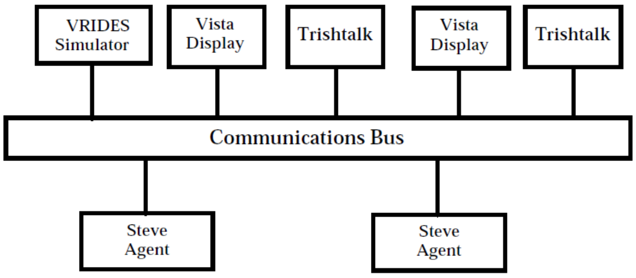

Figure 37: VET architecture for Steve agent (Johnson, Rickel, Stiles, & Munro, 1998).

Integration Approach after Mendez and Antonio (2005)

Mendez and Antonio (2005) adopt an agent approach to the integration. They convert the virtual learning environment that is composed of *tutoring model*, *student model*, *expert model*, and *world model* into an agent-based architecture based on the GAIA methodology. In their proposed architecture, five agents are depicted: *communication agent*, *student modeling agent*, *world agent*, *expert agent*, and a *tutoring agent*. Each agent is further decomposed to achieve sub-goals in the environment (see Figure 38). With this agent-based architecture, the *world agent* is responsible for 3D geometrical information of the objects or other inhabitants of the world and answering questions about the location of the objects. The world agent provides support to *path-planning* to provide 3D navigation in the environment.

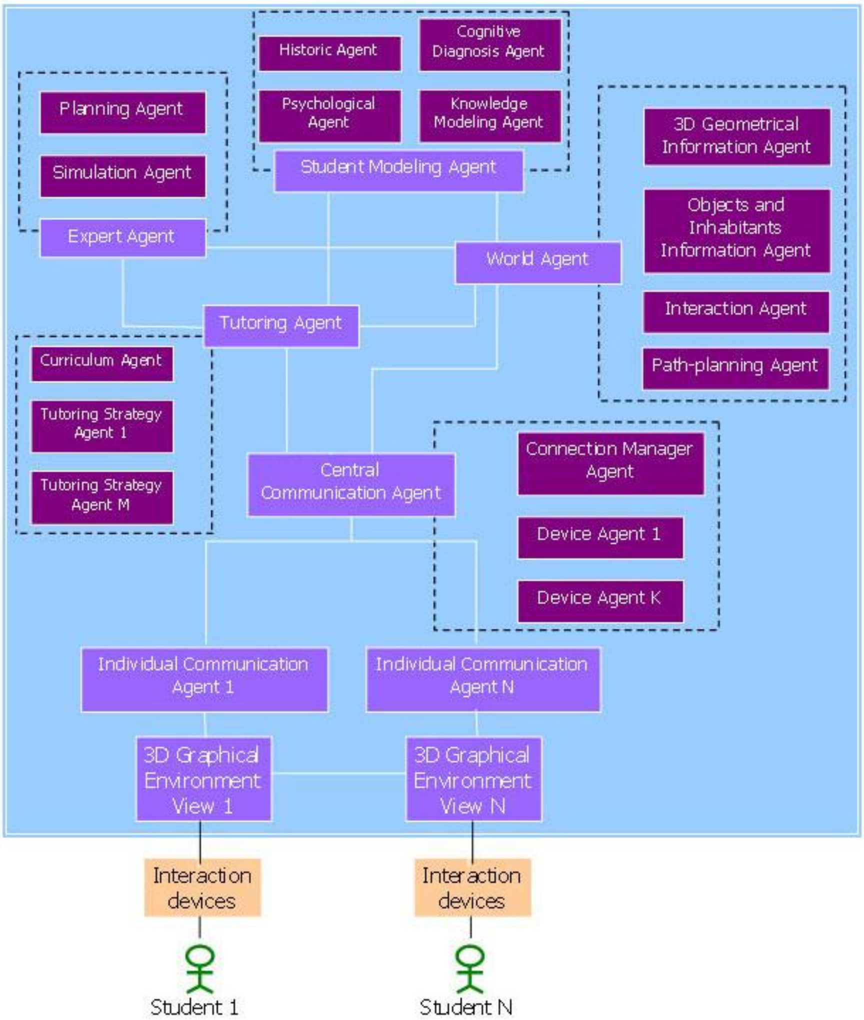

Figure 38: Agent based architecture of Mendez and Antonio (2005).

Conceptual Architecture after Tzeng (2001)

Tzeng (2001) proposed a layered approach conceptualizing pedagogical agents in a 3D virtual environment based on three layers. The three layers in the model are: *network service layer* responsible for communication among the system components, *learning environment layer*, and *learning service layer*. The *learning service layer* provides service functions to the learner of *operation* of a virtual experiment, *explanation* function upon incorrect operation, and *demonstration* upon user request. The learning environment layer consists of 3D *virtual laboratory*, *learning manager*, and *pedagogical agent*. The system architecture of this work is shown in Figure 39. The reasoning model of the pedagogical agent is based on the Java Expert System Shell (JESS). Based on Jess reasoning, the pedagogical agent provides demonstrations and explanations once it receives operation messages from the learning manager. It also provides corrections.

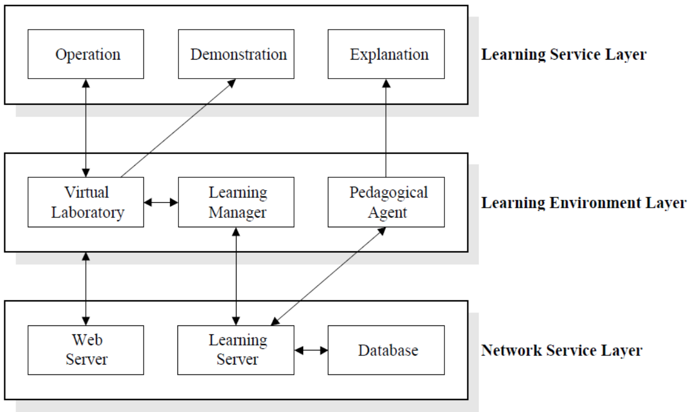

Figure 39: Conceptual architecture by Tzeng (2001).

Summary

Further conceptual models and architectures of learning with integrated pedagogical agents in the virtual world were visited in this Section. The agent based approach to the integration is shown to provide a supporting model to the IPA intelligent actions in the environment. A multi-agent system with different roles supports the IPA in the environment in addition to conceptual model of the learner and the learning object. The IPA aware of the environment has beliefs about the environment, learning objects, and learners to update its belief model. Conceptual elements stressed in models included the *goal model*, the *belief model*, the *user model, the interaction model* (Ashoori, Shen, Miao, & Peyton, 2009) as well as the *world model* (Mendez & Antonio, 2005). With the *role model*, the learning environment, and its evolution, different pedagogical agent roles exist. It was possible to direct the learner to a mentor agent that gives a better utility by the use of a *credit assignment method* of Ashoori, Shen, Miao, and Peyton (2009).

One of the early pedagogical agents relevant architecture is *Steve* that has shown to provide a reference model for concepts of IPA in immersive environments. Steve stresses training with a *simulated learning object* and with perception and motor controlled actions about the immersive learning environment. Pedagogical functions in the immersive learning environment are supported with different models. The *domain knowledge* model, the *pedagogical model, task model, and error model,* visited in several sections in this Chapter, all have relevance to support several pedagogical functions of the IPA in the immersive learning environment.

7.2. Towards an Integrated Conceptual Model

Three main aspects of discussion are categorized to be: the *learning environment*, the *IPA*, and *supporting models*. The three main categories are discussed below.

The IPA

In reference to the review on pedagogical agents in Chapter 3, the requirements discussed in Chapter 6, and the visited conceptual frameworks in Section 7.1 the IPA as center of focus requires different abilities that can be categorized to be: *appearance and animation, observation and decision, conversation*, and *affection*.

The *IPA* appears in a visual environment, and as result it should have a visual embodiment component. As reported earlier, the *IPA* can utilize the *persona* for increased learner performance (Lester et al., 1997; Wang et al., 2008; Chapter 4). *The appearance* element of the IPA is relevant to *embodiment*, *visualization*, and *animation* as well for the needed interaction with the user. In a relevant aspect, emotion elicitation by the pedagogical agent requires animation abilities. The animation aspect of the pedagogical agent gives further abilities to a channel of visual communication as described before. For example, and in similarity to the actual teacher, the virtual teacher pedagogical agent uses its animation abilities to point to relevant learning task location or provide gestures to show agreement or correctness of the task.

The *observation* function of the IPA is important not only to enable the IPA to "sense" learner actions but also to be able to add contextualization (Machet, Lowe, & Guetl, 2012) by sensing the environment and tailor the actions to suit the context. The CycleTalk agent by Kumar and Rose (2009) is an example of an agent that is aware of the environment events and which can tailor its conversation to context. The observation component of the pedagogical agent is also important for the intelligence part to enable informed decisions that are not in isolation of what the learner is doing nor what is happening in the environment. As discussed in Section 7.1.3, the intelligent agent component requires sensing the environment for providing best reasoning. While the sensing component provides input for the decision making ability of the pedagogical agent, acting on the environment is also needed. I.e. to convey decisions to the environment and to the user. Apart from observation, the decision ability of the pedagogical agent is central to an effective realization for different pedagogical relevant reasons. Chapter 4 discussed intelligent methods in relevance to several pedagogical aspects. Lessons from the literature review are taken in considering the decision component to support the pedagogical agent. The decision component of the pedagogical agent is tied to it its behavior and is a very important component that is strongly tied to its pedagogical intelligent support.

Conversation is central to the IPA from the perspective that the IPA is the central point of interaction between the learner and the learning environment. A multi-model communication is necessary for any learner. Without communication, learning does not occur. The *conversation* ability is what distinguishes IPA value addition (Kim & Baylor, 2006). Variation of the type of communication is desirable to suit the learner differences and style. The type of communication can be by textual dialogues, voice conversations, or even by a visual gesture which can also convey a message. It is found by Weusijana, Kumar, and Rose (2008) that hiding text chat during speech is preferred than using dual channels of communication. Therefore, the implementation of conversation abilities of pedagogical agents should consider to the *redundancy principle* while giving multiple disjoint multi-modal communication interface abilities. As the IPA is an artificial entity, the type and realization of the conversation ability is bound to technological advancements in this research area while it positively contributes to the believability of the pedagogical agent.

The *affection* component suggests a pedagogical agent that can better understand the emotional state of the learner and contribute to pedagogy through affective support. This contributes to learner attitude and motivation to increase the rate of task completion in the virtual learning environment. In the found research, a compatible emotion elicitation with the learner and the situation by the pedagogical agent leads to better believability and hence to complete the learning activity. Different methods of capturing the emotional state of the learner are given by Afzal and Robinson (2010). Emotions can be elicited through animated gestures, face of the pedagogical agent, textual, or verbal dialogues with the learner. Therefore, the affection element of the pedagogical agent has an emotion capture methods and control tactics to convey suited emotion to the learner. This aspect is tied to technological advancements and has relevance to the *affective computing* research domain.

Combining the above mentioned categories in the pedagogical agent realization can form its roles and functions. Considering the IPA as a virtual human like embodiment, those functions span the different layers of the virtual human reference architecture by Funge, Tu, and Terzopoulos (1999). The elements of the visual and intelligent pedagogical agent, discussed above, require behavioral functions that are mainly controlled by the top layer which is the cognitive layer. While the pedagogical agent stresses pedagogical oriented behavior, intelligent pedagogical reasoning focus on this cognitive layer as well. Pedagogical intelligent functions require such a high layer that consequently controls the agent. In relation to Steve for example, it has the pedagogical function layer on top of SOAR cognitive architecture (Johnson et al., 1998; Figure 36). With the facilitation of a cognitive layer and the mentioned functions, the roles of the pedagogical agent are better realized. Those roles can include providing a tutorial to a learner in the immersive learning environment, showing tasks, or monitoring and interacting with the learner while performing the task so as to guide, correct errors, and make assessments. Different roles of the IPA should be targeted in depicting a conceptual framework.

The IPA has the potential to play different roles. Not necessarily the IPA will only interact with one learner. But it can act and interact with different avatars who can be teachers as well. Referenced above is the need for learners in the immersive environment to find peers; the IPA can also act as a peer which can provide other functions such as directing to other learners and other pedagogical agents such as in the work by Ashoori et al. (2009). An example depicting a different function of the IPA is found in Sklar, Parsons, and Stone (2004) who reported that incorporating multiple interacting educational robots in course settings brings benefits to learning. In *interactive pedagogical drama* (Marsella, 2003), multiple pedagogical agents are considered who are actors in front of immersed learners or a class presenting a story for a pedagogical objective, with ability of learners to interact as well. With pedagogical agents' interaction and conversational abilities with learner, and in context, the virtual world is considered richer in pedagogical offering in comparison to learning with videos.

The Learning Environment

The environment should not only be rich in learning resources but should also support the suitable pedagogical methods of learning with these resources. It should supply the needs of pedagogical agents to be able to deliver effective instruction and support the needs of intelligent functions reasoning. Integrating a virtual world with an intelligent agent platform should convey the environment state and relevant events to the agent platforms and allow the intelligent agent to affect it for a pedagogical objective. The following questions are important: What are the learning elements needed in the learning environment, what is comprehensive? And what models suit our target learning environment?

While, the virtual world as a learning environment provides interesting characteristics for education, further support is required. It is discussed in Chapter 3 that the immersive environment provides a good opportunity for visual and contextualized collaboration. Basic affordances of the virtual world are also discussed in Section 3.2. It is further discussed that virtual worlds are not originally designed for learning purposes. The existence of such gap motivates the need for other functions and the addition of intelligent pedagogical agents to support its learning offerings. Considering the intelligent pedagogical agent interaction in the virtual world, IPA awareness and support are crucial to provide its services in a contextualized way accordingly.

Learning scenarios differ in a virtual world from other learning environments in 3D visual interaction with learning objects that are not anymore in 2D. Learning events occur and there is a great potential for interaction with other learners in the immersive environment. It is discussed in Chapter 2 that virtual worlds give the opportunity for learning by doing. Furthermore, a distinguishing aspect of virtual worlds is the authentic learning experience and the active explorative nature. Learning by doing and the gained learning upon experience with the immersive environment shift the focus from traditional learning and thus requires its awareness in the pedagogical strategy the IPA will undertake in the immersive environment. Details of interaction with the pedagogical agent, the environment, and the learner in relation to its assessment and goal achievement are important given the relation to the new virtual world characteristics.

The virtual world as an environment of learning is considered for its potential abilities of visualization that is combined with collaborative support to the learner. The IPA is viewed to act as a central point of interaction between the learner and the learning environment to provide learning services to the immersed learners. The components of those immersive learning services are related to the learning objects, spaces and modules that form the immersive learning environment. The conceptual functions adopting innovations of learning in the immersive world mandates supporting learning services from the environment. However, virtual worlds are not necessarily designed for learning, and therefore have two components to add. A supporting component from the environment and the other is from the IPA discussed above. The supporting component from the environment attempts to convert it from a virtual environment, or a virtual world to an immersive learning environment; a learning virtual world. Both dedicate resources, functionalities, and supporting models to be put to serve of the learner individual needs. Another objective is to make the environment pedagogically intelligent. For example, it is to support the IPA to reason and take decisions that achieve its pedagogical goals. Common to those in relation to the environment are the use of a perception module that links the events of the world to intelligent agent platform and to dispose reasoned actions to the environment. Reasoned actions received from the intelligent platform are forwarded to the environment to materialize the actions.

The importance of *learning objects* with pedagogical design is profound. Considering a pedagogical agent in relation to the learning object, it has two objectives: to provide guidance to the resource, and to provide pedagogical guidance to the learner about the resource itself. Hence, the IPA requires understanding and ability of interaction with the learning objects. The semantic description and the ability to control the behavior of the learning object by the agent both facilitate better pedagogical scenarios. Therefore, the *learning object model* is required in a way that can be linked with the *learner mode, activity model,* and *pedagogical models*. In other words, while the IPA design objectives significantly consider pedagogical and context-aware interactions with the learner, the pedagogical agent awareness of the environment and the considered learning objects are necessary. Intuitively, learning objects are designed for a pedagogical goal that is tied to IPA objectives with the learner as well. Gluing different smaller learning objectives from different learning resources becomes important to be form to a learning path, which has an ultimate objective with the learning requirement. This gluing can be either performed by the intelligent pedagogical agent or by the learning environment. Nevertheless, its goal-oriented attainment is related to the learner ability and to the various pedagogical related included models. The goal directed behavior, with the visited goal models contribute to the goal directed behavior of the intelligent agent in relation to the different goals of the various resources available. The goal-directed implementation approach thus is important for completing the learning path with the learning in an autonomous manner, which will be discussed again in the following Chapters. The learning environment hence should support the pervasiveness of various learning resources in a way that contributes to the goal attainment by the agent. In contrary, in absence of learning objects that contribute to pedagogical goals in the environment, those goals are not achievable.

Furthermore, learning evaluation concepts are important for integration with the adopted approach of a pedagogical agent. Within the visited frameworks, and with the authentic learning nature of the 3D environment, the learning situation can generate errors according to learner mistakes or due to environment generated errors. The pedagogical approach for assessment and monitoring can be either an *immediate* feedback or in a form of *delayed* assessments upon finishing the activity. Those were experienced with the *error model*, the *risk model*, and the *environment model* in relation to the learning objects. In learning situations, it might be possible to provide the learner with an opportunity to make mistakes or to complete an experiment with errors. However, in risky situations such as in simulations or training for hazardous scenarios, providing an immediate feedback or blocking the attempted action might be preferred or even mandatory. Thus striking a balance between delayed against immediate feedback is sought. The IMA model (Wesiak, Al-Smadi, and Guetl, 2012) provides a formalized and integrated approach for assessment, with complex learning resources consideration with a learner-centered focus leading to learning efficiency and effectiveness that can also relate to learning in virtual worlds with pedagogical agents. The learning by doing approach that suits learning in virtual world also mandates integrating assessment with the pedagogical agent interaction and behavior with the learner. And with the increased interactive abilities of an IPA, immediate feedback and reporting become both feasible and desirable. It is viewed that the assessment has a strong relation to goal attainment. In intelligent agent systems, a goal directed behavior is necessary for autonomous actions. The goals, as will be discussed later, are subject to reasoning that decides which goals to pursue and which to drop. Determination of goal success or failure should definitely be subject to learner progress in the learning situation and hence should be tied to the intelligent agent behavior.

Considering the cognitive layer of the pedagogical agent in the visited architectures, it can be either centralized focusing on one agent or adopting a decentralized intelligence approach. The decentralized approach is preferred as it glues intelligences from different sources that are multiple pedagogical agents, learning objects, multiple learners, or other environmental aspects. That is in addition to reasoning with interaction with the discussed models. In relation to the learning object and the environment, the *agents and artifacts* model (Ricci, Viroli, and Omicini, 2007) as an example suggests the relevance of the learning object to the reasoning function. In relation to the learner aspect, Section 5.5 discussed the relevance of the intelligent agent model to collaborative learning support with abilities to provide cohesion for cooperative work. In relation to multiple pedagogical agents, Figure 50 of Section 8.3 shows a view of agents supporting multiple IPAs. The electronic institution concept (Bogdanovych et al., 2008), for example depicts a view of multiple agents rather than one. Definitely resembling the concept for a virtual university in a virtual word seeks coordination, awareness, and organization among the multiple pedagogical agents inhabiting the environment. The distributed model thus brings different aspects together to give potential of context-awareness and suit the continuous changes that occur in the dynamic virtual learning environment. Utilizing a distributed model of intelligence in a pedagogical agent thus permits extensibility in this regard allowing this cohesion achievement.

With the above mentioned factors in relation to the virtual world as a learning environment, and in order to provide intelligent pedagogical services, further architectural elements are needed. Those elements can form an immersive learning layer that adds to the known learning affordance provisioning of the virtual world transforming it to become pedagogically aware and intelligent in relation to the scope of IPA-based learning. As the virtual world by itself does not provide pedagogical guidance and follow-up, care is sought for executing and managing the pedagogical approach of learning delivery. The IPA along with the intelligent immersive learning layer, both support the delivery of pedagogical methods.

Supporting Models

Based on the discussion above, the objective is to have the pedagogical agent provide learning support to learners who are immersed in a virtual world that is rich in learning resources. The *IPA*, the *VW*, *the learner* community, and *pedagogy* form important model elements. Those elements are interrelated to achieve the effective and efficient learning. In the focus of implementing IPA in virtual worlds, the IPA becomes more responsible for instruction delivery and hence it has the main need for the models. But also, the IPA provides input as well. As the pedagogical agent provides different functions such as demonstrating, monitoring, and assessment, knowledge about relevant aspects are required to support its functions.

Models of consideration relevant to the IPA not only provide services to the learner but also require understanding from the environment, the learner, and the pedagogical oriented aspects. The IPA requires knowledge about the learner and to be able to also provide further knowledge since the IPA is the major interaction component with the learner. The IPA requires awareness about the environment as the more understanding about the environment and its actors, the more contextualization the IPA can offer to the learners. As the IPA is becoming to support the emotional state of the learner, the affective model clarifies how the affection is dealt with from the different aspects of capture, synthesis, and elicitation. The *affective model* fulfills this need in relation to other relevant models. While the IPA is the central interaction point with the learner, it is responsible to know about the learner needs and provide the required information through its interface.

The intelligence component for both the cognitive layer of the IPA as well as supporting the intelligent immersive layer mandate several relevant models. For example, in visited research in a multi-agent based implementation of traditional learning environment, distribution of roles among agents is important for agents to act. Also, the goal directed and autonomous behavior of an agent show the need for goals assigned to agents. The *role model* and the *goal model*, both found in research, are important to clarify those aspects in the intelligent agent provided support.

The learning object understanding for its behavior is required for all elements, for the environment to integrate it with other components, for the IPA to be able to discover and explain to the learner. Supporting the learning activity mandates understanding about the learning object and the task through an *object model* and *a task model*.

It is central for the virtual learning environment to have a *pedagogical model* which facilitates supporting functions central to learning and learning activities. If there is no *learner model* used, the environment will definitely not be learner centered. Therefore, the learner model is needed given its potential benefits to understanding the learner and the consequent adaptation and personalization. A special use case of the learner model is in open learner models (Mabott & Bull, 2004; Kerly, Hall, & Bull, 2006) that demonstrate the special importance of opening the model to learners, for them to be able to know and track their progress and status. It is the view that the learner model is essential for the IPA and the relevant intelligent reasoning and goal directed behavior as long as the IPA puts the learner-centered approach into action. In the virtual world that is known for its vast opportunities for collaboration, the use of an open learner model support peer discovery and better collaborative learner as learner can infer about other learners abilities and needs. The IPA interacts in an environment that mandates interaction with separate but interlinked learning objects. The interaction component should allow reasoning about what the learner is doing in the environment. The subject of instruction is relevant to the *domain model.*

The models are considered to form a conceptual model for the IPA in the environment. With those models, different functions are targeted. The details of chosen models are given in conjunction with presenting a conceptual model below.

7.3. Conceptual Model

Based on the findings discussed in the prior Section, a conceptual model is proposed based on the three aspects: *the intelligent pedagogical agent*, the *learning environment* enhancement, and the *supporting models* (see Figure 40). The *intelligent pedagogical agent* in an immersive virtual learning environment is viewed as a visual 3D representation of a suitable embodiment such as a virtual human with added pedagogical and cognitive functions. The IPA provides demonstration, mentoring, assessment, and affective support functions. The *intelligent pedagogical agent* acts a central point of interaction between the learner and a pedagogical aware and intelligent 3D environment that provides services to facilitate learning.

An *immersive and intelligent learning layer* is added to give intelligence support to both the pedagogical agent and the users of the *virtual world* focusing on the pedagogical aspects. The purpose is to provide pedagogical services with intelligence that create new learning activities, motivate learners, and make the environment more believable and pedagogically valuable. This layer is supported by an intelligent agent reasoning paradigm to provide pedagogical and context aware intelligence. The immersive and intelligent learning layer is in consultation with the IPA and a set of supporting models.

The third aspect is *supporting models* for pedagogical objectives and activities with the pedagogical agent in the immersive environment. The purposes of the models are to give representation and understanding about the different aspects relevant to learning and the entities of interaction. The models proposed for inclusion are *learner model, task model, goal model, pedagogical model, world model, interactive and smart object model, affective model, and domain model.* Figure 40 depicts the proposed model.

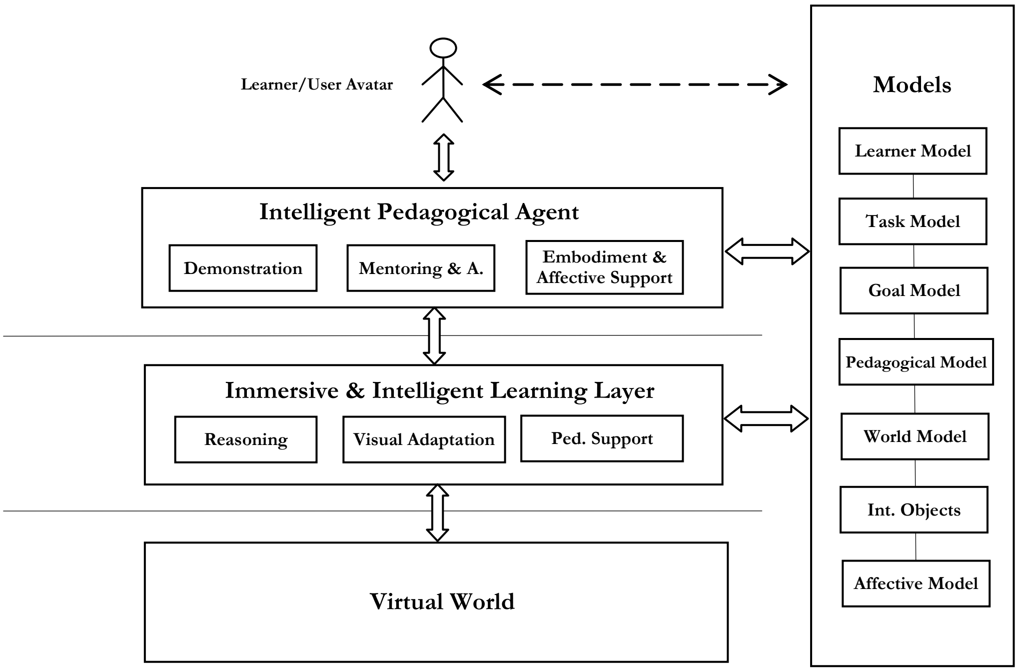

Figure 40: Conceptual framework for intelligent immersive learning with pedagogical agents.

7.3.1. Supporting Models

The pedagogical agent, as well as the immersive and intelligent learning layer, is supported by various models (see Figure 40). Those supporting models are pedagogical-oriented and are detailed below.

The Learner Model

The learner model is central to the conceptual framework supported by learning theories that mandate understanding the learner (see Section 2.1.3) for a *learner-centered* approach. The model gives input to answer inference questions about learners such as preferences, style, knowledge, evaluation results, or even difficulties or misconceptions. As thus it gives input knowledge about the learner needs, its status to infer about adapted methods of instruction. Methods relevant to realizing the *learner model* are previously discussed in Chapter 5, finding the use of Bayesian networks, concept maps, mental models, or BDI models are used for realizing learner models. However, several other methods are possible given its relevance to the research theme of user modeling.

Adopting a learner model supports concepts from different learning theories that are learner-centered that promote the importance of understanding the learner. The user model supports personalization concepts, adaptation, and learning styles. Several learning theories including the experiential learning model of Kolb (1984) which gives importance to learning in virtual worlds endorse the process of *reflection* (see Section 2.1.5). Mabott and Bull (2004) argue that *open learner models* enable *reflection* processes leading to increased learning. The argument is based on that learner models enable learners to inspect and question their performance. Supporting the target of pedagogical agents' adoption, Kerly, Hall, and Bull (2006) conclude that using a chatbot is a method that enhances interaction with the user model and makes it more accurate.

The learner model gives input to intelligent functions of the intelligent agent paradigm. It is important in relation to agent goals to set what goals have been reached, which are not, or being dropped. Thus it gives input to the reasoning functions of the IPA in learning paths; where to start, where to stop, and what is missing. The learner model gives input to the IPA of which methods of preference are to be used in a learning activity, in relation to learning styles for example discussed in Chapter 2. In contrary to the traditional learning setting of the classroom, the learner model is machine readable and hence it adds advantage to automated methods of instruction such as the IPA in a new form that is not possible in learning from a human.

The *learner model* is also important to the added *immersive and intelligent learning layer* for a virtual world given a gap in virtual world implementations and research in virtual worlds adoption for learning. Visual adaptation or any learner-oriented function can be based on the learner model. Even in absence of a pedagogical agent, a remote teacher represented by an avatar can know about remote learners through their learner models.

If the implementation of a pedagogical agent provides explanations of behavior such as the case for the explainable agents, explaining the reasoning behavior of the agent should have a basis that is in relation to the learner abilities available with the learner model. The explained behavior of the pedagogical agent is thus made logical to both the learner and the learning community member of interest.

The learner model can also support the general user of the virtual world. This is to include the learning community members who can contribute to learning activities and processes in the virtual world such as defining learning paths or setting learning scenarios for the IPA. Examples are educators, instructional designer avatars, or those in interest of evaluation reporting.

The learner model is further related to the *affective model*, discussed further below. As the learner affective characteristics are relevant to the IPA strategy, the IPA will convey what is suitable to the context only but what is suitable to the learner abilities performing tactics that increase motivation.

The Pedagogical Model

In the visited research, the *pedagogical model* is found to be required for supporting learning in several architectures for virtual learning environments, from different aspects. For example, PEGASE (Buche & Querrec, 2011) uses the *pedagogical model* to provide the knowledge for taking teaching decisions in relation to both the learner and the context. Buche and Querrec (2011) propose an important requirement of the pedagogical model: to be able to easily add instructive concepts so that it becomes generic and exploitable independent of the learning task. It is formed in PEGASE as a set of rules at different abstraction levels. *The pedagogical model* of Amokrane, Lourdeaux, and Burkhardt (2008) provides training rules of when and why to intervene in the activity, and to explain learner errors.

It is viewed that the pedagogical model ties different learning aspects and resources in the environment together to construct instructional design that is pedagogical aware and consistent with learning aspects of virtual worlds and the intervention of IPAs in the learning activity. It is to support a learning path for a learner in the virtual world.

Given the pedagogical objectives of the IPA, the pedagogical model is central to the IPA in providing several pedagogical aspects. Those pedagogical aspects are in relation to the following constituents:

- *Learning activities* - Such as a physical experiment linking to its learning objects, learning content, time constraints, and its relation to a pedagogical goal.
- *Activity model* can provide pedagogical details that help in learning and assessing learner interaction with the objects and environment. It can also provide activity plan recognition to identify what the learner is doing (supports collaboration and idle time behavior management)
- *Group learning* rules to match learners in teams - team formation rules, group activity description, and group assessment rules.
- *Assessment, feedback, and reporting:* to provide assessment, feedback, and reporting functions. It is relevant to the discussed *error models*. It is used to provide feedback to the learner and update the relevant learner model of progress. It can also give summative reporting about learning effectiveness in general.
- *Other pedagogical elements* such as *learning styles, strategies,* and *preferences* that can be allocated to learners based on their models and the possible offering. *Educational space* aspects such as visual settings or constraints relevant to learning

The pedagogical model gives a higher level of abstraction of conditions in forms of rules relevant to what to do in learning situations. Hence it has the potential to give much support for the intelligent realization from the knowledge level to the pedagogical agent and to enable taking intelligent pedagogical attitudes and strategies. In visited work, the pedagogical model includes elements that are listed separately in this conceptual model. The reason is to highlight the separated models and to allow further functions. For example, the *learner model* discussed above gives knowledge and rules which can also support the learning community.

In relation to the theoretical foundation of learning, the pedagogical model should support learning by doing in virtual worlds such as the four cycles of experiential learning (Kolb, 1984; Figure 3) are enabled. Further work will reveal the mapping between the cycles and the learning activities with the pedagogical agent with different activities. Learning scenarios with pedagogical agent in a virtual world are further elaborated in Sections 8.3, and 8.4.

In relation to the implementation of the pedagogical model, the intelligent agent approach is considered and hence its intelligence support is to be investigated in accordance to how it can fulfill the demand to model and achieve the pedagogical model accordingly.

The pedagogical model triggers the need for a *pedagogical module* that realizes pedagogical process and put them into the service of the pedagogical agent and the learning community in the virtual world as well as other processes. For example, the module can search in the currently deployed learning objects that can satisfy a learning objective in according to current pedagogical situation. This is considered as part of the immersive and intelligent learning layer to accompany the virtual world.

The World Model

The world model represents the immersive environment, its functions and services, its relevant 3D scenes, arrangement of objects, physics, navigation paths, purpose of the environment, users, events, and services provided in the environment. It is needed for the IPA to physically navigate the environment and infer about the context that the learner avatar is interacting in. The environment model gives world state to serve the system request in relation to its constituents and their interrelationships. The virtual world is generally composed of a set of objects that can be either pedagogical or not as well as visual scenes that the learners are immersed in. The *world model* facilitates knowledge inference about world objects and their state, logged users, security rules, and *users' activity identification*. Users' activity identification generally helps to identify who is interacting with which learning objects and what the learner is doing. It can help as well to put rules of learner-learner interaction and reason about it. The latest function is important for the educator or the IPA to either prevent or promote interaction depending on the learning situation.

Reasoning about world events can be viewed to be part of the world model. It provides semantics of the events occurring in the environment. And hence, it facilitates: capturing relevant events to the learning situation, notify IPA of events of interest, and notify intelligent agent module.

The Learning Object Model (Intelligent Objects)

The learning object is important to learning design for immersive environment when it encompasses learning by doing. The learning object in a virtual world builds on its 3D rich visualization abilities. An example of a learning object is a physics simulation experiment module in a virtual world. In this setting, the learning object promotes the learning in virtual worlds with given visualized simulation in 3D.

Schmeil and Eppler (2009) characterize the learning object to be *static*, *automatic*, or *interactive*. All types of objects are required expecting the ones which stress interaction and resulting visualization and animation in 3D to give rise to experiential and explorative learning. Learning objects which add a pedagogical value to learners in the virtual world are of interest. This means learning objects should follow an instructional design method to know in advance the expected pedagogical value as a result of interaction. For automated pedagogical methods to incorporate a learning object in a learning activity or recommend that resource, it should be able to reason about its pedagogical value and relevance.

The semantics relevant to being be machine *understandable, observable,* and *controllable* are important for the IPA to run an experiment, with no human aid and conduct activities with the learner and reason about those activities. The IPA requires ability to *understand* the object and its behavior so as to provide explanations to the learner about it with knowledge from the pedagogical module. The IPA should be able, with knowledge from the learning object model, to *observe* the output so it can explain it to the learner and know its correctness for assessment. The IPA also requires *controlling* the learning object so as to provide tutorials on running it The IPA might intercept the interaction between the learner and the learning object to create situations for learning and observe the consequent learner behavior. It is viewed that the smart learning object is learning artifact that gives ability to obtain pedagogical information that helps in assessing the task completion status. Furthermore, its adoption for learning purposes and facilitating IPA goals are essential. Modeling the smart object with the above properties in a learning object model, in relation to learning situations gives operation and pedagogical knowledge to conduct effective learning activities.

The selection of the size of learning objects in virtual worlds is related to significant research in intelligent tutoring systems (ITS). ITS suggested the use of modular small units that can be grouped to form a learning path. Thus it gives the opportunity to provide sequencing and personalization to suit different needs in addition to make the realization feasible and scalable. In comparison with a large learner object that does not give such flexibility. In presence of such approach, the IPA should be able to understand and synthesize learning paths that form larger learning goals than learning with a single learning object. The methods of synthesizing a learning path forms intelligent guidance by the IPA to lead to the appropriate resources according to the goal model, the pedagogical model, and the learner model in relation to the available objects.

Thus formalizing the learning object model gives pedagogical interoperability and allows desired characteristics: *Just-in-time* learning, *discovery* of best learning resources, and synthesis of larger objects with bigger learning goals. Just-in-time learning gives rise to the active explorative learning characteristic of virtual worlds. The discovery of a best learning resource for a learner is relevant to the IPA to give intelligent guidance to the learner in presence of vast and complex learning resources in a scalable environment. While learning units are explored by ITS research, they are being adopted in virtual worlds for learning as well. Maroto, Leony, Kloos, Ibáñez, Rueda (2011) utilize the concept of Units of Learning (UoL) to orchestrate learning activities in virtual worlds. While e-learning systems standardized learning objects specification in SCORM[1], Maroto et al. (2011) suggest the recent use of IMS Learning Design (IMS LD, 2012) into the virtual world. Consequently, part of the model is the semantics that should be dedicated to the context of learning. For example, to give knowledge about how can the object used in which virtual spaces or in relation to other learning objects.

The Goal model

Pedagogical goals hierarchy: The decomposition of goals in relation to learning activities with objects in the environments is linked through a pedagogical goal hierarchical model. It is important to device learning plans for instructional design. The goal hierarchy is relevant to the pedagogical agent to pursue a pedagogical goal oriented behavior and give the current status of the learner (by relating to the user model) to the required goals. The structure into goals allows organizing the relationship in a form of pre-requisites of learning levels to order a set of objectives. The formation of goals should be tied to highest levels of learning goals in relation to what is accomplishable by learning with IPA into the virtual world given the current conceptual model. Furthermore, it realizes the autonomous nature of the pedagogical. The goal-directed behavior is a nature of an intelligent agent as well being a factor in the decision to select the intelligent agent approach for the cognitive layer of the pedagogical agent. Discussed in

[1] The Sharable Content Object Reference Model (SCORM).

Section 8.3.1 is the *Belief-Desire-Intention* model. The *Desire* part of BDI forms the goals that form the behavior of the agent. In the decision of the goals, the pedagogical nature of goals matches with design objectives of the IPA.

In presence of multiple IPAs, the roles of IPA is defines in relation to the goals it can pursue. When the agent is assigned a role, it follows a main pedagogical objective to pursue with the learner according to his abilities, assessment, interaction with the environment, and environment events. The BDI model of intelligent agents gives how the reasoning occurs in relation to the different parameters. Depending on the agent paradigm abilities, there are different types of goals that can be defined, such as achieve goals or perform goals. The goal model forms a goal-directed behavior of intelligent agents that also include generation of sub-goals. The goal directed behavior has benefits not only to pedagogical goal attainment for the learner but also to the potential believability of the pedagogical agent embodiment as the learner perceives its autonomous intelligent behavior.

The Task Model

In addition to the above discussed models, the *task model* provides knowledge about the task and its decomposition in relation to the learning activity and the context of learning. Therefore, it has relevance to the pedagogical model and the goal models discussed above. Furthermore it has importance triggered by the focus on experiential learning by doing approach in virtual worlds. The *task model* in *Steve* agent architecture (Johnson et al., 1999) gives the relationship among the different steps of the task towards a goal and to ensure its compliance to operating procedures[1]. It helps *Steve* to perform explanations about actions in relation to their goal. The task model has been also used to support collaborative tasks by the aid of a pedagogical agent within the context of virtual worlds (Rickel & Johnson, 2000). The task model is relevant to the cognitive component of the pedagogical agent in the scope of supporting decision processes for performing a task. Furthermore, it gives standardization and input to inference about the tasks of the pedagogical agent and the learner. For example, the W3C[2] community standardized task models describing them as "*They describe the logical activities that have to be carried out in order to reach the user's goals"*. In this standard, different task categories, with different task types, are characterized: *user task, system task, interaction task,* and *abstract task*. Therefore, in complex types of tasks within learning objects and in the context of virtual worlds, it is viewed that the task model gives details to support the pedagogical agent in performing complex tasks for tutorials and achieving pedagogical goals.

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[1] Therefore and in other work, it can be related to an error model. Hence it can be used to differentiate between correct operating conditions and the errors generated.

[2] http://www.w3.org/TR/task-models/

However, in the question of how the task model is created, it found that it results from a *task analysis* process. The purpose of the task analysis process is identifying the requirements from the task that leads to accomplishment. Two main approaches of analysis methods exist: *behavioral approaches* and *cognitive approaches*. Behavioral approaches focus on external observations based on the procedural steps to perform a task. The cognitive approach stresses the importance of the mental process of doing the task. Cognitive task analysis (CTA) is hence important to instructional design that stresses mental processes. Behavioral approaches rather give the input to operating and procedural functions. As an example, it gives *reflexive* behavior of what to do in response to events in the object or a device which can suit training functions. With both approaches, the task model prescribes how to do a task correctly providing input to assessment functions.

Given the above properties of the task model, it is important to investigate its relevance to intelligent agent based reasoning. Intelligence is required to allow reasoning on the tasks and about what the learner is doing at a given instance? And what task best suits learner model and context. In BDI based systems, Discussed in Section 8.3.1, a plan performs a sequence of steps. A reasoning process identifies which plan to perform according to desired goals, beliefs, and the current situation. Therefore, the plan of the BDI model can give the realization of task according to the task model. In other words, and as an instructional design method, task analysis is used to obtain a task model that gives input on writing a pedagogical plan of action. Task–goal relationship and in relation to intelligent systems and while the goal model describes what to be done, the task model gives how to reach it.

The Affective Model

In surveyed literature, affective modeling supports the premise discussed in Chapter 3 that affective support by pedagogical agents work on the motivational aspect and lead to completion of learning tasks effectively.

The model is relevant to deal with the affective aspects including detection, processing, and synthesis so that the IPA can: understand the learner emotional state, update it, and generate appropriate gestures to improve the learner emotional state. It is related to the pedagogical model in relating the emotional state to pedagogical objective and provides emotion processing so as to generate an affective support strategy. It is also linked to the assessment model to provide IPA gestures that are compatible with the performance of the learner. It is tied to assessment as it is viewed that a pedagogical agent gives immediate feedback to the learner. Furthermore, the multi-modal communication module conveys affective messages from the pedagogical agent to the learner. As the simple forms of assessment feedback to the learner as correct or false triggers, the IPA gives encouragement in non-verbal ways or provides a polite correcting behavior. Thus the affective model is tied to the pedagogical agent for emotion elicitation to mandate the character animation aspect of it.

It is viewed that the IPA follows an approach of motivation to complete that task in the domain of learning by doing such as self-efficacy related theories discussed in Chapter 2.

7.3.2. Other Aspects of Interaction: Discussion and Limitations

Regarding the IPA

The intelligent pedagogical agent requires embodiment and animation abilities. In this regard, it can follow the model of Funge, Tu, and Terzopoulos (1999), with reference to supporting models. To support decision making abilities, the *cognitive layer* which is a key characteristic to generating intelligent behavior is proposed to be handled by the intelligent agent paradigm. The IPA reasons, with the aid of an agent framework with pedagogical knowledge obtained from different models including the learner model, the pedagogical model, the goal model, and more. And it interacts with the immersive learning layer. The interaction component with the learner is fundamental to comply with the view that the IPA is a central point of interaction between the environment and the learner to carry pedagogical strategies and perform instructional support in a virtual world. According to Kim and Baylor (2006), *"What makes pedagogical agents unique from conventional computer-based environments is their ability to simulate social interaction"*. This makes IPA interaction with multimodal communication abilities is central to the realization of the IPA.

Regarding IPA Multi-modal Communication

The multi-modal communication module is responsible for providing different forms and pedagogical-aware methods of interaction between the learner avatar and the pedagogical agent. Several forms of communication existed to be text, voice, or through gestures animation. Implementations can consider contextual aware communications as found in (Kumar & Rose, 2009).

An example of a pedagogical-aware communication is to take care or the *redundancy principle* reported by Weusijana, Kumar, and Rose (2008). The main responsibility of the multimodal model is to be able to manage appropriate and timely message passing to the learner through the pedagogical agent modules as well as the coordination with the visual IPA gesture feedback. The Multi-modal communication module handles communication aspects from IPA. For example it handles relevant events in the world, learning object non-visual output, or dialogues. Types of communication are found to be:

- Text-chat.
- Speech supported by Text to Speech (TTS) tools. Some tools can provide emotion-aware TTS.
- Gestures and emotions.
- Illustrations such as with graphics, panels, cells or modules presentations, and cell highlights.
- Other virtual world devices such as Head Mounted Displays (HMD), haptic devices can be considered to be linked to this module.

Regarding a Multi-agent Paradigm

This is a component to provide cognitive functions of the IPA and to the immersive learning layer in forms or reasoning. This aspect was also discussed in Chapter 6 in relation to the IPA requirements. Chapter 5 provided detailed review of supported functions by a multi-agent intelligent platform. This component is supported by different models depending on the level of reasoning. The role model gives input of what agents exists and what are their roles in relation to each other, the goal model provides input to the desires of the BDI agent, and an event model supplies understanding and reasoning about events of interest. The learner model is used to supply and update beliefs about the learner to be able to reason about.

In order for the intelligent agent platform to know and reason about the virtual world as a learning environment, interfacing to it is necessary. In the visited conceptual frameworks, it is found that the platform senses the environment through a *perception module*. The perception is selective because of the numerous events happening in the virtual world. In order for an agent to act in the environment, the interface module uses an actuator method that triggers actions in the virtual world (see Figure 41). The platform supports decisions through distributed reasoning approach that is discussed in a later Chapter.

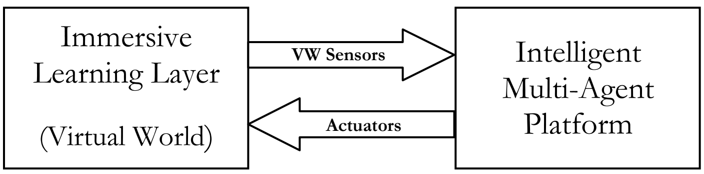

Figure 41: Intelligent agent support to the immersive learning layer. The intelligent agent platform sends events of interest through a sensor and receives intelligent decisions or actions through an actuator.

Limitations

The approach taken in conceptual model finding is generic to find an integrated model that gives functions to the pedagogical agent. An inherent difficulty in this research strand is the resemblance of human aspects from different views of animation, communication, decision, and intelligence abilities that all pose difficulties in implementation. Several of which of the methods used such as text chat, natural language processing, and intelligence all are under investigation and development from the research point of view. Therefore, the approach is to support pedagogical functions as possible from the model point of view while seeking active implementations (as will be shown in the next Chapters) for supporting paradigms. In relation to the models, they require further investigations with some of which have special line of research such as in cognitive task analysis. In relation to the implementation of the models, a selection of priorities is required, including:

- Provide a prototype to investigate basic elements of interaction. It is found that the learning object is a basic building block in virtual worlds, and therefore it should be considered with focus.

- Pedagogical services that support the IPA as discussed in forms of learner interaction.

- To demonstrate possibilities of intelligent agent support.

It is important to mention that the work excludes, as a limitation, modifications in neither the virtual world architectural concepts nor its 3D appearance. It does not consider search of new methods for affection generation or elicitation methods, but rather suggests its potential integration with the IPA given a suited conceptual model. It does not also consider details of the behavior from the animation perspective. Generally, the work focuses on the environment and the supporting models, and how to integrate them to generate a view of adopting intelligent pedagogical agents in the virtual world with details of the resultant pedagogical support.

7.4. Conclusion

This Chapter provided a review of relevant conceptual frameworks in research. Based on the review, models relevant to learning with pedagogical agents in virtual worlds are discovered. Accordingly, an integrated conceptual model of intelligent pedagogical agents acting to provide immersive and intelligent learning services is proposed. The conceptual model is based on an added immersive learning layer supported by models of learner, learning, and the environment. An intelligent agent paradigm is suggested to provide intelligence support to both the immersive learning layer and the pedagogical agent. The conceptual model highlights key components.

While the model is a generalized view for implementations at large, it triggers further investigations to reveal details of interactions and goals possible with an IPA into a virtual world and how to interact with intelligent agent paradigm giving input to realizations. However, for the purpose of realizing intelligent pedagogical agents in virtual worlds and investigate, a simplified prototype is required to show a partial realization for a proof of concept. Key components include a cognitive component for the pedagogical agent, embodiment in the virtual world, and multi-modal communication.

8. Design and Pre-Implementation Studies

Based on the findings from Chapters 6 and 7, a showcase and proof of concept is the next step. The purpose of this Chapter is to target show case implementations by providing design inputs and study components in relation to the inherent requirements and the research goals. The target is to serve as a solution for investigating IPA in a virtual world and enable experimentation in a better concrete form. Thus, the Chapter provides design choices and components selected for the solution. It has the following objectives:

- Adoption of a virtual world platform for experimentation and investigating its relevant architectural and implementation specific properties.
- Finding a suitable intelligent agent platform by evaluating possible ones. For each framework questions include what are its core functions, what are its special characteristics, and if there are relevant projects in relation to a virtual world, and more.
- Obtaining design decisions on implementing intelligent agents and physically integrating them with the chosen virtual world.
- Building IPA learning function and a direction towards materializing learning support methods by IPA, intelligent agent in a 3D virtual world.

An understanding of particular virtual world implementation components and experimenting with it, both are needed in this step. It is required to answer questions relevant to how the virtual world environment provides supporting pedagogical elements in relation to requirements. This is in addition to understanding specific methods to develop in this 3D virtual world.

A practical intelligent agent framework is required to integrate it with a virtual world. Several candidate frameworks are visited and experimented with practically towards the objective of selection and usage of a specific framework. An evaluation provides input knowledge to the possibility of employing and integrating intelligent agent functions and what practical properties are sought. It answers questions of what agent characteristics can provide a solution to the pedagogical agents' requirements practically.

The selection of an agent framework mandates a design approach given that intelligent agent design and development is different from object oriented design and programming. A design approach is required so as to achieve the desired agent functions supporting the pedagogical agent and the immersive learning environment. Properties such as *reasoning*, *autonomy*, and *goal-directed* behavior are required. A study is provided into an agent oriented design approach that acts as a background for the design and integrating an agent with a virtual world from the perspective of utilizing them with a pedagogical orientation.

The intelligent agent framework usage for learning scenario development is important to answer questions of how intelligent support can be provided in relation to the design of the intelligent agent. The learning scenario approaches the components of interaction into the virtual world: the pedagogical agent, the learner, and a learning object. Thus it prepares for actual realization in a virtual world by simulating and giving learning interactions.

This Chapter is organized as follows. Section 8.1 sheds light into a particular virtual world environment providing its characteristics and describing its architecture. Section 8.2 works in the objective of amending intelligent functions to pedagogical agents and the virtual world through investigating intelligent agent practical frameworks. Section 8.3 complements its predecessor with the methods and foundations for the design of intelligent agents in selected platforms with focus on the BDI model. Section 8.4 integrates several aspects discussed in prior Chapter through a view of how the components can interact to form a feasible learning scenario with pedagogical agents in a virtual world that is pedagogically-aware and intelligent. Section 8.5 provides a conclusion. This Chapter adopts published work in Soliman and Guetl (2011a, 2011b, 2012, 2013b).

8.1. The Virtual World Platform

The virtual world is the chosen implementation of the immersive environment. A virtual world platform is needed for proof of concept implementations and experimentation. In academia and industry, several virtual world implementations exist. Open Wonderland is a virtual world open source implementation based on the Java language that has shown interesting features that can serve the target. This Section discusses general Open Wonderland features, especially the educational ones that are relevant to the sought experimentation, its architecture and development process, and how to utilize it for the desired pedagogical enhancement.

8.1.1. Introduction to Open Wonderland

Regardless of the proficiency language of the programmer, the Java Language has become the language of the Internet. This has a particular value for programming that can reach Internet users. The Java orientation of Open Wonderland matches well with this demand. For example, the use of Open Wonderland does not require downloading any client but rather it works through a standard Web browser while giving the 3D navigation. Also, the majority of intelligent agent frameworks are Java oriented to resonate in development efforts with the Open Wonderland environment in comparison to C-based environments such as Second Life[1]. In another note, while Second Life has a wide proliferation, it is not open source and requires costs in using it in the public domain. For example, Second Life requires the use of the Linden Dollars (L$) concept for trade that is convertible to actual currencies. Setting a location in Second Life requires purchasing virtual land. While it makes it an immediately available 3D environment to its subscribed users, it is not deniable that it has an economic based orientation[2].

Scalability of Open Wonderland is realized through a modular and a Java component approach (Kaplan & Yankelovich). To achieve support to a big number of users, it relies on prior MMOG engines that are already scalable through the use of transaction bounded approach which takes scalability and performance as serious factors. However, it should be noted the reported complexity of the development of Open Wonderland. It is reported that the complexity is mainly created as a result of a trade-off with the modular approach that makes modules available for immediate integration (Kaplan & Yankelovich, 2011). This immediate integration, while being managed, requires specific considerations in development of a new module.

Open Wonderland by itself does not support pedagogical models as those described in Chapter 7. Rather, it provides the core to extensions giving possible areas for improvement through the module warehouse and development of new modules. Several educational 3D modules are already available for deployment. Those include the *poster module*, the *whiteboard* module, and the *PDF viewer* in addition to regular Web browser support[3]. Figure 42 shows interaction on a whiteboard in the Open Wonderland environment. The TealSim module has been adopted in Open Wonderland to provide visualizations that target physics learning in Open Wonderland, one of which is shown earlier in Figure 8.

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[1] Second Life uses .NET framework in comparison to Open Wonderland that is 100% Java based.

[2] http://en.wikipedia.org/wiki/Economy_of_Second_Life

[3] See the module warehouse of Open Wonderland at: http://openwonderland.org/download/modules?cat=add_ons

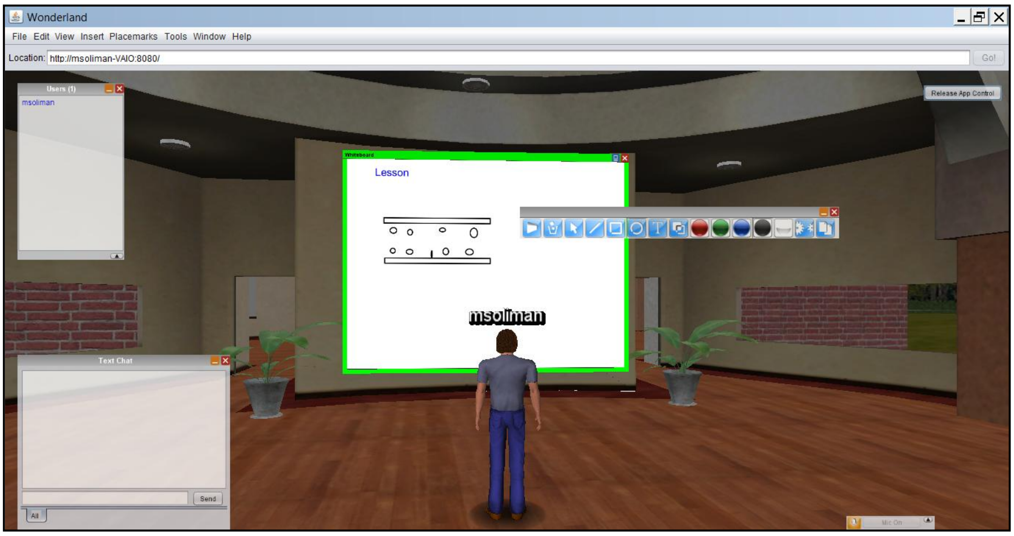

Figure 42: Using the whiteboard module in Open Wonderland. Controls allow adding text and drawings by the participating avatars.

Several universities adopt Open Wonderland environment for educational projects day after day. For example, the University of South Indies utilize Open Wonderland for learning magnetism by the Gouy Magnetic Susceptibility module and learning chemical structures by integrating Jmol modules into Open Wonderland. The University of Essex in UK hosts two educational projects based on Open Wonderland: (MiRTLE) and SIMiLLE (Gardner, Gánem-Gutiérrez, Scott, Horan, & Callaghan, 2011). MiRTLE is the Mixed Reality Teaching and Learning Environment project that enables mixes of real students with remote students represented as avatars. Rather SIMiLE objectives are to evaluate the technical feasibility and potential pedagogical value of the virtual world. SIMiLE uses Open Wonderland reporting positive results for socio-cultural settings and content for second language learning (Gardner et al., 2011).

While individual simulation modules provide significant efforts and a step ahead for realizing learning objects in the 3D virtual world, they still require further pedagogical support and integration in a whole learning activity path and formalized instruction support, and to be supported with pedagogical agents. In this regard, there are other efforts in addition to this thesis that select Open Wonderland environment for pedagogical support. For example, Maroto, Leony, Kloos, Ibáñez, Rueda (2011) orchestrate learning activities in Open Wonderland adopting the IMS-LD (IMS LD, 2012) widely accepted standard. Also, Maderer, Guetl, and AL-Smadi (2013) support pedagogical awareness in the environment through a rule-based assessment to learning scenarios in Open Wonderland. The availability as a 100% Java open source, extensibility, and modular approach even in lack of concrete pedagogical support are opportunistic for experimentation and research purposes in the area of work.

Therefore, Open Wonderland has great potential for deployment for academic institutions. Those deployments should consider some reported difficulties that include the need for more documentation and stabilization of incomplete modules. Open Wonderland as a virtual world is convenient for being open source, has adoption for educational projects and team usage, and has extensibility properties (Kaplan & Yankelovich, 2011). However, this does not hinder the applicability of the approach of this thesis to other practical virtual world platforms.

8.1.2. Open Wonderland Architecture and Development Process

Open Wonderland architecture (Kaplan & Yankelovich, 2011) is depicted in Figure 43. Open Wonderland is client-server oriented that is based on the Representational State Transfer approach (REST) for achieving scalability and high performance. Its client access and server administration are performed through a web browser. Its server performs several services including *object persistence* and *connection service* to the client nodes. Those services also include *shared application services* to synchronize and exchange state changes among the different clients with different applications. With the *Shared Application Server* (SAS), it is possible to share a common application among server users, such as *Open Office* to several Open Wonderland clients for collaborative work. A key component of the Wonderland server architecture is the *Darkstar* transaction server that is a key for scalability in high performance need of massive users. Wonderland also uses Darkstar to maintain the world state, such as location of the avatar or cells in an internal database, managing state consistency between the client and the server through messaging. With the need for scalable strong graphics in 3D, Wonderland uses *jMonkey* game engine for rendering[1]. Furthermore, Open Wonderland puts importance on *immersive and spatial voice* through the use of *jVoiceBridge*[2] to give the sense of immersion in 3D. Open Wonderland also supports *telephone integration* that enhances voice conversations among virtual world users through telephone audio.

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[1] Rendering is a Graphics term that refers to the process of generating an image from a model. Rendering requires extensive features such as shading, texturing, and transparency, see http://en.wikipedia.org/wiki/Rendering_(computer_graphics) Shading, texturing, transparency, and more are applicable in Open Wonderland.

[2] https://java.net/projects/jvoicebridge/

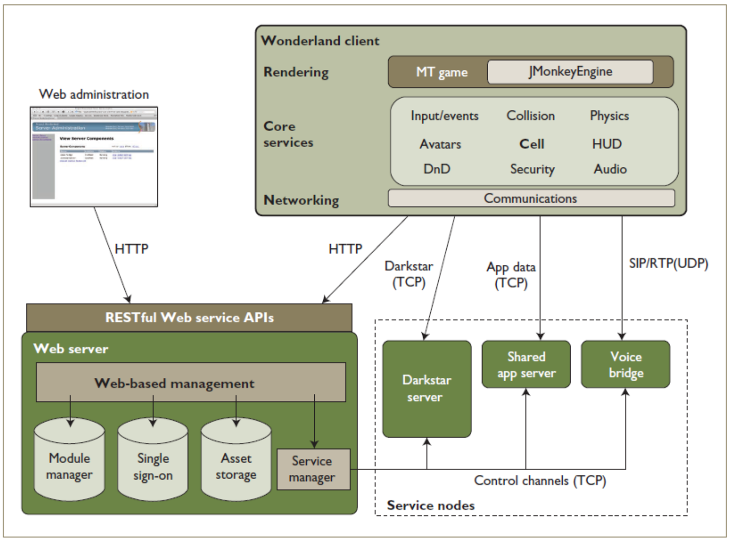

Figure 43: The Open Wonderland architecture showing various components and how they communicate (Kaplan & Yankelovich, 2011).

In the sound aspect of Open Wonderland, a virtual microphone cell can broadcast the sound to logged-in avatars. This allows creating virtual world based lectures while learners attend a virtual classroom with the lecturer using the virtual microphone cell. Rather learners who would like to study or interact with no interference can go to sound isolated areas by the means of the *cone-of-silence*. User management of students attending a virtual class is supported.

The development workflow for Open Wonderland is studied as it has a modular and component approach through the *Cell* concept. A cell in Open Wonderland is a visual object that is deployable in the word as a *jar* file. This concept is important for the management server to synchronize its state for several clients. The synchronization concept has two major observations: 1) A message passing technique that the programmer has to do to request or change the state of the cell, 2) The message passing approach not only ensures that transactions are synchronized to the several clients but are also being done in a time-controlled fashion so as to optimize the performance given the potential load of massive multi players. Cells are placed in a customizable world model that gives the 3D representation for the user.

The security aspect is important to formal learning settings. Open Wonderland provides sorts of special security mechanisms through object level security. For example, a cell as a unit of work is not accessible from other cells. A *security capability*, when added to a cell, can control who can view the cell while non-authorized users will have a view that lacks those cells. Also, with the cone-of-silence space, it is possible to protect from listening to conversations occurring in that area. While object level security protects from unauthorized access from other cells, it creates challenges in integrating for a learning activity that involves already developed cells, for example when the pedagogical agent requires listening to events of learner interaction with other virtual world objects.

The user in Open Wonderland is represented as an avatar. The user controls the avatar through the keyboard and the mouse. Users or avatars can discover who is online and have conversations either through text or voice. Text chat is done by a text chat Head Up Display (HUD) window. The HUD concept is a suitable choice for viewing the window given the 3D scene. And also the user can have a voice conversation with another user as well. While the user communicates with other avatars textually through a HUD, a text chat one is also needed to chat with the pedagogical agent.

Open Wonderland supports the virtual world property of *persistence*. A learner who is immersed at a specific setting can resume the last state after logoff and logon again. Generally, as the virtual world evolves through changes by users, login does not return the user to the initial state but to the new state as stopping and restarting the server yield the same state. The property of persistence is supported by several concepts from the Darkstar server including Managed Objects (MO) concept that surfaces in requirements for developing new cells. New developed cells have to conform to requirements of cell state that is in return for the Darkstar transactional and managed objects properties (see Figure 44). Notably, this persistence is only relevant to scene or state of the cell or the avatar but not to immersive learning experience and progress, as mentioned earlier.

Figure 44: The server Managed Object (MO) class of a cell helps in synchronizing state among different clients. State synchronization is performed through exchange of messages to update client or server states. Image is adopted from Open Wonderland Tutorial for developing a new module.

8.1.3. Open Wonderland Development for Pedagogical Enhancement

In the conceptual model suggested in Chapter 7, an immersive and intelligent learning layer is added to the virtual world. While adding a character in Open Wonderland is achievable, providing intelligent decision abilities are required. Towards creating a prototype and in addition to the selection of Open Wonderland, the selection and integrating an intelligent agent framework with Open Wonderland is required to support the pedagogical agent and the immersive learning layer. This is to fulfill the objective of adding reasoning abilities to the pedagogical agent and the environment.

It is noted that the development in Open Wonderland is not scenario driven, but rather component oriented. I.e. development of isolated visual cells and deploying them into the world give the rise for many possibilities of interaction, but do not control how the scenario is taken from the avatar perspective. Furthermore, there is a lack of management that monitors what avatars are doing in relation to the cell objects they are interacting with. Scenario-oriented development and management of different objects or avatars by administration, in online interactions are both important for management of learning activities and learners. And also those are considered in developing agent supported learning activities and management. The immersive learning layer proposed can take care of this requirement (see Sections 7.27.3).

Upon materializing the concept of a pedagogical agent in Open Wonderland, a character embodiment that is similar to the avatar is required However, it should not be user-controlled but rather self controlled or *autonomous*. A potential choice of embodiment is the use of the *Non-Player Character (NPC),* which is also an Open Wonderland cell module used for character embodiment and it is not user controlled. Thus it requires interface abilities of voice and text. Providing control is also required for the character autonomy, text, and voice conversations. Generally the available functions of the NPC or relevant modules should be inspected against the requirements of the pedagogical agent discussed in Chapter 6 and the conceptual model in Chapter 7. Furthermore, and of the environment aspect, development in Open Wonderland for pedagogical purposes adds several requirements:

- Pedagogical models to support the pedagogical agent based learning support.
- Management of learning activities.
- Realizing a pedagogical agent.
- Text-chat for textual communication with the pedagogical agent.
- Natural language support.
- Possible text to voice integration.
- Cognitive support and integration through an intelligent agent platform and an interface between the intelligent agent platform and Open Wonderland.

8.2. Evaluation and Pre-selection of an Agent Platform

Two approaches, for realizing agent functions in a virtual learning environment, are initially considered: 1) developing agent functions in the VLE itself using the tool or 2) deploying an already developed framework and integrating it in the VLE. The first choice somehow implies reinventing the wheel of intelligent agents' DAI implementations. Although the second choice seems plausible, it might not be easily implementable due to the differences in implementations of the VLE and the platform design restrictions. For example, equipping the avatar in Open Wonderland versus Second Life with an intelligent agent functions requires awareness of availability of this possibility as well as the agent framework. Ranathunga, Cranefield, and Purvis (2011) report the difficulty of integrating an agent framework into Second Life suggesting an interface solution. Therefore, the second approach is considered while seeking lessons from prior project implementations that considered both intelligent agents and virtual worlds.

Several research and commercial intelligent agent frameworks are already available and becoming more mature across time. The functions, those platforms provide are not trivial in regards to simplifying developing agent functions from scratch. Nevertheless, investigating the potential agent platform helps to start adding intelligence properties sought for learning in virtual worlds and serve as a step ahead towards the objective. Since there are numerous agent platforms found, the focus will be on some of them based on *functionalities*, *popularity*, *maturity*, *standardization*, *projects implemented*, and *potential integration* with virtual worlds.

8.2.1. Practical Intelligent Agent Platforms[1]

With the selection target for a practical intelligent agent platform, several ones are considered. 3APL, JACK, JADE, Agent Factory, and GOAL are found to be candidates for selection to posses potential properties sought. For each platform, interesting characteristics are summarized below.

3APL

3APL is a tool and a specific programming language for the development of intelligent cognitive agents based on the BDI approach. 3APL is an academic experimentation environment that is developed and maintained in the University

[1] Several paragraphs of this section are adopted from Soliman and Guetl (2011a, b).

of Utrecht, Netherlands[1]. 3APL creates agent behavior based on actions, beliefs, goals, plans, and rules. Those incorporated in the 3APL language are logic oriented. 3APL is used for programming autonomous robots in dynamic and unpredictable environments. This autonomous behavior of agents is a desirable characteristic of pedagogical agents (Dastani, Dignum, & Meyer, 2003). 3APL follows a standard for agent communication among different platforms, named FIPA[2].

JACK

JACK (JACK, 2013; Winikoff, 2005) is a commercial multi-agent framework based on Java with development history that dates back to 1997. JACK is equipped with a graphical JACK Development Environment (JDE) that is viewed to facilitate the design by visualizing components, their dependencies, and interactions. JACK is relatively a strong framework supporting BDI (Cheong, 2003). JACK is characterized by a high performance-bounded execution time supported by benchmarks. That makes it suitable for mission critical systems. Agents in JACK post events in which other agents can respond to, by executing an agent plan. An agent plan, in JACK is a sequence of actions the agent will take in responding to an event. JACK agents possess beliefs representation; with changes to those beliefs BDI events are triggered. An agent can have different plans to respond to, depending on their relevance or context. Figure 45 shows the agent design tool in JACK with an agent having two plan types to respond to an event depending on the event relevance. In JACK, capabilities are functionalities that can be "plugged in" to the agent which gives rise to the extension abilities of the JACK framework. Based on JACK, CoJACK is a BDI cognitive architecture for modeling human behavior thus allowing humanoids or virtual actor development. The *JACK Teams* product extends JACK to provide a team oriented modeling framework.

[1]http://www.cs.uu.nl/3apl/
[2] http://www.fipa.org/

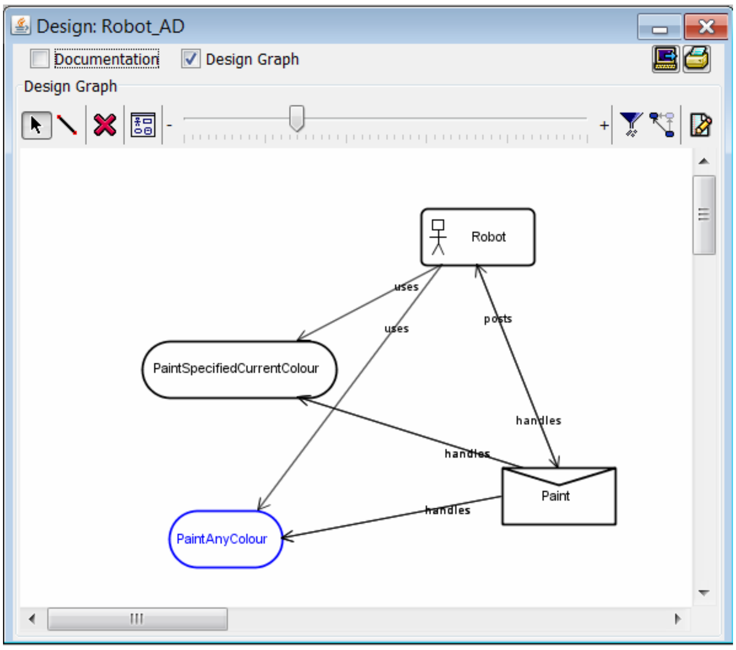

Figure 45: Graphical representation of a JACK robot agent with two plan types responding to the same event. Image is based on JACK tutorials.

JADE

The Java Agent DEvelopment Framework (JADE) (JADE, n.a.) is an open source Java-based framework. JADE is popular for following the Foundation for Intelligent Physical Agents (FIPA) specifications including the FIPA Agent Communication Language (ACL) standard (FIPA-ACL, 2001). Standardization was regularly regarded as a method to enhance conversation among different distributed and heterogeneous agent based systems leading for better interoperability and integration. This means that a FIPA compliant agent such as a JADE agent can communicate with any other FIPA compliant agent even if it belongs to another framework.

JADE includes a set of graphical tools for agent-based design and development. The JADE platform has a distributed characteristic to reside on different machines that can give better performance upon high loads. While JADE has a wide range of implementations and research projects, the BDI function is not directly implemented in JADE. It is possibly due to stress on providing a reference implementation that is focused on the distributed and standard nature. BDI is extended to JADE through the Jadex framework (Pokahr, Braubach, & Lamersdorf, 2003) or the BDI4JADE extension layer (Nunes, Lucena, & Luck, 2011). Blair and Lin (2011) reported integration of JADE with Open Wonderland to support learning functions development.

AgentSpeak/Jason

AgentSpeak is a logic-based agent programming language that started in 1996 based on BDI (Rao, 1996). AgentSpeak specifies a set of beliefs, plans, and goals. A plan is a unit of code which can be triggered by an environment event. The agent can have two types of goals; *test* goals or *achievement* goals. An *achievement* goal is a state of the environment that the agent wants to reach while the *test* goal is to check a predicate of whether the goal is reachable by checking if a logic formula evaluates to true or false. Alechina, Bordini, Hubner, Jago, and Logan (2006) reported deficiencies that require enhancement to AgentSpeak. They indicated the need for communication enhancement, ontological support, and belief knowledge update abilities to AgentSpeak. Those abilities are implemented in a new platform extension named *Jason*. Jason is an open source interpreter extension to AgentSpeak to allow the programming of cognitive agents (Alechina et al.). Figure 46 shows a sample project and an associated agent in Jason. Although, as indicated by Alechina et al. (2006) that *Jason* is Java based, the agent syntax as shown in Figure 46 is logic oriented following the AgentSpeak syntax (.asl extension) that makes it not 100% Java oriented.

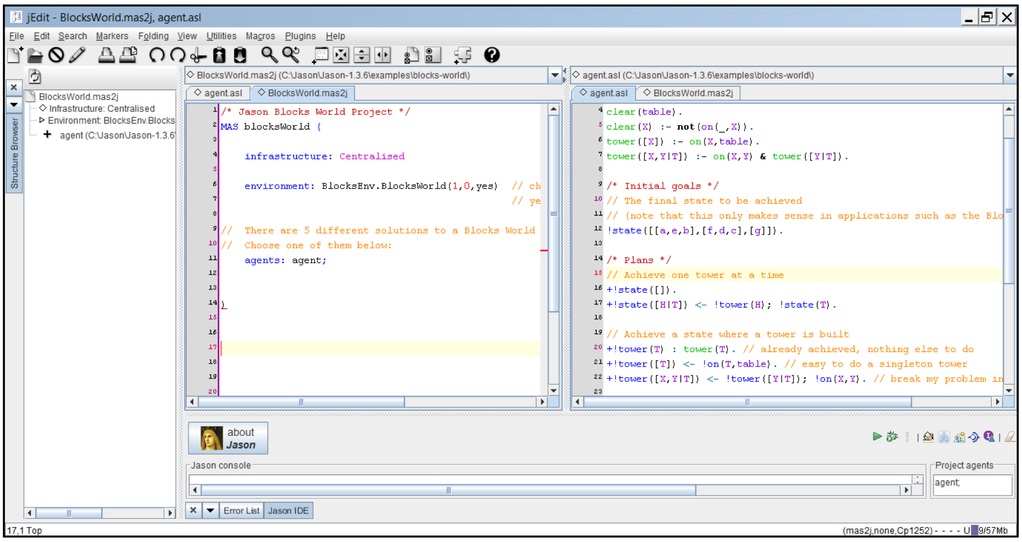

Figure 46: Jason IDE showing a BlocksWorld example project and an agent code. The agent is formed of belief rules, goals, and plans.

Agent Factory/Agent Speak Extension

Another extension to AgentSpeak is Agent Factory (AF-AgentSpeak) which is a collection of platforms, and tools for agent development and deployment (The Agent Factory, 2013, March). Agent Factory is a Java based open source platform that is also FIPA compliant with several common features to Jason[1].

[1] http://www.agentfactory.com/index.php/AFAS::Overview

With AF-AgentSpeak, relevant projects are found: NEXUS[1], MiRA, and AF-EISOpenSim. NEXUS is a project to build virtual characters for mixed reality. MiRA is Mixed Reality Agents. AF-EIS-OpenSim is a project in the University College of Dublin (UCD) to integrate AF-agents with OpenSim[2], which is the technology that underpins Second Life. Figure 47 shows agent controlled avatars to autonomously act in the OpenSim environment (OpenSimulator, 2013).

Figure 47: Autonomous AF-agents controlling OpenSim avatars. Snapshots are taken from presentation video (The Agent Factory, 2013, March).

GOAL

GOAL is a programming language and platform for developing intelligent agents (GOAL, n.a.) that is maintained in Delft University, Netherlands. Agent actions in GOAL are derived from beliefs and goals. GOAL allows knowledge representation of goals and beliefs with Prolog. It is reported that GOAL is advantageous to other frameworks as it offers a declarative only goal and belief definition methods separating goal declaration from the way to achieve it. Figure 48 shows the IDE for GOAL displaying an agent specification. Its declarative nature shows knowledge, beliefs, goals, and action specifications.

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[1] NEXUS supports multi character agents and an augmented reality environment while utilizing the BDI model (intentional agents), please see http://nexus.ucd.ie/

[2] This integration is useful to Second Life in considering implementing agents, since the approach is through an interface standard that allows integration to interface-compliant agent platforms, http://www.agentfactory.com/index.php/AF-EIS-OpenSim.

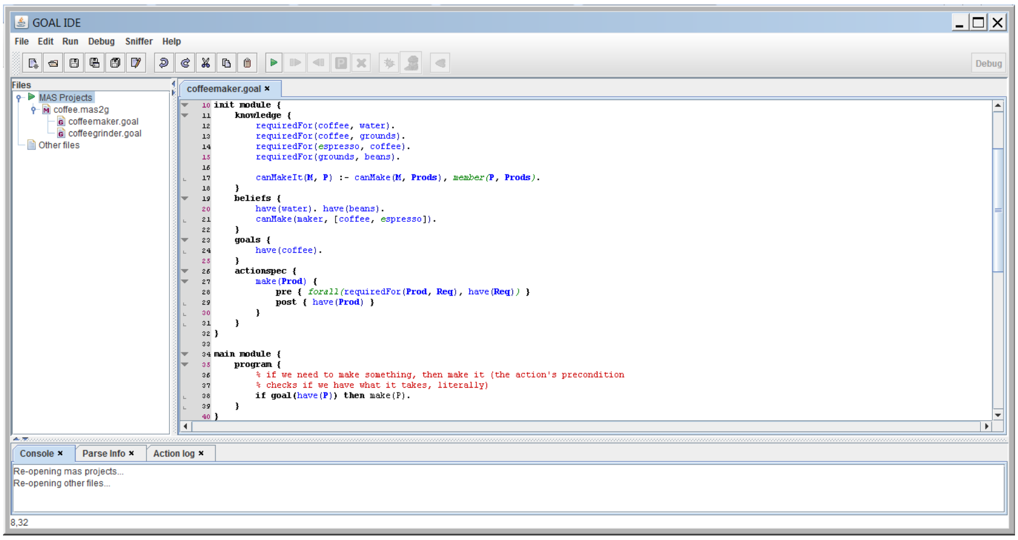

Figure 48: The IDE of GOAL intelligent agent framework.

8.2.2. Further Discussion and Lessons Learned for the Agent Platform Selection

Several agent platforms have been initially considered for selection. While there is agreement on the agent desired properties such as autonomy and interactivity with other agents, several properties do not exist in all platforms. First, the standardization aspect is found to be an important factor for integration in heterogonous environments. FIPA is found to be the most relevant agent desirable standard. For example, Silveira and Gomes (2003) developed personalized pedagogical agents based on FIPA. Second, not all the tools are found to be mature enough. Several of the tools are for academic experimentation. Compared to a commercial product, frameworks created for academic experimentation show lack of details in documentation specially in starting to write agents with requirements of integration. Third, most of the tools are logic oriented to resemble Prolog for example while on the other hand Java orientation is needed to ease development specially towards integrating it to the Open Wonderland Java based environment. Lastly, the most important factor is the cognitive orientation. It is common to see in major tools their focus on the *Belief Desire Intention* model (BDI) and its relation to reasoning functions in the platform. While JADE is considered a good tool that has strong support in the research literature, it lacks this BDI support. Rather, JACK shows to be strong and easy platform to begin with, having the advantage of providing graphical design tool to support easy creation of intelligent agents. JACK supports Java and the BDI model. Furthermore, JACK provides interesting extensions such as JACK Teams and CoJACK. Some experimentation is performed in creating beliefs, desires, and intentions with multiple interacting agents as will discussed below. However, JACK is not an open source that triggers other framework consideration.

The choice of an intelligent agent approach is supported with discovery of several projects relevant to realizing agent-based characters in virtual worlds. Examples are NEXUS, MiRa and the project integration of JADE and Open Wonderland (Blair & Lin, 2011). However, several of the works focused on the implementation of artificial character agents in virtual worlds to target general autonomous behavior such as navigation and imitating human physical action behavior. Those were not necessarily focused on the pedagogical oriented aspects as a main focus. Additionally, they did not consider the aspect of pedagogical elements in the virtual worlds such as interaction with a learning object in relation to the learner.

A challenging factor in those environments is the development approach that requires better understanding of intelligent agent concepts necessary for using the platform to create required features of intelligent and autonomous behavior. This complexity triggers the need to experiment with a tool that is easy to use, yet has the important features that include standardization, BDI support, Java implementation, and integration to Open Wonderland. Common to the platforms is the structure and approach to dynamic and autonomous agent realization through beliefs, plans, and goals that are needed for structuring and developing agents. That shifts the focus from traditional object oriented design approach to experiencing how to design an agent. Remarkably, with the similar structure of BDI supported agents, and standards supported in different agent platforms, it is possible to carry the realization to another environment that can be more complex but has extended features[1].

8.3. Intelligent Agents Design

Designing intelligent pedagogical agents mandate the three properties; intelligence, pedagogical properties, and being an agent. The agent notion yields the meaning of an agent that is differentiated from a regular software objects by its autonomous ability to act in an environment (Wooldridge, 2002). The agent is an actor in contrary to the software object that only responds to stimuli. In agent research, intelligent agents provide different types of actions, *reactive*, *proactive*, and *social* behavior. The *reactive* behavior means the agent, once perceives an event performs a resulting action. With a so called *reasoning* process, the agent makes

[1] This will be demonstrated in Section 8.4 in the case of moving between two JACK and Jadex intelligent agent platforms.

decisions on actions with intelligence. The *proactive*[1] agent takes initiatives and pursues goals in no wait for an outside trigger. *The social* nature of the agent suggests communication with other agents to better perform different functions as those discussed in Section 5.5. A group of agents are named agent society in which they collaborate, cooperate, or negotiate to achieve actions. Thus the distributed nature of an agent society, with reasoning reflects a distributed AI approach that obviously extends to a centralized problem. Compared to an object, the object is only reactive component that executes methods upon invocation, while the agent has the above autonomous properties with intelligence. Agreeing to the agent platforms visited, the agent achieves those properties through *beliefs*, *plans*, *goals*, and triggering events that are tied to reasoning processes to give the desired intelligence. Utilizing agent functions for the pedagogical agent support yields interfacing an intelligent agent to the pedagogical agent in the virtual world according to the view in Figure 49 below.

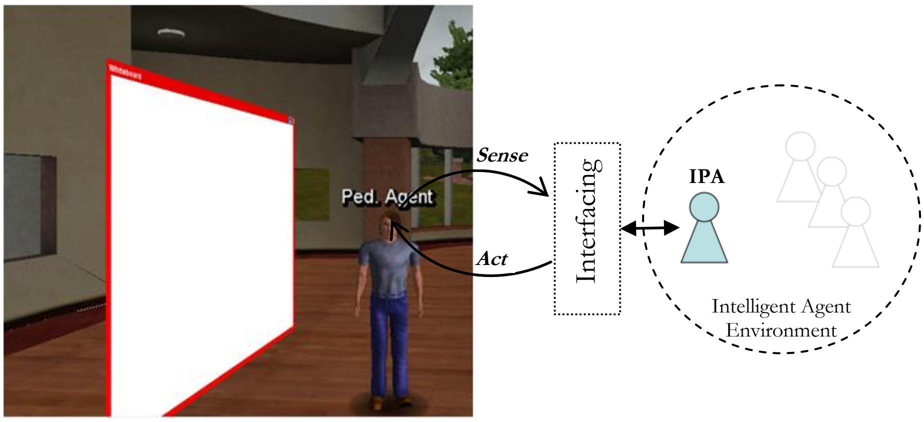

Figure 49: An agent from the intelligent agent environment is linked to the pedagogical agent in Open Wonderland. In this view the intelligent agent needs to perceive events in the environment and feed intelligent actions through an actor interface. Those actions are performed by the pedagogical agent.

The *social* ability forms a collective ability rather than an individual one taken from intelligent Multi Agent Systems (MAS) that falls in the distributed AI research. It yields a future direction of research with pedagogical agents is when multiple agents are interacting and in cooperation to achieve a collective pedagogical function. This function can be to oversee, mediate, or manage learning for the group of learners at large. Several of these functions, in the intelligent agent facet are discussed in Chapter 5. However, the focus should start with a single pedagogical agent. Thereafter, the collective function of pedagogical agents is extendable as long as the pedagogical agent is backed by intelligent agent framework. Figure 50 depicts an extended view of how a group of pedagogical agents are supported by the intelligent agent framework. A mediator agent

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[1] Agent reactive behavior in a learning scenario is still useful to provide responses with or without reasoning to events in the environment or as a result of interacting with a learning object. For example, is to identify the learner's errors or to provide immediate feedback.

collects and manages a group of agents; each of which is responsible for supporting an individual pedagogical agent in the virtual world. With a single pedagogical agent support, a character in a virtual world, in Open Wonderland is backed by an intelligent agent in the selected agent framework. The agent provides intelligent actions with reasoning support to combine with the character basic behaviors.

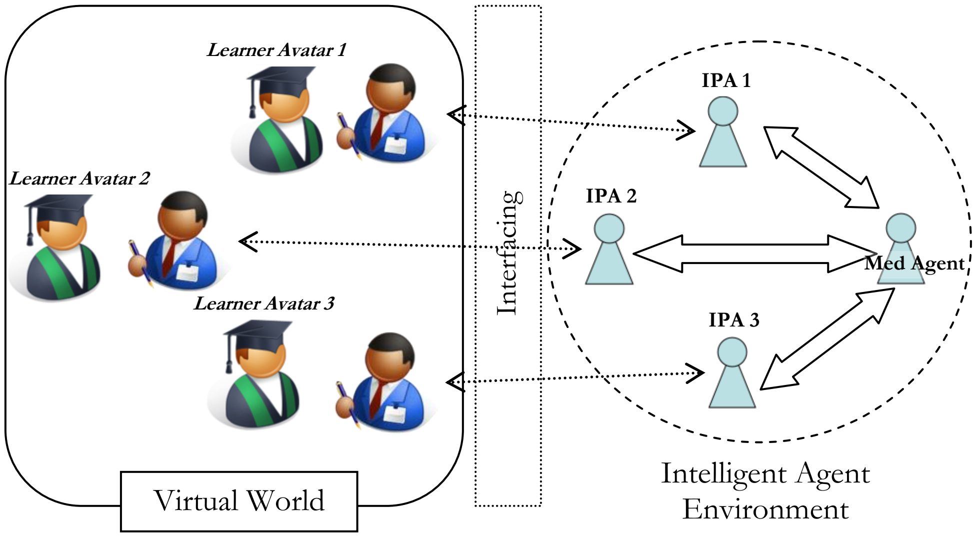

Figure 50: Given a mapping between one IPA and an intelligent agent, extensibility can yield more coordinated and group functions utilizing agency concept.

Considering intelligent agents for a virtual world, it is viewed that the virtual world has several actors with learners interacting in the environment; making changes and triggering events. The virtual world is dynamic and *non-deterministic* for the following reasons:

- The world changes continuously with persistence. As noted earlier, when a user avatar logins for the second time, the world changes from the previous login.
- Learner behavior and actions are unexpected in the virtual world. With the given possibilities the learner can perform, unexpected outcomes are possible.

Thus, and based on intelligent agent research, a multi-agent environment suits that non-determinism. An agent, compared to a classical view of design such as objected oriented design, has the reasoning ability, named *action reasoning* that chooses the best course of action based on the surfaced situation rather than if the outcome is known in advance. Design objectives for intelligent agents are to mimic human behavior in similar situations as the human who has better abilities to give the response in situations that were not known in advance. Agents are also concurrent meaning that it can be used to simulate or model those actors in the virtual world.

Agent *reasoning* refers to the process of decision making and forms the intelligence component. According to the Merriam-Webster dictionary, reasoning is *"the process of thinking about something in a logical way in order to form a conclusion or judgment"* While different methods exist to support AI reasoning under uncertainty, the multi agent paradigm is viewed as an umbrella that integrates the different approaches as the agent can implement different methods. For example, Chapter 5 showed agents that reason with different methods such as with *Bayesian Networks*, *BDI, Case Based Reasoning (CBR)*, and more depending on the problem nature. A distinctive feature of intelligent agents is to be able to exhibit different reasoning approaches to integrate multiple interacting agents who can solve a bigger problem depending on the best approach to target the pedagogical problem domain.

In the design dimension, while object oriented programming concepts have found its way into success, its tools and methodologies supporting its design became relatively mature. Rather, agent oriented programming is not straightforward given the non-deterministic nature of environments, problems it supports, and required experience in setting beliefs, plans, and goals. Furthermore, the use of a software engineering methodology enables to document alternatives, to oversee the systems, and to carry the design to a different multi-agent environment. While there are methodologies and minor tools found, those methodologies are considered yet premature and several are extensions based on the OO methodology. Generally the agent-oriented methodology is supported by a design tool.

Example agent oriented methodologies with tools are *GAIA*[1], *AUML* that is extension to UML, *Tropos* with *TAOM4E* tool, *MaSE with Agent Tool*, and *Prometheus* with *Prometheus Design Tool* (PDT)[2]. Evaluation and development of such methodologies and tools are ongoing in the strand of agent oriented software engineering research. Common to the agent oriented methodologies, are:

- Determination of the role of the agent and distribution of roles are important at the design stage.

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[1] GAIA is referred in Sections 5.5 and HABA model in Section 7.1.3.
[2] AUML: www.auml.org
Tropos and other tools details: http://www.troposproject.org/files/Henderson01.pdf
TAOM4E: http://selab.fbk.eu/taom/
Prometheus: http://www.cs.rmit.edu.au/agents/pdt/
MaSE: http://www.sharprobotica.com/2011/01/agent-oriented-methodology-selection-o-mase/
Agent Tool: http://agenttool.cis.ksu.edu

- Definition of a top down approach for setting a goal oriented behavior for an agent, creates a view in advance of how agents behave and helps in the definition of goals and plans to achieve them.

- Those tools support the determination of goals, plans, and supporting agent knowledge.

The question is how the agent oriented approach helps in achieving autonomy and proactive behavior in relation to the pedagogical orientation. How the reasoning occurs is relevant to *beliefs*, *plans*, and *goals* basic design elements found in the visited agent frameworks. As it is found that the BDI model details beliefs, and plans, and goals to achieve the sought *reactive* or *proactive* behavior. The design thus requires deeper understanding of the BDI model in relation to the requirements of supporting intelligent pedagogical agents in a virtual world.

8.3.1. Explaining the Belief-Desire-Intention Model (BDI)

The BDI model is considered as a basis for intelligent agent behavior. It is rooted to human behavior as how intentions are formed, based on work by Bratman (1987). The BDI model is a mean of decision making with reasoning mechanism. It is based on the following:

- *Beliefs:* It is the agent knowledge about the world. The decision taking ability of the agent is based on current and prior knowledge about the situation and state.

- *Desires:* form the goals of the agent, what is the agent willing to do. These form goal oriented programming for the agents. There is a reasoning mechanism in the agent framework to work towards achieving the desires of the agent.

- *Intentions:* Are the actions the agent is willing to do to achieve the goals. Intensions are formed as a set of plans the agent performs. The plan is simply a piece of code that is tied to a desire. It is the recipe of how to achieve the code programmatically.

Taking Jadex as an example of implementation, and similar to other BDI supported agent frameworks, beliefs, desires, and intentions translate to beliefs, plans, goals, and triggering events (see Figure 51). Plans represent a manifest of what the agent should do, also in accordance to a situation that arises in the environment. When an event occurs, an agent plan executes a course of action which represents a reactive behavior or contributes to achieving a goal. Desires of the agent translate into goals. In the BDI model, achieving goals require a method or "recipe" to follow which are plans. Beliefs, desires, and intentions are subject to reasoning processes that govern their operation. Practically reasoning which refers to two main subordinates: *deliberation* and *means-end reasoning*. Deliberation is the means to decide what to do, while means-end reasoning is deciding how to do it. Also deliberation influences selection of goals while means-end reasoning influences selection of plans. Events, being internal or external trigger changes about an internal status or represent change in the environment.

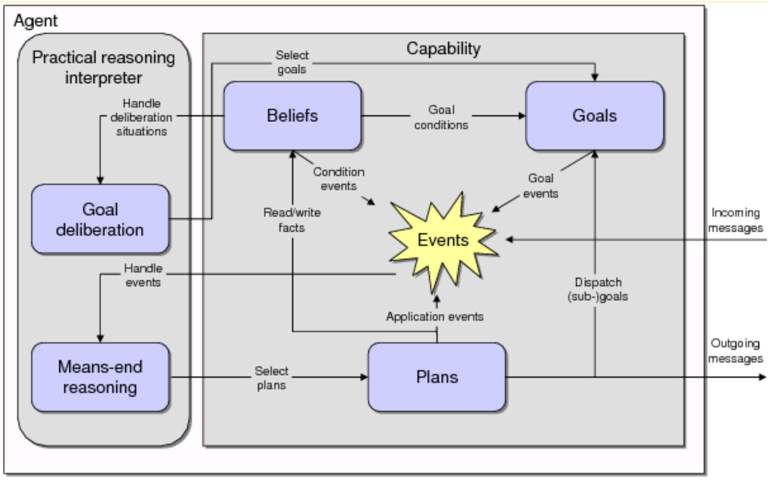

Figure 51: BDI components interaction in Jadex (BDI Model of Jadex, 2012).

Thus the reasoning processes with beliefs, desires, and intentions, in resemblance to human action formation and decision making create an intentional stance to form intelligent behavior for the agent. Also, it contributes to creating action oriented behavior that has been shown to suit character human like behavior as seen in several researches in creating agents. However, the pedagogical aspect of this behavior should be inspected particularly for the pedagogical orientation of the pedagogical agent.

8.3.2. Depicting the BDI Model in Pedagogical Context

While the BDI model has been extensively used to depict character human-like behavior, a focus should be given to pedagogical awareness. The idea is to embed pedagogical awareness into the agent intelligence component found through the beliefs, desires, and intentions. Thus it can lead to a better pedagogically intelligent behavior.

Mapping BDI Components in Pedagogical Context

The BDI model, in the context of learning with pedagogical agents in a virtual world is proposed to be utilized as:

- *Pedagogical beliefs:* It is the agent knowledge about the world's aspect that contributes the context of learning, the learner, and the learning activity. Agent decisions being pedagogical aware is based on instantaneous new knowledge in relation to prior beliefs and state. Thus the intelligent agent seeks to capture knowledge updates about learning interactions. This knowledge helps the agent to reason to form intelligent pedagogical decisions.

- *Pedagogical desires:* The agent should pursue pedagogical desires; i.e. pedagogical objectives. Reasoning mechanisms support decisions towards learning objectives. The formation of the agent desires are according to a learning design that suits the activity, the learning needs, and the context of the virtual world, all with BDI reasoning.

- *Pedagogical intentions:* are the means *"recipes"* for achieving pedagogical goals. Learning methods are varied to suit different situations, learner abilities, and state. Pursuing the best method is the responsibility of the pedagogical agent to work the best method to learning as seen the virtual world but internally formed through the intelligent agent BDI method.

Furthermore, *reasoning* processes consider the pedagogical orientation of learner needs. For example, in forming agent goals, decisions are from the pedagogical context such as in the agent desires to provide a tutorial, lead correct interaction with a simulation or performing assessments. Reasoning processes influence decision making in a way that can consider learner abilities to select a pedagogical plan that suits the learner style for example.

1. Pedagogical Beliefs

Pedagogical beliefs entail awareness of all knowledge aspects that are relevant to the learner and the learning activities. In relation to the proposed conceptual model in Chapter 7, the agent knowledge is not only for the learner model, but also for the world model, task model, and other pedagogical models. While the learner interacts in the virtual world performing learning activities, updates are fed to the agent (through an agent interface) to give the agent up-to-date knowledge about the environment state and the learner. In the context of the learner, beliefs about the learner abilities are not only relevant to the learner model but are also tied through learner assessment. Generally agent belief knowledge for pedagogical objectives and decision making involves knowledge about several pedagogical models (see Figure 52).

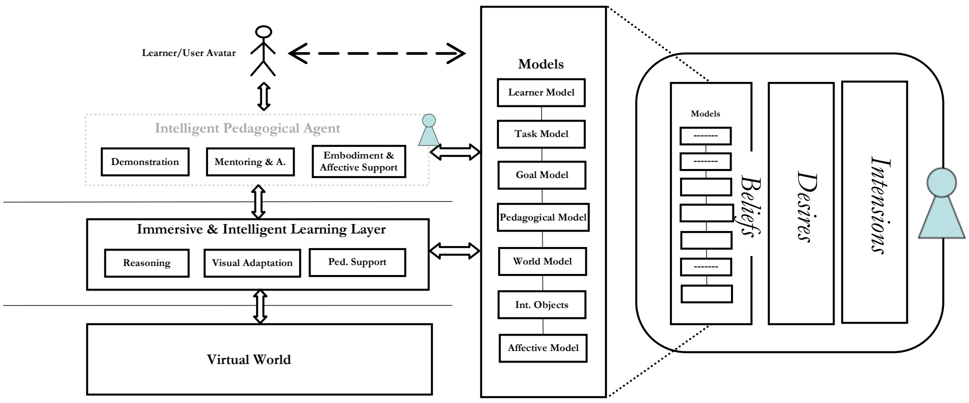

Figure 52: Agent belief knowledge for pedagogical objectives and decision making involves knowledge about several pedagogical models.

2. Pedagogical Desires: Pedagogical Agent Autonomy and Pedagogical Goals

Goal-directed behavior for pedagogical agents is desirable for the following reasons:

- A virtual embodied agent needs autonomy property which is achieved by dynamic goal-directed behavior.
- The proactive behavior of a pedagogical agent contributes to the *persona* of the pedagogical agent leading to improved learning as concluded Lester et al. (1997). The agent *persona* contributes to its believability that improves learner engagement and interaction.
- The pedagogic orientation is a special need of the IPA. And the proliferation of pedagogical goals in the virtual world gives it the desired educational nature with intelligence. The learning design process is goal-oriented.
- Contribute to pedagogical goals attainment through reasoning in a dynamic non-deterministic environment. Open Wonderland as a virtual world is supposed to be scalable with scalable vast resources. The learner has different unforeseen outcomes. Compared to the gaming orientation of a virtual world, pedagogical goals have stressing needs to better assure learning results.

While the design process for an agent involves stating agent roles, those roles have a goal-oriented nature depicting the agent proactive behavior. For example, the learning by doing uses a task decomposition that forms the learning task as a goal that branches to sub-goals. Fulfilling the goals not only implies that the learner has accomplished the learning activity, but also has reached the pedagogical goal and thus it updates the assessment belief of the learner.

Constructing the agent goals are considered with importance. As a learning task is cognitive, the decomposition of the learning task into smaller modules is important for learner accomplishment, assessment, and for the pedagogical agent to follow the progress. This decomposition is usually relevant to the learning design of activities that use task analysis methods that significantly investigates the elements of the task to convert it into achievable learning elements. This subdivision resembles goals formation that structures to smaller pedagogical sub-goals. The *cognitive task analysis* process follows a similar approach for structuring goals and sub-goals, each of which has pedagogical relevance. Figure 53 shows how a task goal is subdivided for the agent to achieve learning of capacitor simulation with the learner. Manipulation to accomplishment of goals is handled by goal deliberation while methods serve the goals through plans that form the agent intention, discussed below.

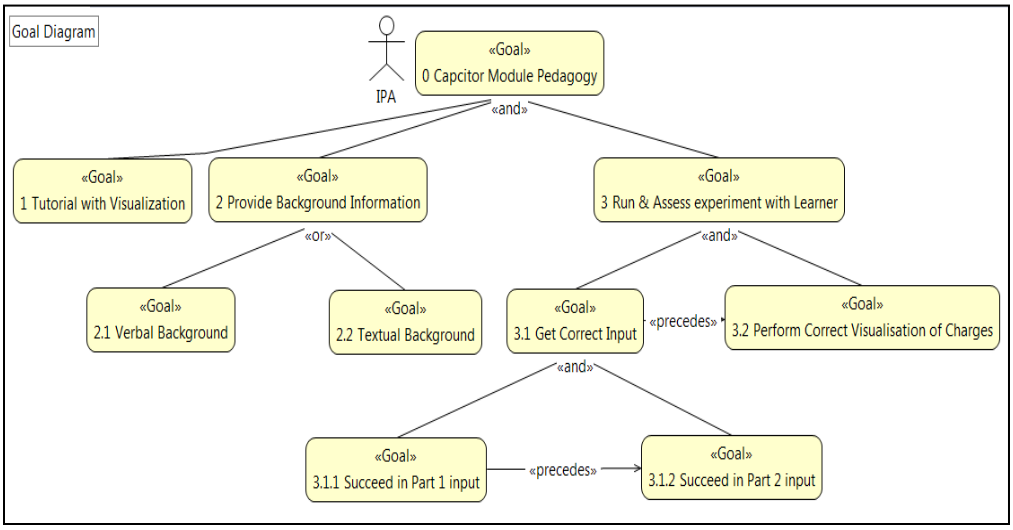

Figure 53: Example goal structure with decomposition in supporting a learner for a capacitor simulation module. Sequencing of activities is possible through goal ordering with precedes operator.

3. Pedagogical Intentions

The agent intention, realized into a plan provides a "recipe" for processing towards achieving a goal. Thus a pedagogical-aware plan gives the means to realize pedagogical methods. For example, in learning by doing, the learning task is to be performed by the learner while the pedagogical agent task is to scaffold learner interaction with the learning and gear it towards completing the task. The scaffolding agent behavior is in parts of the agent plans. Adaptive behavior can be added through varying the chosen plan according to learner abilities or style. Multiple plans or recipes are formed to target the same goal. In such case, the *means-ends* reasoning process triggers a different plan from one learner to another adapting to specific learner needs based on current belief state of the learner (learner model) and more.

In regular instruction, varying instructional methods are suggested by experts to provide better learning. In virtual learning with intelligent agents, the plans provide the varying methods of instruction. It is thus evident to enrich the pedagogical ability of the agent by increasing the methods of learning through adding different pedagogical plans. It is viewed with this depiction that several desired pedagogical properties are achievable. Instead of one plan, dividing the plan into smaller plans yields different pedagogical alternatives that can be suitable to different styles, environment situations, assessment, and more. For example, adaptiveness detailing the verbal style is shown in Figure 54.

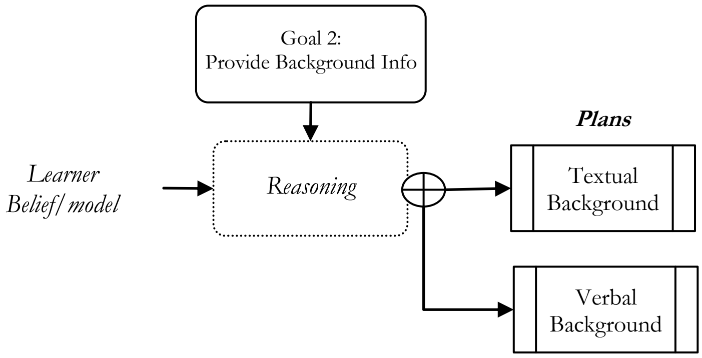

Figure 54: Example of plan selection. Based on the learner, an alternative plan is selected to achieve Goal 2.

As plans provide the main processing mechanisms in the intelligent agent platform, they are also the means to read or update agent beliefs from the plan. Thus the plans are also pedagogical aware as they capture pedagogical knowledge from belief bases, which can be any of the pedagogical models (see Figure 52) in accordance to the proposed conceptual model provided in Chapter 7. The plans also update belief knowledge, such as assessment into the belief base.

Attention should be given to who is controlling the task; the agent or the learner. While learning by doing in a virtual world suggests main control by the learner, the IPA throughout agent plans provide desired intelligent instruction support that relate to a learning facilitator. Practically, decisions on when to leave control to the learner can be handled in relation to Figure 53 depiction that assumes both learner control through plans that handle Goal 3, for example and plans for IPA control such as Goal 1. Varying instruction methods in skills teaching is in accordance to the *cognitive apprenticeship* instructional paradigm that proposes *modeling, coaching, scaffolding, articulation, reflection,* and *exploration* processes (Collins, 2006). While not all those processes are "straightforwardly" achievable in an artificial virtual world, *modeling*, *coaching,* and *scaffolding* are direct desired functions by the pedagogical agent. It is noticeable that the control of learning in these processes of the cognitive apprenticeship model is not always with the instructor. Baylor (2001) suggests that agents should accordingly vary the control between the agent and the learner through the *permutations of control* model in agent plan construction. Similar to a teacher who varies teaching methods in the classroom following the cognitive apprenticeship model, the permutations of control model of Baylor (2001) is also applicable for the BDI supported pedagogical agent. However, the sequencing of the agent plans, in reference to the cognitive apprenticeship model might be handled in the goal structure illustrated in Figure 53; for example to order activities from easy tasks to difficult tasks. In the targeted implementation of those goals, the plan can be either at the agent control, or at the learner control with the ability of the agent to record achieving the activity. However a *mixed control* mode between the learner and the agent, such as in scaffolding requires further clarification that is detailed in the following Section.

8.4. Detailing IPA Supported Learning Scenario[1]

Based on the findings from previous sections, integrating an IPA in the virtual world is targeted with a focus on the Open Wonderland environment with an intelligent agent platform is to be used for IPA reasoning support. The functions that the IPA should provide in a virtual world, as discussed in Chapter 6, are inputs to the implementation with a view of the conceptual model depicted in Chapter 7. The IPA provides pedagogical support and guidance in the virtual world environment. In general the IPA acts as a central point of interaction between the environment and the learner to enrich the learning experience intelligently. IPA implementations require of adopting a lifelike character. This mandates functions in the IPA of conversation, embodiment, animation, emotional abilities, and mediating interaction with environment.

Currently in a virtual world such with Open Wonderland, the learner avatar interacts with learning objects such as the TealSim module to run experiments and observe its resulting visual simulation. As a result, the targeted pedagogical agent is viewed to interact while giving the learner an active role with the experimentation module as a learning object. This implies two properties of the pedagogical agent:

- The pedagogical agent listens to the learner and interacts with, to give pedagogical support.
- Pedagogical support is not in isolation but in relation to *experiential learning* activity by interacting and observing the object of interaction in the virtual world according to the view of the IPA as a central point of interaction.

An illustration is given in Figure 55. It is based on addition of a character that represents the pedagogical agent, and a sample control panel of a simulation experiment in Open Wonderland. This situation is stated here for the purpose of

[1] Several paragraphs of this section are taken from Soliman and Guetl (2013b).

envisioning what can be performed before discussing a virtual world prototype[1] in Chapter 9. The Figure shows a visual representation of a learning setting based on Open Wonderland including an IPA, learner avatar, and a learning object. The learning object represents one of several experimentations in Open Wonderland such a TealSim module (Scheucher et al., 2009; Pirker et al., 2012), a device simulation or any Open Wonderland educational cell. In lack of a pedagogical agent, the learner has to interact with the learning object with no guidance or pedagogical support. Implementing the pedagogical agent targets adding tutorials, mentoring, and assessment functions, all aided by different supporting pedagogical models in the context of the learning object that is essential to the learning activity.

Figure 55: An IPA, a learner avatar, and a learning object (experiment simulation) in an interactive learning scenario in Open Wonderland. The IPA intervenes learner-learning object interactions to provide learning support.

Irrespective of the details of learning activity proceedings, a complete implementation faces the following challenges in the pragmatic dimension:

- Architectural, development, and implementation requirements of the virtual world. It is reported and discussed earlier the challenges in implementation with Open Wonderland.
- In the particular implementation, the IPA requires communication functions to support its pedagogical mission mainly in: *verbal* and *non-verbal* communication as well as *animation*.
- Interfacing requirements from the virtual world to an external intelligent agent platform.

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[1] A prototype implementation is performed in parallel with different stages in the thesis and is further detailed in Chapter 9.

- The implementation of an IPA imposes requirements of interaction with complex learning resources that have been designed for the purpose of deployment in the virtual world such as experiments in (Scheucher, Bailey, Guetl, & Harward, 2009; Pirker, Berger, Guetl, Belcher, & Bailey, 2012). In a virtual world, special interactivity of learning objects is required (Jorissen & Lamotte, 2004). The IPA in an immersive learning environment requires *understandable* and *controllable* learning objects to enable leading tutorials on the learning object.
- The implementation of several virtual worlds is at developmental stage especially for open source environments. For example, while the Non Personal Character (NPC) module in Open Wonderland is appealing for experimentation on the topic, it is categorized as "unstable"[1].

However, the use of this special model raises several questions in comparison to design with traditional methods such as the object-oriented model. For example, how to set agent goals, how to set *beliefs*, *desires,* and *intentions*? Which agent framework to choose, what design methodologies are suited? What could be learning scenarios with those agents, and how to design and implement BDI-based pedagogical agents for those learning scenarios towards situating them in 3D virtual worlds?

Therefore, an agent-based simulation is targeted to investigate agent development of behavior, answer design questions, and isolate implementation challenges to focus on interactive and intelligent learning possibilities. In the agent platform, and with a simulation, details of verbal or non verbal communication can be isolated. Also, the learning object can be abstracted to simulate input and output with no need getting into details of other issues that are hard to deal with in virtual worlds' implementations. It is also to shed light into how the pedagogical agent can support learning in a virtual world regardless of specific platform. Before going into detailed implementations in a virtual world, the agent-based simulation can yield a proof-of-concept to support actual implementation thereafter. A proposed learning scenario interaction that is supposed to occur in a virtual world is described in the following Section followed by its corresponding simulation in the agent environment.

8.4.1. Agent-based Learning Scenario Simulation

There are three benefits to simulating learning with an IPA in the agent environment. 1) to stress intelligent agent interaction with the learner avatar given a learning object, 2) to simplify and isolate implementation challenges and efforts

[1] Unstable modules are: "*either examples or experimental modules: there is no guarantee they will work at any point in time*", http://code.google.com/p/openwonderland/wiki/DownloadBuildModules05

of the virtual world, and 3) to enable further agent-based extensions to learning. The simulated learning scenario involves three agents: an intelligent pedagogical agent, an agent to represent the learner avatar, and a device agent representing an experiment device simulation (see Figure 56).

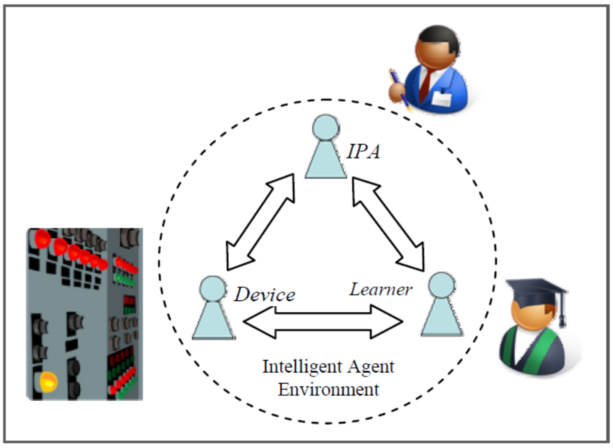

Figure 56: Three agents in the agent environment: learner agent, IPA, and device agent. The IPA intervenes between the learner and the device.

In regular learning scenario settings, a learner interacts with a learning object conducting a simulation of a device operating the experiment through a control panel, which will in turn provide parameters to a simulation resulting in displayed output or 3D visualization in the virtual world. In this case, there is no guidance but a possible teacher avatar with regular virtual world settings. In simulating the virtual world scenario, the intelligent pedagogical agent is added in a way that intervene the interaction between the learner and the device to mediate the learning functions. The pedagogical agent observes learner interaction with the learning object. At particular instance when the learner is responding incorrectly to a device observation, the IPA records it in the learner record and initiates a sub-goal so as the learner masters this particular situation. The purpose of the pedagogical agent is to add the following design objectives:

- Provide support to the learner through a tutorial.
- Monitor learner interaction with the learning object while assessing the learner and updating the learner abilities in regards to the activity.
- Provide immediate feedback. Providing such feedback has a special requirement to intervene according to environment or learner-learning object specific interactions. In the virtual world setting, the feedback is not only textual, or verbal, but can be emotional as well through IPA gestures.
- Intervene in situations when the learner is interacting incorrectly with the learning object so as to mitigate incorrect operation of the learning object.

Early correction in a learning situation can be favored than waiting till the end so that the IPA provides an immediate feedback.

- Control the learning object so as to generate specific behavior to check and assess the learner response.

Details of interaction are replaced with events or inter-agent communication that represents the interactions in the virtual world.

This learning scenario is important compared to a one without a pedagogical agent, as shown, so as to provide a step-by-step guidance to the learner, improve engagement, add interactive assessment abilities, and provide facilities for integration with learning paths and other learning objects. This can be facilitated by a multi-agent implementation.

8.4.2. Intelligent Agent-based Implementation

In order to implement the learning scenario with intelligent agents, a BDI-based agent system is needed. Several agent platforms such as 3APL, JACK, JADE, AgentSpeak/Jason, Agent Factory, and GOAL are good candidates for implementation, as visited in Section 8.2.1. Several of such environments are used to develop and integrate agents for virtual worlds. However, the selection and implementation are not trivial and hence, experience, evaluation information of specific platforms, and relevant issues are reported. One major obstacle in a selection is the lack of experience with those frameworks that have differences in implementation and the challenge in designing BDI-based agents that are non-deterministic. An ease of use, or pragmatic importance such as tool support gives a good start to the novice developer who considers it as an important factor. While JACK (JACK, 2013) is a commercial platform, it provides graphical tools that can facilitate easy development and generation of intelligent agents. Then further criteria of evaluation can be investigated. Braubach, Pokahr, and Lamersdorf (2008) provide details of evaluation criteria and results concerning those agent platforms. While the work by Braubach, Pokahr, and Lamersdorf (2008) resulted in good scores for JACK in the evaluation result, a non-commercial open source agent platform is essential. Considering a non-commercial open source platform, Jadex is a good candidate given its JADE standard orientation while fulfilling the deficiency of the BDI implementation (see Section 8.2). Therefore, experimentation with both JACK and Jadex is beneficial.

Experimentation with JACK

Implementing the learning scenario with JACK involves creating three agents: *pedagogical agent*, *learner agent*, and a *learning object*. The role of the pedagogical agent is to direct and monitor learner-to-learning object interaction. Since it is not implemented directly into the virtual world, the purpose of the learner agent is to simulate the learner avatar. The learning object agent simulates a virtual world learning object that can by a physics experiment. The simulation allows running the device with simple controls that results in different observations. The experiment runs as either the pedagogical agent asks the learner to run the experiment or provide a step-wise guidance. At certain instances, the pedagogical agent intervenes so that the device generates an alternative behavior that the learner should respond differently. Upon learner incorrect input, the pedagogical agent updates the learning result belief base. Figure 57 illustrates JACK design diagrams of the learner agent and the pedagogical agent. Events generated are sent, posted, or handled by different plans.

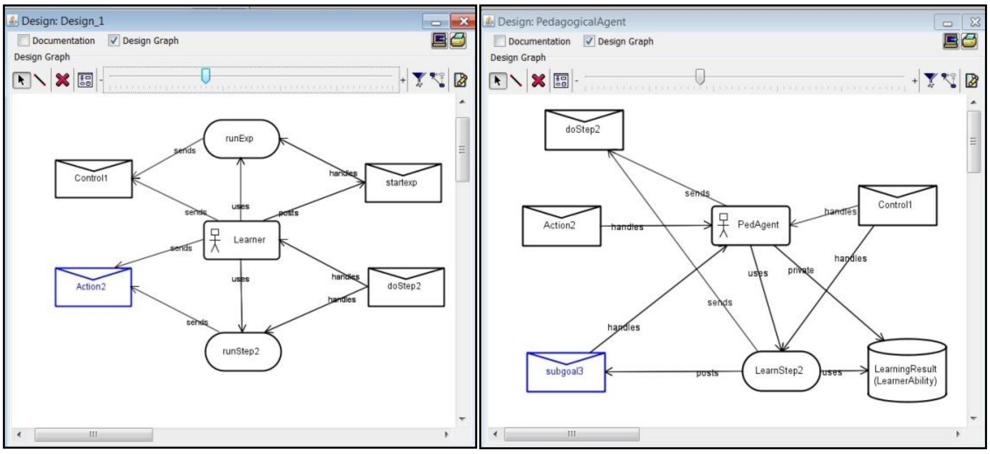

Figure 57: JACK design diagrams of the pedagogical agent and the learner in the learning scenario. The envelope shape represents an event while the oval represents plans.

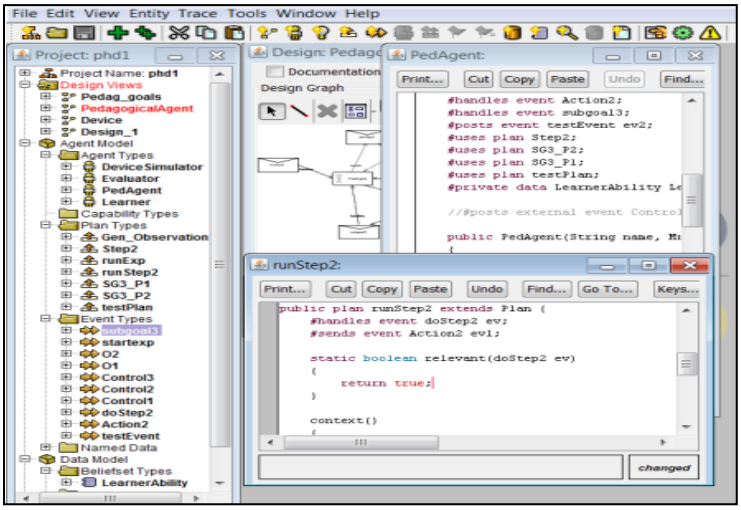

Figure 58: JACK IDE. The left panel shows lists agents, plans, events, and Beliefs. The right side includes an agent definition and a sample plan that is relevant to a particular event.

Jadex based Implementation

Jadex (Jadex, 2012; Braubach, Pokahr, & Lamersdorf, 2005) has similar BDI concepts to JACK in agent plans, goals, events, and beliefs. Jadex has importance in relation to JADE as it is regarded as its BDI extension. Being built on top of it gives JADE features, especially the FIPA standardization. Communication in Jadex follows the Agent Communication Language (ACL) FIPA standard as well. A major characteristic of Jadex is the XML based Agent Definition File (ADF) that describes the agent, goals, and beliefs (see Figure 59). A plan in Jadex is a Java-based program. There are two types of plans in Jadex; a *service* plan that handles multiple events, and a passive plan for each event. Events can be message events, goal events, or belief updates. Figure 60 shows plan definition and two event types in a Jadex implementation of the learning scenario. In Jadex, there are four types of goals: 1) *achieve*, 2) *query*, 3) *maintain*, and 4) *perform* goals. An agent, defined in an ADF along with the Java plans can either run individually or through the Jadex Control Center (JCC) (see Figure 61).

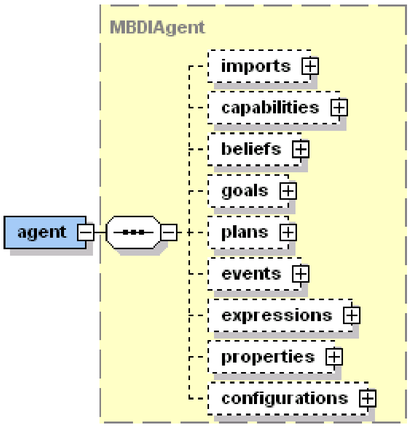

Figure 59: Jadex Agent Definition File (Jadex, 2012).

```
        <!-- A Learning plan - step 2 -->
        <plan name="runStep2">
            <body class="Step2actionPlan"/>
            <trigger>
                <messageevent ref="do_step2"/>
             </trigger>
        </plan>
</plans>
<events>
         <!-- 1. action request do step 2 of the experiment initiating this plan
             with perfor. request. 2. learner performs action2, internal ev. -->
         <messageevent name="do_step2" direction="receive" type="fipa">
                <parameter name="performative" class="String" direction="fixed">
                   <value>SFipa.REQUEST</value>
                </parameter>
        </messageevent>
        <internalevent name="action2_update">
               <parameter name="content" class="String"/>
        </internalevent>
```

Figure 60: Code snippet from Jadex agent ADF showing plan definition and two types of events: plan triggering event and an internal event.

Similar to JACK, three agents to represent the simulation are created: pedagogical agent, learner, and device simulator as separate ADFs with the corresponding plans. One major difference from JACK is in the inter-agent communication between different agents. In JACK, an event can be processed from another agent plan rather than the one that has generated it as long as it is declared to be handled. In Jadex, events are handled by different plans but for the same agent as long as inter-agent communication is handled through ACL message passing.

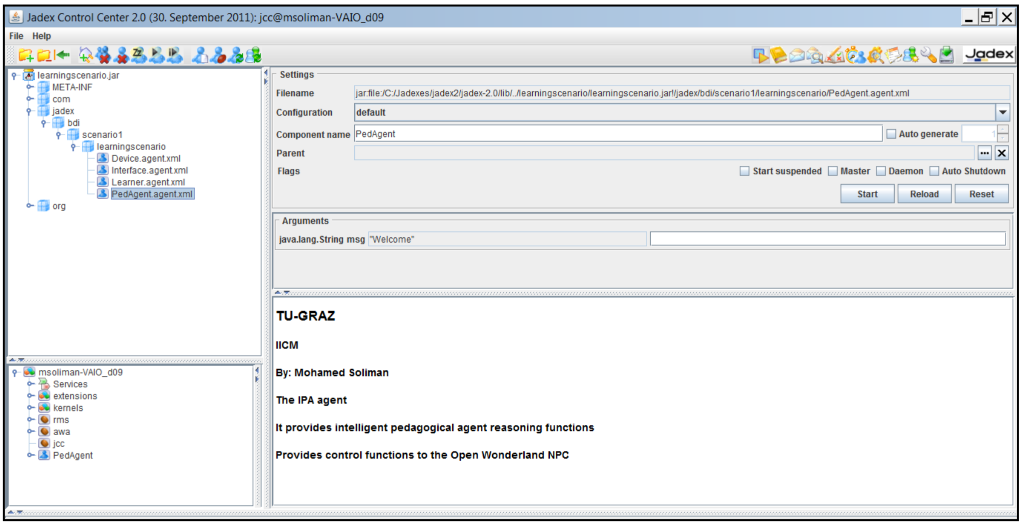

Figure 61: Jadex Control Center (JCC) using simulation Java package (learningscenario.jar).

Implementing the learning scenario in Jadex yields the following results:

- It shows feasibility of a mixed mode of agent control and learner control. In this simulation, the learner is an agent while in Open Wonderland implementation, the learner is an actual avatar.

- It provides a proof-of-concept detailing interaction details that helps in the design process of an agent system supporting a pedagogical agent in Open Wonderland (see Chapter 9).

- It provides input on the expectations of the device design aspects. For example, it shows the need for the simulation device to generate alternative behavior and the pedagogical agent control on the device operation rather than the expected user.

- It provides an input about the assessment component. As learner succeeds or fails certain steps, the pedagogical agent records in the learner belief base.

- It gives an input of experience for further implementation or enhancement in the intelligent agent side in both the design of plans with BDI agents, and the implementation details.

- It reveals the method of inter-agent communication. In this implementation, the learner agent, the pedagogical agent, and the device agent send and receive message. The communication among them shows a FIPA style details. Initial messages can be propagated through the conversation center of JCC. In subsequent implementations, pedagogical agents, through their supporting Jadex agents, communicate using the same method.

8.4.3. Further Considerations with Agent Oriented Implementation

A Simulation of a learning scenario is provided. Further aspects of concern include how to integrate the agent platform with the virtual world to allow agents to send actions to the environment and perceive events from it. This integration is not trivial given a large number of events the environment generates while not of interest to the agent platform (Oijen & Dignum, 2011) and the differences of the virtual world design and the agent design (Oijen, Vanhée, & Dignum, 2011). In agent systems, a percept defines methods to send and to receive events of interest and manage them between the two environments which are not trivial considering specific virtual world implementations. A major aim of the Environment Interface Standard (EIS) (Behrens, Hindriks, & Dix, 2011) is to standardize the interaction between the agent platform and the environment which is a virtual world in this case. An interesting feature is its ability to link to connect an agent platform to any environment that implements the interface. Jadex is supported by EIS as reported by Behrens, Hindriks, and Dix (2011). Jadex also provides environment support through EnvSupport for virtual environments (see Figure 62).

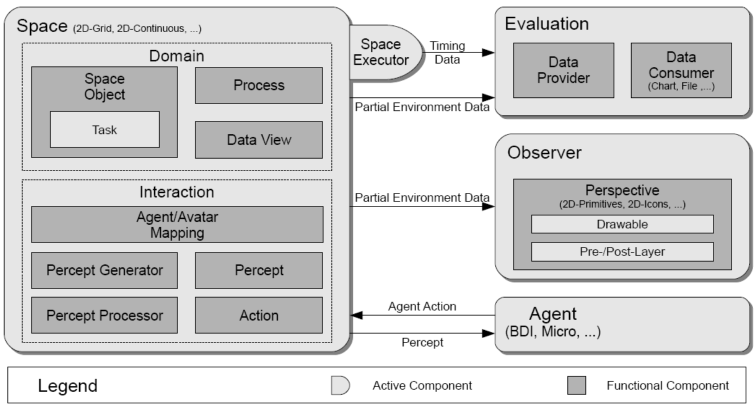

Figure 62: Main conceptual building blocks of EnvSupport in Jadex (Jadex, 2012).

The learning object in the above scenario is modeled as an agent so as to contribute to reasoning. Adding objects and environment behavior and interaction into the reasoning can yield better goal attainment and further intelligence. But it adds requirements to the selection of the agent platform and the ability of the environment to provide agent-aware objects. How the environment can provide more flexibility for assigning and achieving pedagogical goals? And how objects are designed to contribute to pedagogical goal attainment? The Common Artifact infrastructure for Agents Open environments (CArtAgO) by Ricci, Viroli, and Omicini (2007) adds this dimension by suggesting an agent-aware approach to engineer environment objects, named *artifacts* based on the activity learning theory. It suggests the *Agents and Artifacts*

(A&A) paradigm considering the cognitive aspects of learning objects to engineer artifact-based environments. C4Jadex has been developed as a bridge for Jadex platform to allow such integration to CArtAgO (Piunti, Ricci, Braubach, & Pokahr, 2008; C4Jadex, 2011).

On the other hand, JACK provides interesting features for group reasoning and team oriented modeling by using JACK Teams. Furthermore, CoJACK is a BDI cognitive architecture extends on JACK for modeling human behavior thus allowing for humanoids development.

8.5. Conclusion

Open Wonderland is an interesting virtual world implementation. It has advantages of extensibility, modular approach, and open source Java-based orientation. Development with Open Wonderland involves creating cell modules and deploying them into the virtual world through an administration tool. While there are useful features in it, there is still a need for adding functions to support the pedagogical agent and supporting learning functions. The pedagogical agent is not sufficiently represented by just deploying an NPC module, but it requires further development such as adding conversation abilities and operating animation gestures. Realizing support functions to the NPC should be targeted.

This Chapter also detailed learning scenario with intelligent agent-based pedagogical agents. An implementation and evaluation with two agent platforms; JACK and Jadex are discussed. The choice of JACK and Jadex resulted after visiting several agent platforms including 3APL, JACK, JADE, AgentSpeak, Agent Factory, and GOAL. The evaluation of JACK compared to Jadex yields similarities in the agent functions while differences include the representation of ADF, open source ability, standardization, availability of graphical design tool, extension to teams, deliberation cycle, plan representation, supported goal types, environment support, and understanding ability and its impact on manipulating learning objects. Strong functions in Jadex are found. Consequently, it was possible to transfer the implementation from the JACK environment to Jadex without losses due to the similar BDI structure of beliefs, goals, and plans.

Intelligent agent tool support mandated further investigation of the BDI model, to know how to design intelligent agents and utilize it for pedagogical objectives to support the IPA in the virtual world. Pedagogical beliefs represent the support models that stress pedagogical orientation, pedagogical plans represent the "recipe" for achieving pedagogical functions, and pedagogical intentions reflect goal directed behavior of agents. Pedagogical plans stress the need to detail mixed control mode between the learner and the pedagogical agent. Pedagogical intentions yield a goal directed orientation that matched cognitive based and goal directed learning design approach. With this depiction, it is possible to widen the functions of the IPA at large with design and control is achieved from the intelligent agent side.

A proof-of concept of how an intelligent pedagogical agent can provide learning support, in relation to the learner and the virtual world learning object is provided. It is achieved through simulating the interaction with corresponding three agents interacting in the Agent Communication Language (ACL). There are several benefits to this approach in isolating implementation difficulties, provide proof-of concept, facilitate creating further learning scenarios that stress the intelligent agent component, and provide input to actual implementation in the virtual world environment.

9. IPA in Open Wonderland: Development, Implementation, and Evaluation

This Chapter reports showcases implementation of an IPA interacting with a learner and a learning object in natural science experiment in a virtual world while providing supporting multi-modal communication abilities. The IPA adopts visual behavior of a Non-Player Character (NPC), has features of text chat based on the Artificial Intelligence Markup Language (AIML), a text-to-speech synthesis function, and non-verbal communication abilities through gesture animation. The implementation is presented through explained scenarios of the IPA tutoring an experiment or monitoring a learner avatar interaction with a learning object in a virtual world. The IPA and the learning scenarios are implemented in the Open Wonderland virtual world platform. The pedagogical agent mediates interaction between the learning object and the learner avatar to either allow tutorials or to monitor interaction in the 3D environment thus realizing simulated interaction scenarios discussed in the previous Chapter.

This Chapter is organized as follows. Section 9.1 discusses selections, planning and decisions for an implementation explaining features of internal, external modules adopted, and developed ones. Section 9.2 discusses the showcase of learning with the implemented intelligent pedagogical agent in Open Wonderland illustrating different learning scenarios. Sections 9.1 and 9.2 adopt work published in Soliman and Guetl (2013a). Section 9.3 gives an assessment of the design and development discussing applicability of the approach, strengths, areas of additions, and possible improvements. Section 9.4 discusses an evaluation study to the showcase and its findings, and is reported in Soliman and Guetl (2014). Section 9.5 summarizes and provides a conclusion.

9.1. The Implementation in Open Wonderland[1]

Providing narrative and dialogue functions by pedagogical agents increase engagement and immersion in the environment. McQuiggan, Rowe, and Lester (2008) reported increase in the sense of presence as a result of utilizing narrative characters in the environment. Lester et al. (1997) reported that animated pedagogical agents play a powerful motivational role, and the *persona* effect of a lifelike character increase learner perception and performance. Furthermore, adding conversation abilities to the pedagogical agent enables better interaction with the learner (Weusijana, Kumar, & Rose, 2008) in accordance to discussions in Chapter 3 and the pedagogical agent requirements in Chapter 5.

In this context, important requirements for an intelligent pedagogical agent in a virtual world include:

- Multi-modal conversation abilities with the learner.
- Embodiment and animation.
- Sensing and affecting the environment, learning objects, and the learner.
- Being pedagogical-aware providing learner management functions such as idle time management, providing intelligent support and guidance and awareness of the learning activity to provide expert response.
- Acting as a central point of interaction between the learner and the environment providing verbal and non-verbal support to the learner.

The development of the pedagogical agent, rather than a simulation, requires embodiment of a character module to visually play the role of the pedagogical agent. Furthermore, the learner avatar to pedagogical agent interaction in the environment mandates a multi-modal communication module. The agent intelligent behavior should provide input to the IPA communication module, should interpret learner questions and respond to it, as well as providing gestures compatible with the learning situation.

A schematic diagram of the implementation is depicted in Figure 63 while the details of interaction among the different components are further detailed in Section 9.1.3 and interfacing with Jadex has further details discussed in Section 9.1.2. The implementation is based on the Open Wonderland virtual world and uses external open source modules. In Open Wonderland, the NPC module is utilized to represent IPA embodiment and give animation aspects. A text-chat module is developed to provide dialogue functions and is interfaced to external

[1] This Section adopts several paragraphs and work from Soliman & Guetl (2013a).

chatbot support. The interface of the IPA is to an external Text-to-Speech synthesis server.

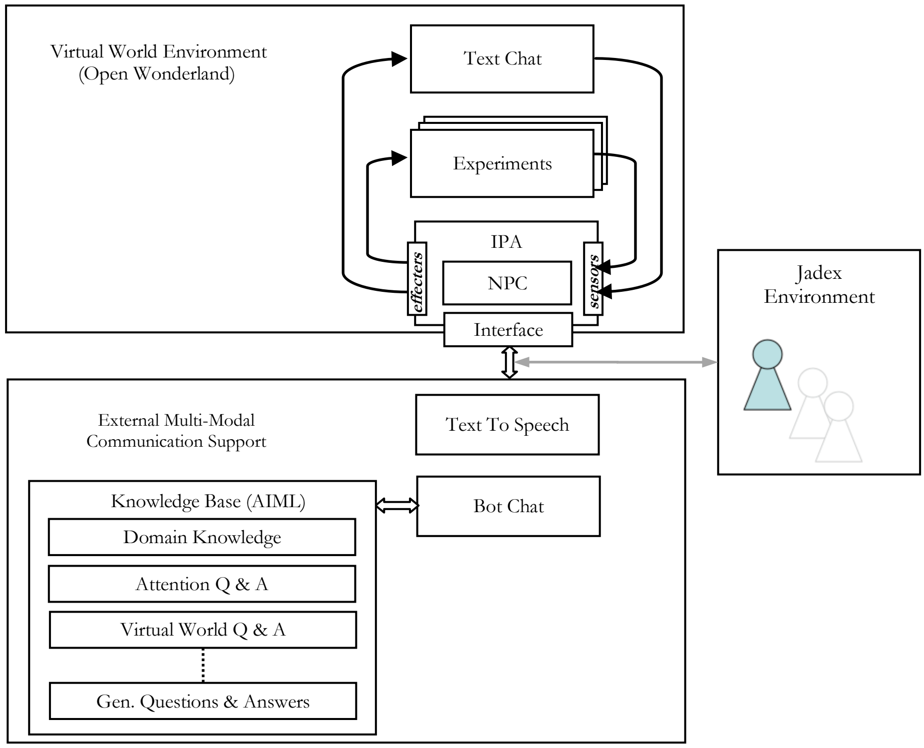

Figure 63: Schematic diagram of incorporating an intelligent pedagogical agent module in relation to sub-modules, external modules, and Open Wonderland, modified from Soliman and Guetl (2013a).

To enable intelligent agent functions, integration with the chosen intelligent agent framework of Jadex is sought. The implementation of the integration complements Figure 63 as an enhancement according to depiction in Figure 41. Section 9.1.2 gives more details in particular integration with the Jadex intelligent agent platform. To regulate external functions in relation to Bot Chat module, for example, and the experiments in relation to the Jadex platform, the interface component of the IPA manages coordination and control to the NPC module and the chat modules (see Sections 9.1.3).

9.1.1. Key Components

This section discusses the different components of interest referred in Figure 63 including the *NPC module,* the *TextChat* module, the *Text To Speech* component, and the *learning object*. The details of interaction, in relation to specific learning scenarios are discussed afterwards in Section 9.1.3.

The NPC Module

The Non-Player Character (NPC) is an available module in Open Wonderland that is a 3D embodiment representation similar to an avatar but with no user control (Open Wonderland, 2012). Therefore, it is appealing for utilization since it has several humanoid functions: appearance, movement, and providing gestures. However, it lacks decision functions. Therefore, the target is to develop functions on top of NPC module in Open Wonderland adding cognitive and decision abilities. This can be achieved by adopting it as an intelligent agent while the NPC takes the appearance and animation in Open Wonderland. Furthermore, the NPC lack of conversation abilities should be considered.

A useful feature available with the NPC module is the proximity event listener that senses objects as becomes in proximity. When the learner gets into proximity of the IPA, the IPA knows and identifies the avatar and tries to initiate conversation and shows attention.

Providing gestures to the learner is important to support the emotional state and has influence on learning (Lester et al., 1997). Therefore, adding this feature and for evaluation become important. Upon answering a question, the IPA provides a supporting gesture instead or with the text-based answer. This is achieved by forwarding a request to the NPC based on the chatbot answer to issue the gesture. Since the NPC module is based on the avatar implementation, several avatar gestures are also available to the NPC as well according the Open Wonderland implementation (Open Wonderland, 2012). For example a *"Yes"* gesture is used to show approval and encouragement and the *"No"* gesture is used to show an occurring mistake and disapproval.

An interesting aspect is when the IPA senses avatar emotional state in Open Wonderland. An approach is to detect the avatar module gesture generation or in the work of (Amarakeerthi, Ranaweera, Cohen, & Nagel, 2009) where a text chat module carries Open Wonderland compatible gestures through writing emoticons in the text chat module.

Text-Based Chat Module

To allow textual learner-IPA interaction, a text-chat Head Up Display window (HUD) is developed in Open Wonderland. Text messages sent by the learner to the IPA are typed in this window and IPA text directed to the learner is displayed as well in this window. An example text is the IPA to welcome the learner upon starting a conversation. Further details of interaction in relation to key components and the intelligent agent platform are provided later in Section 9.1.3.

In order to allow question and answer conversations, RebeccaAIML is employed for chatbot language support (Rebecca AIML, 2006). The tool relies on the Artificial Intelligence Markup Language (AIML), an XML-compliant language to provide textual natural language processing of questions and answers to virtual characters (AIML, n.a.). The design decision to incorporate AIML is prominent given the non-human entity to give answers back to entered questions. An example of the populated AIML file is shown in Figure 64. The text-chat module of the IPA is linked to RebeccaAIML that sends questions asked by the learner to its server that will send a reply back of the answer according to pre-defined knowledge base in various scenarios (see Section 9.1.3). Processing allows variations of the syntax so as to adapt to different names of the Bot, and variations of the questions.

```
<category>
    <pattern>
        How can I run the simulation
    </pattern>
    <template>
        Very simple. First, take control of the panel
        then select number of charges
    </template>
</category>
```

Figure 64: A Sample AIML file containing a simple question and answer about the experiment.

The AIML based knowledge is populated by different types of questions and answers that include:

- Domain knowledge. Examples are: capacitor knowledge, answers about how to run the experiment, and the level of difficulty of the experiment.
- Questions and answers about the environment. For example, which experiments are available? This is to allow the learner to obtain information about the environment.
- Attention and gesture supporting knowledgebase to emotional state of the learner. For example, *"Can I help you?"*, *"It is not a difficult experiment"*. In conversation the answer can be linked to gesture.
- General questions and answers.

An important aspect in considering human question making is the potential big variation of the same question syntax. AIML specification allows extension to context, variation of the question pattern by synonyms, and wildcard usage.

AIML files can be added to the knowledge base by incorporating general or domain AIML files through the management tool of *RebeccaAIML*. Also new questions and answers can be added into the existing knowledge base files. This feature is used in a training mode the conversation of the IPA to expand its conversation knowledge from Open Wonderland session to allow an educator or administrative user to add to the IPA question / answer knowledge base.

Furthermore, control commands to IPA, by the learner, are given in text. Thus, the interpretation of the commands is also supported by AIML. This design decision, to manipulate learner entered commands by AIML, facilitates variations of syntax in favor of flexibility and for convenience to the learner user for interaction in natural language. Similarly, sensing suitable gestures for the NPC in response to learner questions are triggered accordingly after AIML processing. If the conversation is not triggered by the learner, influence of the agent platform should be expected and thus the details of interaction are led by the IPA through the intelligent agent platform with further details as provided in Section 9.1.2. Specific details of interaction in relation to other key components, and with Jadex are shown in relation to particular scenarios depicted in Section 9.1.3.

Adding Voice

The voice feature is added by a Text-To-Speech (TTS) synthesis tool. Mary TTS is a Java based open source (TTS) system that has been developed as a joint effort of the German Research Center for Artificial Intelligence (DFKI) and the Institute of Phonetics at Saarland University and is currently maintained in DFKI (Mary Text To Speech, n.a.). Mary TTS is client-server based allowing sending speech synthesis requests through the HTTP protocol to Mary server. Several other features of Mary TTS are provided in (Mary Text To Speech, n.a.; Schröder & Trouvain, 2003). An interesting feature is its ability to provide synthesis of emotional speech. When it is needed that the IPA speaks in voice, it sends HTTP requests with the required text to be synthesized to Mary server which will return the speech in voice.

The implementation incorporates adopting simple calls, at needed circumstances, from the IPA module to form HTTP requests that are sent to the TTS server which pronounces the text in the corresponding voice. Details of interaction with other modules are provided in Section 9.1.3.

Experiment Object and its Interaction

An experiment has three aspects of interest: control panel, visualization of the result, and its internal operation. The objective is to take an experiment module as a unit of learning that allows the pedagogical agent to manipulate it in learning interaction with the learner avatar. An example learning object is a TealSim Cell (see Chapter 3, Figure 8). While the IPA could instantiate and remove any Open Wonderland cell in the learner scenery, awareness and control of its operation is required to vary its behavior (Soliman, Guetl, 2013b). A mock-up Swing-based module is developed and deployed in Open Wonderland to represent the learning object control panel and to provide necessary information useful for the IPA to provide step-wise guidance and to be able to assess the correct operation, with the following goals:

- It simulates experiment or device operation.

- Events are propagated to IPA upon avatar selecting a control and value. It is useful for the IPA to be notified upon learner interaction with the experiment.
- IPA has the ability to control the experiment internally by the IPA to enable providing tutorials.
- IPA has the ability to intervene the operation preventing the learner form incorrect operation of the experiment.

9.1.2. Integrating Jadex Agents with Open Wonderland

Another important aspect is the IPA ability to take intelligent decisions and reason about pedagogical actions to take in the virtual environment. This is to provide cognitive support to virtual human model such as found in (Funge, Tu, & Terzopoulos, 1999). Chapter 8 refers to BDI based simulation of a learning scenario that involves a pedagogical agent, a learner, and a learning object using JACK and Jadex agent platforms. The purpose is to simulate a similar situation in the virtual world. The agent role is to either provide step-wise guidance to the learner who is interacting with the learning object or to control the learning object for demonstration purposes while utilizing the learner belief base. In the overall, the design takes a goal directed approach, from a pedagogical perspective to scaffold learning functions in Open Wonderland in accordance to learning by doing and the learning design approach that is translated into agent plans. However, integration and adoption in the virtual world is needed that is reflected in Open Wonderland to intelligent agent integration.

The design of the perception module has three functions: 1) to sense the environment on events important to the agent, 2) filter the events of interest, and 3) act in the environment with affecter. Therefore, the design of the interface between Open Wonderland and Jadex has two main components:

- A virtual world component that listens to the events of interest and filter them, dispatch the events through HTTP requests to Jadex agent.
- A Jadex interface agent that receives the requests, dispatch them to the corresponding agent and manage effectors to the virtual world component.

Interfacing to Jadex agents is achieved through HTTP requests to a server that is listening for a port. This motivates a design of an interface agent that listens with a service plan to HTTP requests and forwards the requests to the corresponding agent. Since the forwarding mechanism is among different Jadex agents, it is possible by ACL messages. Furthermore, a sub-goal is triggered upon receiving an event to further process it in a goal-based manner. For example, to interpret events based on agent beliefs (see Figure 65). The interpretation can provide the relation of the event of interest to which agent or it can generate an event in the simulation agent environment. Open Wonderland is compatible with this approach; through HTTP requests and replies, the NPC module receives actions suggested by the intelligent agent environment and sends events of interest. The events of interest include learner interaction with the device. Example events are:

- The learner gets into the proximity of the pedagogical agent: This is important for the agent environment on reasoning to initiate a learning plan detailing for example, what resources the pedagogical agent suggests for the learner avatar.
- The learner starts interaction with the device. Upon starting interaction with the device, the learning task starts. The intelligent agent environment, monitors interactions in the suggested sequence.
- Inappropriate interactions. Such as the learner is working with an prohibited operation or pressing a wrong button in the simulation control panel.
- Other events can be added such as communication with other avatars.

The intelligent agent environment sends back actions to the NPC module in the Open Wonderland environment. Those actions should be primitive that isolates the intelligence from the intelligent agent platforms to simple actions the surrounds the NPC functionality. Example actions are:

- Asking the learner to come closer upon distant proximity with a simple text.
- Start the experiment learning upon closer proximity: The IPA, in Open Wonderland gives communication to the learner to start the learning module.
- Greet the learner. For example, upon leaving the proximity and finishing the experiment, the IPA to issue a message *"Good Bye"*.

```xml
<beliefs>
        <!-- This beliefset contains the dictionary as facts. -->
        <beliefset name="egwords" class="Tuple">
                <fact>new Tuple("event1", "Go")</fact>
                <fact>new Tuple("event2", "Dont Go")</fact>
        </beliefset>
</beliefs>

<goals>
        <!-- goal containing the socket for client communication. -->
        <achievegoal name="translate">
                <parameter name="client" class="Socket"/>
        </achievegoal>
</goals>

<plans>
        <!-- Passive plan for processing an event from event.
                Selective Reacts on changes made based on the belief set clients. -->
        <plan name="egtrans">
                <parameter name="client" class="Socket">
                        <goalmapping ref="translate.client"/>
                </parameter>
                <body class="TranslationPlan"/>
                <trigger>
                        <goal ref="translate"/>
                </trigger>
        </plan>
        <!-- Initial plan for starting a server thread waiting for client connections.
                Adds new sockets with the new connection to the client belief set. -->
        <plan name="server">
                <parameter name="port" class="int">
                        <value>9099</value>
                </parameter>
                <body class="ServerPlan"/>
        </plan>
</plans>
```

Figure 65: Snapshot from the Agent Definition File (ADF) helps an interface in Jadex.

In sending and receiving actions and events, details such as the learner identification and the type of action are needed. In order to manage the details of the events and actions within HTTP requests and replies between the Jadex environment and Open Wonderland, a simple Tuple approach, that is compatible with the belief set Jadex requirements, is used. The Tuple includes event identification, the action, and the learner ID. In Open Wonderland, the NPC module is amended with an *IPAController* class that has the following functions:

- *Server listener* to Jadex through a port.
- *Sensor_dispatch:* senses the Open Wonderland environment in the events of interest that includes learner interaction and send it to Jadex HTTP listener. It adds the user avatar ID.
- *Actuator*: Listens to Jadex commands, process the received Tuple, and form basic actions.
- *IPA_action*: translates the received requests into NPC actions.

The intelligent agent corresponding to the pedagogical agent has plans to perform the following:

- Respond to received events. Simple events that require no reasoning, such as asking the learner to come closer, can be reflexive. I.e. a direct respond is sent back to the interface to issue an action.
- Pursue pedagogical goal oriented behavior issuing goals and closing fulfilled ones. Goals are generated according to the depiction in Figure 53. Each goal corresponds to an agent plan depending on the goal. For mixed control mode that requires significant agent to learner interactions, an interface plan facilities communication.

9.1.3. Components Utilization and Learning Scenarios Formation

The components described in Section 9.1.1 are thus used to create learning scenarios with the IPA. The purpose of this Section is to provide further technical details of the learning scenarios which are composed based on the available supporting components while detailing interactions among them.

As discussed earlier, learning with a pedagogical agent by a learner avatar imposes certain requirements to finally create possible use cases that have the potential to provide a learning service. Evident possibilities include the need to make a conversation with the IPA by the learner and ask the IPA for providing tutorials, feedback, and consequently the IPA is to attempt learner engagement functions. Figure 66 below shows four use cases that are facilitated by the implemented components while the description of each use case, from the technical aspect is described subsequently.

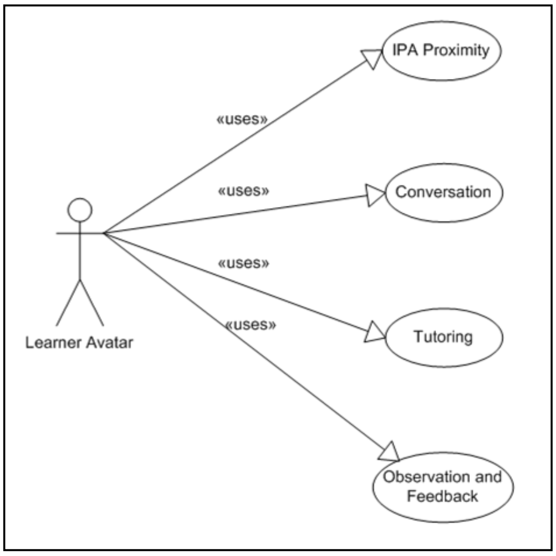

Figure 66: A use case diagram for a learner avatar for interaction with a pedagogical agent.

A: IPA Proximity

Having the NPC module as a Cell in Open Wonderland inherits the interesting *proximity* feature. The NPC class utilizes the *ProximityListener* of an Open Wonderland cell to listen when an avatar approaches two *BoundingVolumes*. The *BoundingVolume* class defines the geometry in a 3D volume that defines each proximity zone of the NPC. Figure 67 depicts a sequence diagram of components interactions on approaching an NPC. The objective of engaging the learner is directed by a Jadex IPA agent. The sequence adopts the agent interface depicted in Section 9.1.2 for providing a proof of concept on the agent control.

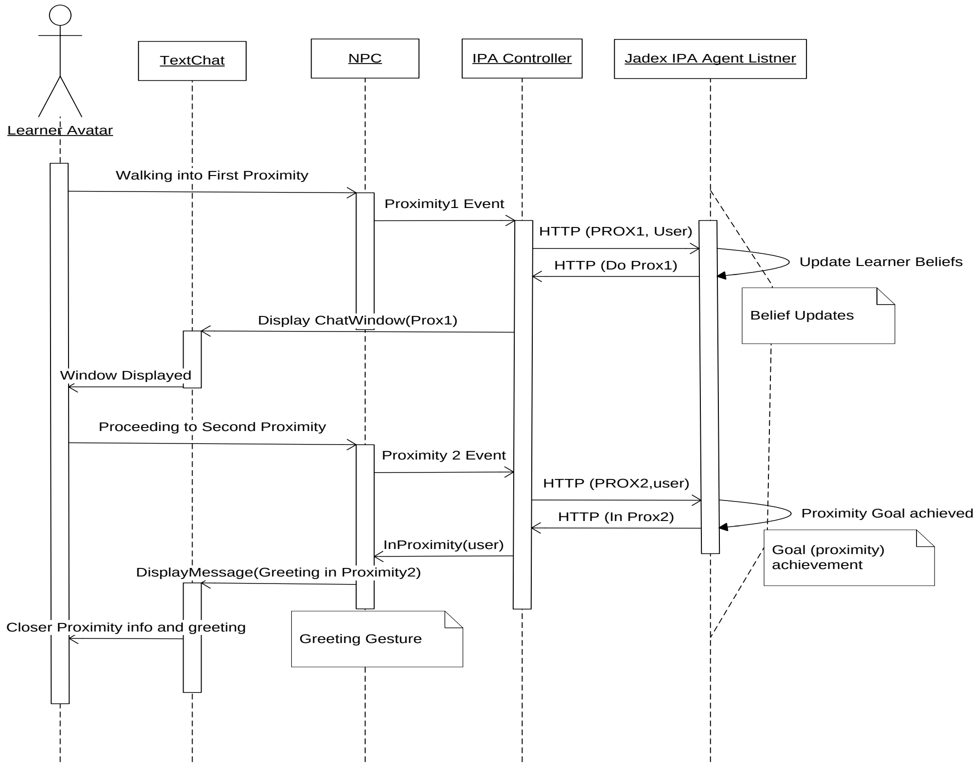

Figure 67: A sequence diagram illustrating learner to IPA proximity use case.

The sequence starts when a learner avatar walks into the proximity of the NPC cell. The NPC module consequently notifies the *IPAController* Class (see Section 9.1.2) of learner avatar proximity. As a proximity event is an event of interest to the *IPAController*, it processes it to send it to the Jadex environment, via HTTP, along with the user details for resolution. The IPA agent listener plan in Jadex will consequently receive it and process it in the agent environment. The response, fed back from Jadex, is received by the *IPAController* class to perform control instructions to the various IPA components including the *TextChat* module. The action from the *IPAController* requests to display a message through the *TextChat* window. Subsequently, if the learner avatar walks further close to the NPC, a similar sequence occurs, but with different interpretation in the Jadex IPA agent, to make an update to that particular user. In both proximities, the *IPAController* class notifies the *TextChat* to display appropriate message and the NPC to make a gesture accordingly.

B: Learner to IPA Conversation

The conversation use case depicts the major method of communication between the learner and the IPA. Figure 68 shows the elements involved and the sequence of interactions among them when the learner leads the conversation. When a learner enters an input in the *TextChat* window, it must be interpreted first. The entered text by the learner is extracted and sent to the AIML module to obtain a corresponding answer, which is displayed in the *TextChat* window for the learner to read. However, when the answer is received from the AIML module, it is further filtered to be interpreted as *NPC* actions, such as to instantiate a new experiment or delete an existing one (see Section 9.2.2). Furthermore, supporting gestures can be performed by the NPC accordingly.

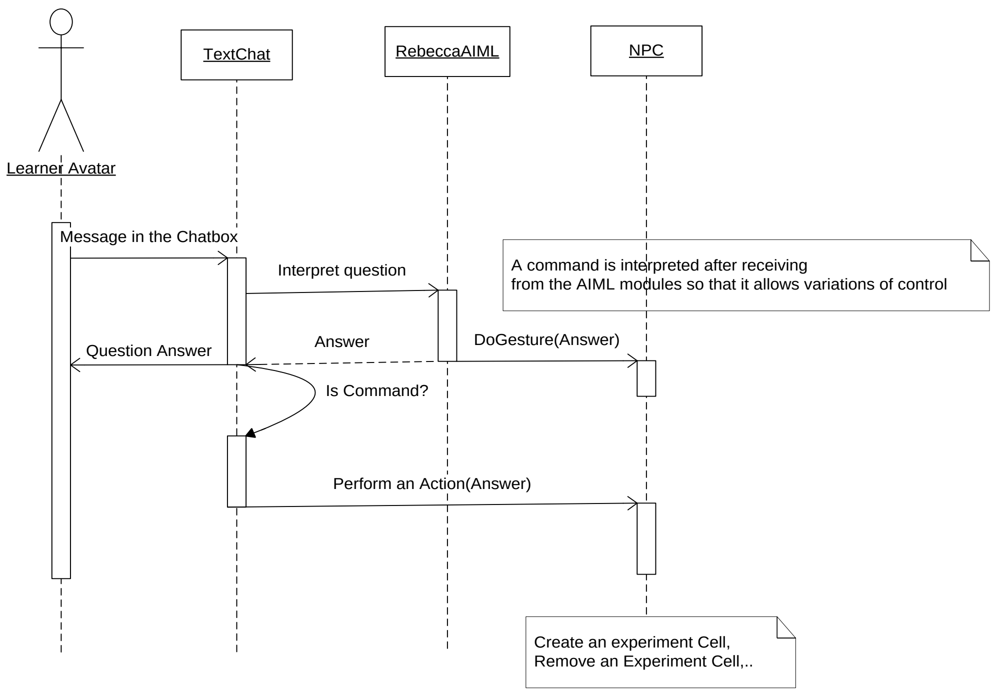

Figure 68: A learner controlled text-based conversation sequence diagram.

Performing checks on those basic actions are preferred after AIML processing than before, to allow variations of commands sent to the NPC that result in the same action. For example, *"Can you show me capacitor experiment"* and *"I need to see a capacitor experiment"* questions in the AIML module should result in the same NPC action of instantiating capacitor cell in front of the learner avatar. Alternatively, providing voice is enabled from the responses by sending the text to the TTS system through HTTP requests (not shown in Figure 68).

C: Providing a Tutorial

With the ability to know and control the learning object, the IPA tutorial scenario is facilitated; also by using the *TextChat* module. The dummy Swing module, described earlier, is used as a mock-up to represent a learning object in action in Open Wonderland. Figure 69 shows a sequence diagram when the learner asks the IPA to have a tutorial on the learning object of interest. Each input the learner should use with the learning object interaction, the IPA has to consider it in the tutorial. For each of the input steps, the *IPA* provides instructions to the learner, through *TextChat* for example, on how to perform this step. The IPA will trigger that input in the learning object cell to be highlighted accordingly to bring it to the attention of the learner. For the subsequent inputs, the same sequence repeats while a change of focus and a different Swing highlight is performed accordingly depending on the step performed. Between each two steps, a pause is made in favor of the learner comprehension.

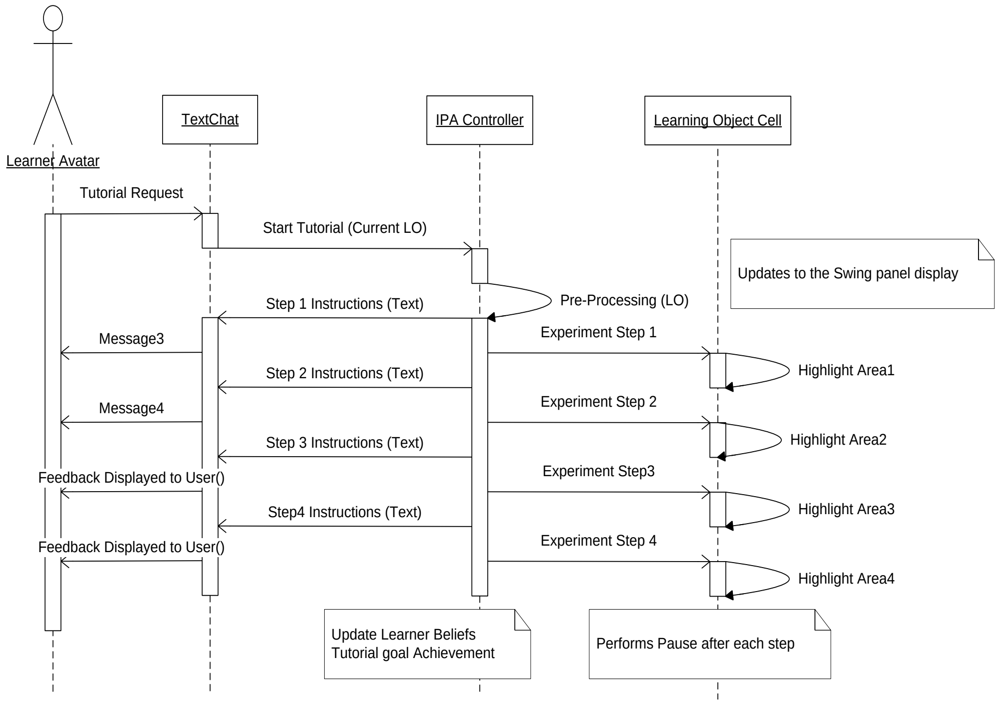

Figure 69: Sequence diagram for a learner avatar requesting a tutorial on a learning object cell.

While Figure 69 shows the sequence diagram for the TextChat module, extending it to voice just involves calls, with the displayed text to the TTS system. Furthermore, updates to the Jadex system, is to be forwarded by the *IPAController* class to update the learner belief and goal accomplishment of the tutorial requirement.

D: Observation and Feedback

In this use case, the control of the learning object cell is with the learner avatar. When the learner changes a value of a learning object cell, the IPA is notified. The objective is that the IPA should be aware of the actions the learner is performing in the learning activity and to help in goal accomplishment (see Figure 53). Figure 70 shows the sequence diagram upon learner performing a change on the learning object input of one input field in the Swing panel.

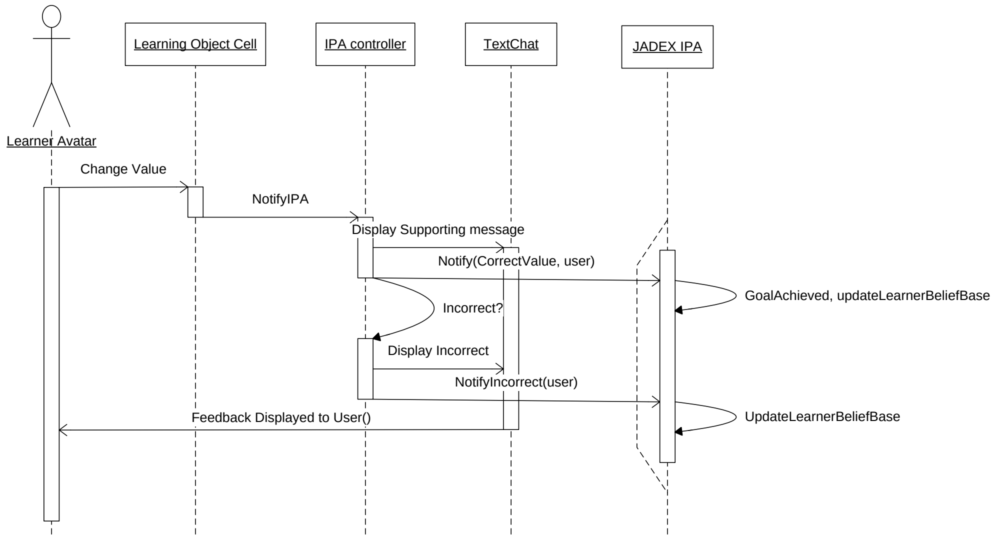

Figure 70: Learner avatar sequence details upon interaction with a learning object.

As the sequence is led by the learner, it is not assumed that the input is always correct. If it is correct, the learner is notified through the *TextChat* window. Conversely, if the input is incorrect, the learner is notified about incorrect input asking to re-enter the value correctly. Additionally, the NPC module is notified to provide supporting or disapproving gesture, depending on the result. Consequently, the Jadex IPA agent should be notified, along with user data to update the learning beliefs accordingly. While Figure 70 showed only one step, the process similarly repeats for the three remaining steps in reference to the Capacitor module.

9.2. Description of the Showcase[1]

A showcase demonstrating an IPA in a virtual world is developed. The purpose of the showcase is to provide proof-of-concept to show capabilities, learn from development and implementation, and act as an apparatus for evaluation study. For that purpose, the architecture and the supporting tools described in the previous Section are utilized in specific learning scenarios showing particular interaction possibilities with the learner. The showcase takes into consideration the desired objectives and the potential affordances for learning in a virtual world in relation to the IPA. The target of the IPA utilization is to add learning support, interactivity, and engagement in a materialized form in the environment. Furthermore, it is to take input from the agent simulation to depict in the virtual world. The learning activity is visualized through the learning object cell while physics experiment simulations give a good example of such learning object in the virtual world environment with several possibilities (Scheucher, Bailey, Guetl, & Harward, 2009; Pirker, Berger, Guetl, Belcher, & Bailey, 2012).

Different learning scenarios are provided in the showcase. The proximity scenario shows how to capture learner attention and intention to engage in a learning activity. Conversation abilities with questions and answers demonstrate how the learner can ask questions to the IPA and give requests, such as creating an experiment object or removing it. The tutoring, observation, and feedback scenarios demonstrate other forms of learning, scaffolding, and support to give input to learn from the development and enable evaluation.

9.2.1. Capturing Learner Attention upon Proximity

While learner avatars roam in the virtual world, intelligent pedagogical agents should be available to offer help. A question arises is how IPA to learner interaction should be initiated. On the goals of the IPA is to be actively supporting learners in the virtual world and attempt to increase the learner interactivity and engagement. In this scenario, when the learner avatar gets into proximity of the IPA, the IPA initiates conversation in attempt to capture the learner attention and improve engagement. A text-chat window will appear as a result of the proximity event to show the intention of the IPA to have a conversation and show the method of conversation. The IPA can provide hints on being available for help, such as "*Do you need any help*" and "*Please use this panel to ask questions*".

[1] This Section adopts several paragraphs and work from Soliman & Guetl (2013a).

Different possibilities are assumed when a learner is approaching an IPA in the 3D space: the learner can be interested in knowing what are the IPA and what it provides, the learner is already aware and would like to learn with what is available, or the learning is exploring. On the other hand, from the provisioning side, it is needed to identify when the IPA can provide the service to the learner or the when learner is able to interact with the IPA. It is assumed that not all the inhabitants of the virtual world are necessarily to engage with the IPA in specific learning activities. In all cases, the IPA should attempt to capture the learner intention, answer questions, and motivate to learn and interact. Engaging the learner with the IPA in interaction is the objective of this scenario.

In order to differentiate between exploration and intention to interact and learn more, and to enable the IPA to attract the learner avatar, two proximity zones (Zone A and Zone B) are proposed (see Figure 71). As the avatar is moving to closer proximity to the IPA, more interest is assumed, and IPA attempts to offer more. This proximity scenario is Jadex supported. Events of approaching the proximities are sent to Jadex, and appropriate actions to be sent back to the IPA in Open Wonderland depending on the context (see Section 9.1.2).

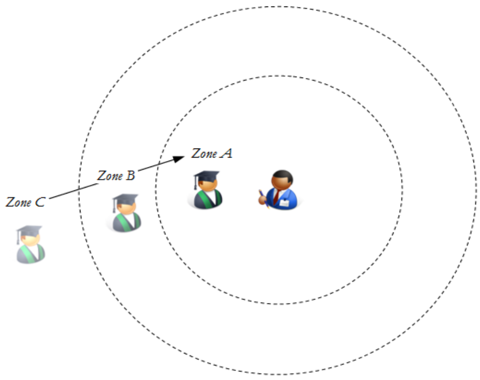

Figure 71: Two proximity zones with the IPA.
Zone A assumes more intention to learn and engage in a learning activity than Zone B.

The IPA attempts to attract avatars moving into its large zone proximity (Zone B) instantiating communication, through the text chat window giving information on what it can do and encouraging moving closer. The IPA shows what it can provide of a learning activity, such as capacitor simulation (see Figure 72). Questions and answers are allowed in this time period. In case the learner is interested in performing an experiment or learning the activity, the user moves closer giving the IPA strong indication of desire to learn and interact more. The IPA by then assumes the activity to start and the user intention to engage in a learning activity. It greets the learner with a gesture and enables further activities such as tutoring.

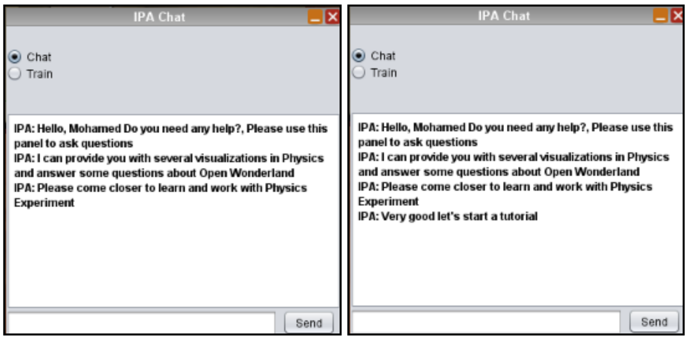

Figure 72: The text chat window at two moments. The left window shows at approaching proximity Zone B while the right window shows a new message approaching the closer proximity of Zone A.

It is important to add attention functions to the IPA so that it can be more sensitive to attentive learner actions and respond to it. In addition to gestures, the IPA should be facing the learner avatar to give more respect to the learner (Jaques & Viccari, 2004; Wang et al., 2008). Therefore, a function is added to rotate the IPA to face the direction of the learner avatar that approaches its proximity from different angles.

9.2.2. Learner Conversation

Learner conversation is important throughout all the scenarios. The requirement for the conversation from the IPA side is to provide information, engage and motivate the learner, and convey activity feedback. The prototype tool allows the IPA to provide different methods of communication to the learner through text, voice, or gestures. On the other hand, the learner seeks conversation with the IPA to know possible activities, ask knowledge questions, or issue action requests to the IPA.

With the text chat tool, the learner has the option to ask questions such as "*What experiments do you have?*" and knowledge questions such as "*What is a capacitor?"* The IPA will answer those questions based on the available AIML knowledge base. Questions can be recognized to provide simple emotional support through gestures. For example, when the IPA receives the question, "*is it an easy experiment*", the answer with "*yes*" in either voice or text is accompanied with yes gesture, and conversely with no. Figure 73 shows a dialogue between the learner and the IPA.

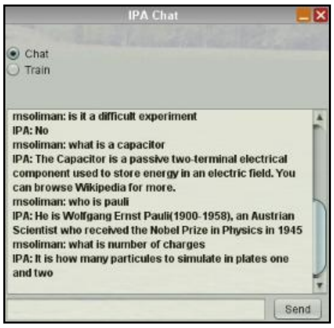

Figure 73: A text chat window showing a dialogue between the user and the IPA.

Instantiating and Terminating Learning Objects in a Conversation

The Learner can also ask requests such as "Can you show capacitor experiment". This question is interpreted as a request to instantiate a learning activity of "Capacitor learning". Accordingly, the IPA will invoke the Open Wonderland learning object. After invoking the simulation experiment, the learner can further ask questions and provide requests to the IPA. Figure 74 shows learner interaction with a pedagogical agent in a learning setting for a capacitor simulation experiment displaying the text chat tool for communication. The learner asks knowledge questions to the pedagogical agent or asks for providing a tutorial. The actual capacitor simulation module contains a visualization of particles animation. Upon completing the activity, the learner can issue the statement request *"I am done"* that triggers the IPA to remove the learning object from the scene.

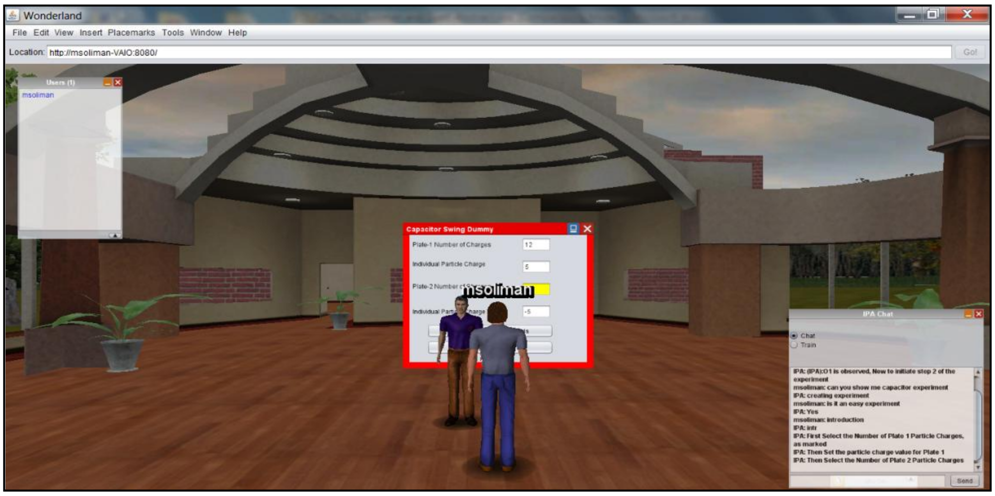

Figure 74: A Pedagogical agent providing a tutorial on a capacitor experiment in Open Wonderland.

Training the IPA for New Question/Answer Pairs

With the facility of updating the knowledge base of the IPA, the user provides questions and the corresponding answers with the train mode selected. This has two purposes. First, for educator avatars to update the knowledge base of the IPA to be able to support different experiments that can have different domain knowledge. Second, is for the learner to be able to teach the IPA. The later feature falls in the category of teachable agents (see Section 5.4). In the first case, it will be considered as *"reliable knowledge"* while in the later, it can be considered as *"unreliable knowledge"* that can be used for research purposes of an agent representing a student but with further considerations. This feature is explained with two avatars, the first avatar represents an educator who enters both a question and its corresponding answer, and the second avatar represents a student who asked the newly added question. The trained answer was obtained by the second avatar.

9.2.3. Tutoring the Experiment by the IPA

Similar to the human teacher tutorial activities, a part of the pedagogical agent role is to provide tutorials in the virtual world. In both real and virtual environments, there are four aspects to consider: the educator, the learner, the environment, and the learning task. In the virtual world environment, the educator is a pedagogical agent while the learner is avatar represented. The learning task however has special importance in the artificial setting that takes a practical form for learning by doing or training approach to match the immersive environment affordances. For example, the task of the pedagogical agent is to provide a tutorial on a learning task that the learner, through the avatar will perform it afterwards. The tutoring task is a fundamental learning activity. Therefore, it is essential to create it in a pedagogical agent realization. While it is advantageous in the artificial environment to perform individualized tutoring, i.e. in awareness of a learner model, pedagogical objectives, and more. For the sake of proof-of-concept and to enable further experimentation, the prototype elements discussed in the prior section are used to enable a tutorial scenario in relation to the given experiment object.

In this scenario, control of the experiment is with the IPA. The learner task is to observe the IPA stepping through the tasks. Thus, the IPA should not only do the actions the learner will perform, but also explain them and give details. Hence, it depends on the learning task on how to provide the tutorial. In the implementation design, and with investigating several experiments such as from the TealSim module, it is found that the learner will mainly control an experiment through a Swing panel. Therefore, in the training and learning by doing settings, the IPA will simulate the learner control to the swing 2D panel on control to run the experiment, but with additions for communication with the learner.

In addition to questions about the experiment mentioned above, the IPA provides a stepwise tutorial on the experiment by sequencing on the panel entry control and explains the purpose of each field with supporting information (see Figure 75). This is conducted in either text or voice while visually highlighting the selected field to the learner.

Figure 75: A pedagogical agent tutoring an experiment while highlighting the corresponding field in the panel.

This tutoring scenario is activated based on a learner command request to start a tutorial. It uses the text chat window, NPC functions, Text-to-Speech engine, and the dummy Swing. The Dummy Swing receives commands to highlight corresponding entry field in synchronization to what the IPA will provide in the tutorial either in text chat window or through voice.

9.2.4. Observing Learner Interaction with an Experiment and Providing Feedback

Observation and correction in a learning activity is an important objective in active learning environments. It mandates teacher fluency of the subject matter to be able to convey it and transfer the skill to the learner. To foster experiential learning, the learner has to perform an active role, not in lack of observation of an instructor, who can, with mastery of the task, to inform if the task is performed correctly or not.

The IPA observes the interaction with the learning object so as to ensure correct operation and correct learner interaction with the experiment. The IPA provides two types of feedback: *supporting feedback* and *correcting feedback*. When the interaction is correct, the IPA provides, in text or speech, a supporting feedback to “continue” with a positive gesture. Updating learner data can occur in conjunction with this scenario to update learner skills and with the IPA being able to judge on the performed task. Figure 76 shows the pedagogical agent monitoring learner interaction with the learning module to check for correct operation and providing feedback to the learner avatar.

Figure 76: A pedagogical agent monitoring learner interaction with the experiment providing feedback.

For the IPA to be able to observe and decide on correct task performance, it should be aware of the task; what is needed, how to perform it correctly, and the result. In the agent based simulation preformed in chapter 8, the representing IPA agent sent commands to the device agent to alter its behavior and check how the learner agent acts accordingly. In a realization prototype in the virtual world, the IPA can inspect the learning task and check for the learner response accordingly. The objective of the prototype in this scenario is to provide a proof of concept on the observation aspect based on a simulation object. Similar to the tutoring scenario, learner interaction is captured through the Swing control panel events. Control of the task in this experiment is given to the learner for performing the learning task and for the IPA in regards to communication. Figure 77 below shows the communication thread occurring between the learner and the IPA in this scenario to provide feedback on correct or wrong input parameters. In addition, the IPA gives an agreement-like gesture or disagreement gesture through shaking the NPC head accordingly.

Figure 77: A Communication thread between the user and the IPA, given at different moments to provide feedback. When the user performs the task correctly (the window in the middle), the IPA assures correct input. When the user gives an incorrect input, the IPA provides a feedback to correct the value (the right window).

9.3. Assessment of the Design and Development

This section provides a discussion about the feasibility of the approach taken for realizing and developing IPA in virtual worlds as well as the prototype from the development point of view given earlier in this Chapter. It refers to what has been developed or utilized against the viewed potential and the open possibilities seen. Hence, the strengths versus what can be improved are discussed.

9.3.1. Feasibility of the Approach

One of the challenges discussions in the conceptual model (see Chapter 7) is the complexity of achieving accurately imitating lifelike behavior[1]. That has been considered in the solution approach from different angles. First, the focus on providing a pedagogical solution has taken importance. This is exemplified in Chapter 5 depiction of intelligent methods that focused on learning in general as an objective. Second, during the different stages of conceptual model development, more investigations were in relation to what are practically feasible. That required experimentations with technologies including the Non-Player Character (NPC) in particular and in virtual world in general. The iterative approach has served this purpose with different features and research elements were investigated in parallel to the depiction of a conceptual model or a prototype. However, providing the learning support with specific method remained to have greater importance. The solution approach through utilizing a learning object, such as the capacitor simulation cell discussed in this Chapter form an approach of the solution. Thus the premise on the ability to generate

[1] Furthermore, Section 7.3.2 discusses limitations of the proposed conceptual model.

new possibilities of learning support with the pedagogical agent has been supported in the showcase. It is believed that the pedagogical agent knowledge of the learning object, as per the requirements discussed in Chapter 6, is analogous in importance to teacher or trainer proficiency in the subject matter. This has gained support through the tutoring and task observation learning scenarios. Another aspect in the premise of what pedagogical values the IPA can provide in relation to thinking and decision abilities of the human versus the machine. As humans have the ability to vary interactions with their intelligence, computer systems are rather able to provide usage patterns. Use cases and scenarios in computer systems provide appropriate methods for requirements elicitation and evaluation of appropriateness. And thus, formation of learning scenarios can help in this regard while the approach allows integrating them through the selection by the user, through an intelligent agent reasoning function, or according to a learning design goal (see Section 8.3.2, Figure 53).

Practical intelligent agent platforms with utilization of the commonly used cognitive approach of BDI enable pragmatic realization of functions. Only basic features of the model are depicted while different intelligent features such as *explainable agents*, *teachable agents*, and more can be considered by implementing their methods of learning support (see Chapter 5). How the approach serve the different types of agents can is only bound to implementation and integration in the used agent framework.

The model of the IPA takes learning by doing with simulations as an important approach with awareness of the learning object and establishment of learning activities accordingly. A semantic approach description of learning objects and utilizing a learning object model helps discover and tutor with further learning objects in the virtual world (Maroto et al., 2011). The approach further facilitates cognitive apprenticeship (Collins, 2006) through *coaching, scaffolding,* and *modeling,* but further functions are sought for realization and validation (see Table 3). The active learning approach and flexibility was fostered for the learner giving rise to the experiential learning paradigm of Kolb (1984) (see Figure 3). However, extension and further validation to complete the experiential learning cycle of Kolb are can give more prominent results. This is for example to test implications of new concepts in new situations tracking, or stage three, and complete the cycle of experiential learning. Consequently it is essential for the pedagogical agent to track, control, and measure shifting between the four cycles. Assessments in relation to the different stages are allowed by the approach through the pedagogical models of learning objects, but it requires validation through future prototype extensions with further details.

The approach and the conceptual view foster possibilities of learning design as the pedagogical agent can take charge of not only a learning activity but of a complete learning path. Through the various supporting models (see Chapter 7), the pedagogical agent can offer wider activities that are compatible with learning demands and according to pedagogical objectives through supporting models proposed in the conceptual model and according to learning design principles (see Figure 40).

The pedagogical agent and the prototype have shown to support individualized learning. However, the conceptual model and with the intelligent agent approach support for group learning discussions in Section 5.5 shows that the approach is extensible to collaborative learning settings. In such case, identification of when and how control is left to different learners can be identified in a simulation and/or extended in the prototype. This shifts the responsibility of the pedagogical agent to distribute the control (in tutoring, feedback, conversations, etc) among the different learners according to collaborative learning rules for enhancing learning results. The pedagogical agent role by then can be reduced to more observation and facilitation given the availability of several learners with varying knowledge levels.

A contribution of the approach is considering both an agent based simulation and the prototype in conjunction to provide proof of concept. While the simulation part isolates implementation difficulties, it gives the focus on the interaction pattern for engagement with the pedagogical agent as a method of abstraction prior to realizing the function that can be considered as a first factor. A second factor is in the approach of realization of pedagogical agent functions through learning scenarios that shows episodic interactions in relation to multi-modal communication module, and in relation to potential models support. With the learning scenarios realization, it adds to a pool of possible scenarios extending pedagogical agent features as a list of services it can feasibly provide to the learner, assuming the feasibility of the approach. Thus enhancing the approach is extensible to expand in systematic steps that can be shown by example below. Extending new features that add to pedagogical agent support to collaborative functions, as an example, can take the following steps:

1. Investigating the requirements to identify what is needed as per objectives. For example, collaborative learning support is needed that considers prior learner abilities in modes of interaction among different learners.

2. Abstract the interactions in the virtual world following a simulation approach in the intelligent agent platform similar to proof of concept in Section 8.4.

3. Utilize the conceptual model elements for support.

4. Use pedagogical agent multi-modal communication features and the learning object to develop the collaborative learning scenario given the simulated interaction.

5. Evaluate the resulting learning scenario.

6. If the results are positive proceed by enhancements and integrate the pattern with contextual selection reasoning in the agent framework along with prior learning scenarios.

7. Test integration of learning scenarios to selection and operation under appropriate conditions.

8. Enhance and add to a pool of available features to the pedagogical agent and establish the reasoning conditions in the agent framework.

9. Repeat steps 1 to 6 for each new possibility.

In other words the learning scenario approach along with the simulation and the core prototype can provide a proposed incremental and iterative approach to enable enriching the pedagogical agent functions.

Another aspect of the approach that is not tested with the given constraints is the specialization of the pedagogical agent on tasks it can do. The approach for the prototype considered tutoring, observation, and feedback functions. The pedagogical agent, in comparison to human teacher roles, performs other pedagogical functions such as assessment for example. While automated and online assessments are research topics on their own, assessment is an essential component to consider especially for pedagogical agents. Learning processes include an assessment component that can not only provide feedback but influence the behavior to be tailored to learner abilities and needs. Section 7.1.4 incorporated such functions but the discussion in relation to the method and prototype is important. Figure 53 shows different pedagogical goals. Furthermore, Figure 52 shows an intelligent agent updates and reasons its beliefs based on various pedagogical supporting models. In other words, applying an intelligent agent method is pluggable into the used intelligent agent framework to enable such a feature. Those features are generalized in relation to the proven abilities to be solved by the intelligent agent methods (see Chapter 5). Those include features that enable the pedagogical agent to be with one specialty or more of being explainable, teachable, etc (see Section 6.3). The decision on specialization in the intelligent agent paradigm is taken based on the ability to handle a role in goal directed behavioral manner, or more. This falls in the scope of examining the approach to handle multiple interacting pedagogical agents (see Figure 52). The simulation environment, in intelligent agent platform becomes the decision factor on whether to equip the virtual world pedagogical agent with one major role, or more. Unless there is a developed facility, that is not yet provided or proved feasibility to be able to switch a pedagogical agent control to another controlling intelligent agent. Regardless, having multiple roles enrich the pedagogical agent(s) offerings to learners in relation to realization constraints and challenges.

The approach, the immersive environment, and the simulation of experiments, stress the ability of the approach to support training with the importance of the role of the pedagogical agent and the learning by doing approach. Bothe factors support training in immersive environment with several visited conceptual models and utilized for training (see Chapter 7). On the other hand, and on the aspect of general education, the prototype did not consider how the text chat tool by questions and answering can be used for conceptual learning. Consideration to conceptual learning can also be thought of, also in iterative approach, in relation to the text chat and verbal communication but requires further investigations and considerations of particular methods of discovery in relation to specific prototype elements.

9.3.2. Assessment of the Prototype: a Development View

Given the constraints in development (see Chapter 8), not all desired functions are implemented. Several functions are required for addition including how to make the IPA more active and responsive to user movements similar to the scenario of approaching the IPA (see Section 9.2.1). Enabling more gestures can be added as well. The NPC abilities to provide gestures of the current version include weaving, bowing, handshaking, and more. However, not all functions are added in the prototype while including some given the importance of appropriateness of the context. However, they can be available for other functions or learning contexts.

The text chat feature along with the voice ability enables a user interface that might be more suitable than a traditional 2D menu interface since it allows more variations and possibilities. For example, it does not only allow asking a question to the IPA but it also gives a command such as for creating an experiment object. This approach is directly extensible to add more commands for more actions or learning scenario details by extensions to the AIML module. Furthermore, adding a training facility provided an outlook for possibilities to train for more question answer pairs. This training facility allowed basic features for the sake of proof of concept testing and experimentation. It should be noted that there are further more possibilities to extend to the module with more concrete questions with patterns of variations.

While the considering the intelligent agent platform posed challenges such as depicting agent oriented design, its integration to Open Wonderland enable several feature extensions to the prototype. A proof of concept about how an intelligent agent control a pedagogical agent may is exemplified in the proximity with IPA case (see Section 9.2). This required implementation of the interface concept (see Section 9.1.2). This development was achieved after several experimentations with JACK and Jadex platforms that also have given experience in how to devise an intelligent agent. This experience can now be extended to include more features to the IPA in Open Wonderland by just encoding into the agent platform such with Jadex recommendation.

While the approach did not consider aspects of the environment of changing or constructing a 3D view, the conceptual model assumes the IPA awareness of the environment through the *world model*. The IPA being able to know about the learning object was essential to perform tutoring and observation functions. Similarly, the IPA can provide tutorials about the environment. The text chat tool, through adding question/answer pairs to AIML files allows queries by the user to know general information about the virtual world. Semantic descriptions of the virtual world, or similar methods, can enable those questions to be asked in context such in regards to specific 3D room property and its offering, but this feature is not provided. But changes to the world scene by the pedagogical agent was not considered can act as for constructing and personalizing the 3D view according to the learner needs with aid from learner and world models. Similarly, different supporting 3D cells of Open Wonderland can be added to support the pedagogical agent mission such as providing help on how to use the chat system with a 3D cell object. While the prototype provided a mock-up tool to an experiment object as the control panel, extension should be enabled to demonstrate IPA manipulation control over the particle animation part (see Figure 8), and the learner control observation depending on the cell features. It should also relate to enable question answering in the context of the learning task being performed.

The prototype provides basic input to potential security requirements. In the learning domain, the security aspect is not as in other application types such as commercial applications, but it is important from a different angel. In educational applications, the learner is treated differently from others and it is expected to protect individual learner data. The prototype implementation obtains the user identifications from Open Wonderland API and enables the IPA to great the learner with his/her name. The ID is also sent to the intelligent agent framework to enable reasoning about the individual user such as in relation to tracking activities progress. The IPA inherits security aspects from Open Wonderland. While it is seen that IPA role is not for security but it should comply with guidelines that are implemented similarly in real educational institutions.

Given multiple scenarios become more possible, integrating them in an explainable form, such as with semantic descriptions, enable providing recommendation of resources and intelligent guidance by the IPA. In the provided prototype, the IPA instantiates experiment object such as the capacitor while assuming its role of tutoring, observing, etc. It is possible to extend the prototype, in a new learning scenario, so that the IPA recommends visiting resources with or without IPA influence such as providing details of coordinates or place marks of other learning objects in the virtual world environment through the conversation feature.

In order to gain the second perspective and further evaluate the prototype, an evaluation experiment can help provide further input. There are two possible approaches, a *user evaluation* or *expert evaluation*. While the user evaluation can provide usability aspects in regards to the user interface with the pedagogical agents, the input required is in regards to the approach and the design and has potential to cover a wider scope rather than the user interface; for example, lifelike behavior. An expert evaluation with focus on individuals involved in immersive education, pedagogical agents, and at least e-education can shed light into aspects of the approach and the design rather than the usage pattern, which is preferred at this stage. In order to gain further opinions in regards to the prototype not only it can be put in the focus of evaluation, but also its design elements in relation to the effects and appropriateness they can provide. One approach is to depict the learning scenario concept to evaluate the episodic aspect such as the ones discussed in this Chapter of tutoring, observation, etc while the focus can be given to evaluate its detailed components in qualitative and open nature. Further assessment and input is obtained throughout an evaluation experiment conducted by experts and detailed in the following Section.

9.4. Expert Evaluation

This Section discusses and reports evaluation study process and results. It discusses relevant aspects to the problem and *research design*, *experiment setting, procedure, participants' details*, and summarized results in relation to specific issues in the prototype implementation.

9.4.1. Problem Statement

In order to obtain evaluation and gain feedback support to shed light and add further perspectives, a research design study is required. The adopted approach for performing the evaluative study is through a qualitative expert evaluation. A study is conducted by participating active experts in relevant research fields of work that include *Computer Science, Cognitive Science, E-education,* and *Virtual Worlds*. The purpose is to check, evaluate, and obtain opinions, feedback, and perspectives in specific areas and questions discussed below.

9.4.2. Research Questions and Design

The purpose is to obtain insights about the impact of intelligent pedagogical agents in a 3D virtual world in relation to the learning experience and research objectives of the thesis described in Chapter 1. For the study, research goals also raised that require the study process to obtain insights and feedback of how far those goals are reached, and how to further improve while obtaining the second perspective and the expert opinion (see Section 1.2). In order to obtain evaluation to the research questions of thesis and the resulting research goals, in relation to discussions in the prior Chapters, the following hypotheses are checked in the experiment:

H1: The IPA, in the provided setting, provides appropriate mechanisms for increasing learner engagement in the virtual world.

H2: The IPA furnishes important guided instruction for enhancing the learning experience.

H3: The IPA contributes positively to learner motivation through guidance and task-completion support.

H4: The IPA provides the learner with an appropriate feedback mechanism that is positive to the learning experience.

H5: The pedagogical agent positively contributes to the learning experience in the virtual world setting.

Consequently, the study has the following objectives:

O1: Evaluating and testing hypotheses H1:H5.

O2: Evaluating appropriateness and alternatives of the design elements such the text chat tool.

O3: Evaluating how can this prototype implementation potentially support the IPA concept.

9.4.3. Apparatus

In order to evaluate the research questions mentioned in the prior Section, the prototype reference implementation described in this Chapter is used for the expert qualitative evaluation. Learning scenarios and the setting in Open Wonderland are considered for the evaluation. Table 11 shows a list of input scenarios and their relevance to the experiment.

Table 11: IPA supported learning settings for evaluation and validation.

IPA scenario	Relevance
A. IPA proximity	It is important to capture learner intention to start learning activity.
B. Using multi-modal communication	It allows the learner to be in communication with the IPA. There are different methods of interaction in this scenario that require evaluation.
C. Tutoring	The IPA is in control of the experiment so it is different from the above scenarios and is new. Tutoring is a main aspect of traditional teaching activities.
D. Activity feedback	This is an actual learning scenario performed by the learner. However, control is shared between the learner and the IPA so as to allow the learner to run the experiment activity while receiving feedback from the IPA.

The details of each learning scenario in relation to the evaluation and validation experiment are discussed individually below.

A. IPA Proximity

One challenge in designing the none-human controlled IPA is the requirement to reason about the learner interest in interacting with the IPA and the particular learning object. There are two alternatives; 1) to give the learner the choice to explicitly select to add an IPA (through Open Wonderland 2D menu system), or 2) through the proximity approach discussed in Section 9.2.1. Both approaches are possible in the prototype. Perceptions about an appropriate method are considered important to be evaluated as a function that adds to IPA realization.

B. Using Multi-Modal Communication

As discussed above, the IPA communicates with the learner through the text chat module. In the design, questions are sent to an AIML module for resolution; then the answers are displayed to the learner through a text chat module, and more (see Section 9.2.2). The objectives of the evaluation of this scenario are in relation to learner interaction with the pedagogical agent affecting the usability and effectiveness. In this scenario, subject information and answers to questions are provided to the learner. Thus the objective of the evaluation is to evaluate and validate its appropriateness.

C. Tutoring

In this scenario, the participant observes the IPA providing a tutorial on a sample learning object similar to several cells in immersive worlds. It is considered as an interaction pedagogical method for presenting work to learners in the 3D world depicted in the showcase of Section 9.2.3. The objective is to validate the approach and its importance to learning functions by a pedagogical agent in similar settings.

D. Activity Feedback

In this scenario, the learner has control over the learning object through the control panel. The learner runs the experiment. The goal of the IPA is to observe this interaction, correct learner behavior, and provide feedback and support with correct values. This scenario refers to details provided in Section 9.2.4 earlier in this Chapter. It is also a method for the IPA to provide judgment about learner abilities in relation to the learning activity. Feedback and assessment are considered important components for pedagogical design objectives. The purpose is to validate such design objectives and the method taken in relation to the learning object. Also, to provide opinion and evaluation in relation to IPA scaffolding functions at a learning by doing setting in relation to learner motivation.

9.4.4. Description & Participants

Experts from relevant fields are carefully chosen and invited to participate in the evaluation study. Six experts from Graz University of Technology participated in the study. They have specialties depicted in Table 12 below with multiple selections are possible.

Table 12: Expert areas of specialty and their relevance to the study. Experts can have multiple areas of experience.

Area of Expertise	Relevance	Number of participants (%) who have this area
1. Cognitive Science	Cognitive science is relevant to the thought processes of the learner. In addition to exposure to artificial methods for e-education.	3 (50%)
2. E-education	Experience with tools and methods for electronic instruction. Education background is desirable for the education foundation aspect.	4 (67%)
3. Computer Science	Facilitating methods of IPA foundations.	5 (83%)
4. Virtual Worlds	Virtual Worlds represent the main immersive environment the pedagogical agent operates in. Input to appropriateness of IPA and methods in particular environment are sought.	5 (83%)

Some of the experts are already in research and experience of more than one field of the above mentioned multidisciplinary specialties. The selection of these fields is relevant to the qualitative nature of the experiment as with experiences shown. All participants are working at least one year in research in: computer science, cognitive science, e-education, and virtual worlds (see Table 12). The age of the participants are in the range [24,44] with (Mean = 30.3 & SD = 7.2). In terms of gender, 3 (50%) participants are females and 3 (50%) are males.

9.4.5. Procedure

The procedure of the study includes four main tasks or stages performed for each participant as follows:

Stage 1: Filling pre-questionnaire.
Stage 2: Introduction to the system.
Stage 3: Participant performs four IPA supported scenarios (A, B, C, D).
Stage 4: Filling post-questionnaire.

The times needed for performing each stage of the experiment by participants are shown in Table 13 below.

Table 13: Approximate times needed for each stage of the experiment.

Procedure Stage	Times for each stage
1. Pre-questionnaire.	5-10 minutes
2. Introduction to the system.	15-20 minutes
3. Performing four scenarios.	20-30 minutes
4. Post-questionnaire.	20-30 minutes

Given the qualitative and expert nature of the evaluation experiment, and the post-questionnaire questions, there is important time to be considered for filling it by the participants. In addition, discussions and clarifications on the scenarios should be considered, given the study nature and experts knowledge, which can add to the time allocated for the second stage of system introduction. The overall experiment and interview duration was in the range of 1-1.5 hours for each participant.

9.4.6. Results

The pre-questionnaire has three parts (A, B, and C): general information, expectations of the virtual world, and expectations of the IPA. The provided information relevant to participants' background knowledge and area of expertise (Part A) are discussed above (see Section 9.4.4). In part B, all participants indicated to have knowledge and usage of virtual worlds with distribution of 4 (67%) to strongly agree and 2 (33%) agree (see Table 14).

Table 14: Responses summary to pre-questionnaire parts B and C Likert type questions.

	Question	**Response Distribution (No. of participants for each choice)**				
	(1-Strongly agree, 2-Agree, 3-Neutral, 4-Disagree, 5-Strongly Disagree)	(1)	(2)	(3)	(4)	(5)
Q7	**I have already read and used 3D Virtual Worlds a lot.**	4	2	0	0	0
Q11	**11. I have already read and heard a lot about pedagogical agents in a virtual world.**	0	2	3	1	0
Q12	**I have experiences with pedagogical agents in virtual worlds.**	0	1	1	3	1

They answered the open question "*Which application types you find a virtual world useful for*" with different application types of *collaboration, simulation and visualization, language learning, scientific research,* and *games*. Table 15 summarizes participant responses to expectations of virtual worlds (Part B) and pedagogical agents (Part c). In Part B, participants reported the following as their view of advantages of using virtual worlds for e-education: flexible location, visualization in 3D, spatial information, immersion, freedom, collaboration, simulation of history, physics, learning together for physically apart students, and meeting native speakers for language learners. They stated the following as disadvantages of using a virtual world for e-education: The demanding requirements of good Internet connection and graphics, usability issues, being hard for new users, user interface challenges, not always up to date, can seem to be complicated for users with low IT skills. In part C, 2 (33%) of the participants have knowledge about pedagogical agents (Agree), 3 (50%) are neutral, and one participant (17%) doesn't have pedagogical agent knowledge (disagree). One participant (16.7%) agree to have experience with pedagogical agents in virtual worlds, one is neutral (16.7%), 3 (50%) disagree, and one (16.7%) strongly disagree. The expectation on the IPA is to provide guidance and hints, explanations and repetitions, being intuitive, easy to use, and flexible. They see advantages of IPA in the virtual world to help in the learning efforts, help to perform a task, having more knowledge, provide easy instructions, support learning at any place and any time. Some participants expressed their concern of pedagogical agents' disadvantages of distraction of the task, and of possessing less in personality (compared to face-to-face learning).

Table 15: Pre-questionnaire questions relevant to expectations on virtual worlds and pedagogical agents.

Q8. On what application types you find a Virtual World useful for?	**(6 responses)**
▪ Collaboration, meetings, learning, games. ▪ Language learning, simulation, collaboration (conferences). ▪ Simulations.	▪ Collaboration, meeting, language learning. ▪ Learning, collaboration, scientific research. ▪ Collaboration, online meeting, e-learning, visualization, simulation.
Q9. Where do you see advantages using a Virtual World for e-education?	**(6 responses)**
▪ Visualize in 3D, immersion, flexible location. ▪ More immersive, simulation of history/physics etc. ▪ Flexible experiences / "presence"→ higher motivation.	▪ Learners can learn together if physically apart. ▪ I.e. in language learning, one can meet native speakers and experience daily situations. ▪ Collaboration, freedom, spatial information.
Q10. Where do you see disadvantages using a Virtual World for e-education?	**(5 responses)**
▪ Usability issues, graphics. ▪ Can be too complicated for people with low IT skills ▪ Requires good Internet connection, graphic cards etc.	▪ Slightly less "personal", reduced through mimicking. ▪ Hard for new users, graphically not up-to-date user interface.
Q13. What do you expect from a pedagogical agent?	**(4 responses)**
▪ Flexibility, easy to use. ▪ Guidance, Hints.	▪ Intuitive, easy to handle. ▪ Good explanation, possibility to repeat things.
Q14. Where do you see advantages using a pedagogical agent in a virtual world?	**(4 responses)**
▪ More knowledge, easy introductions. ▪ Help to perform a task.	▪ Could help learning effort. ▪ Learning at any place (provided a pc) and any time is possible.
Q15. Where do you see disadvantages using a pedagogical agent?	**(2 responses)**
▪ Can distract from a task.	▪ Less personal, cannot focus on students independently.

Post-questionnaire questions are of three types: multiple choice, Likert type questions (Likert, 1932), and open questions. The purpose of the open questions is to enable expert opinion especially for what they like, don't like or how to provide an enhancement. Likert type questions are dominant in the post-questionnaire (1-Strongly agree, 2-Agree, 3-Neutral, 4-Disagree, 5-Strongly disagree). In order to summarize the Likert questions, three methods are provided. First, the Mean, Standard Deviation (SD), and Mode (most repeating value) are provided. In such a case, the mean can be in the range of 1 to 5.

Assuming that differences between each response are equal in distance, interpreting individual question responses for all participants gives an average of 1.95 to be approximated to indicate "Agree", for example in the Likert scale. Regardless, the Mode calculation is added for convenience (Boone & Boone, 2012). With the assumption of equal distances is not necessarily taken, a second approach of calculation shows the percentages for each individual choice of the Likert values, which has more agreement on its appropriateness for measuring Likert type data (Boone & Boone, 2012). If the result shows 66% of participants chose agree, for example, it indicates that majority of participants *"Agree"* as an answer to the particular question. The third calculation is with either Agree or Disagree, which has also shown appropriateness for ordinal measurements. It gives the percentages of participant who agree to the claim, and percentages of those who disagree. Given that the original question in calculation is Likert scaled, a neutral opinion can be either included or excluded from the population. In this calculation, participants who chose Neutral for the question answer were included in the population but not in Agree or Disagree inclusions. The three objectives for the evaluation discussed in Section 9.4.2 are reported below. Table 16, Table 17, and Table 18 below summarize the results of the Likert type questions in different methods and list the responses to open questions respectively followed by a subsection of discussing the results in relation to the objectives of the study and the hypotheses in further detail.

Table 16: Percentages of participants responding to each of the Likert scale items. (Q2, Q3, and Q21 are none Likert scale based and are handled separately).

	Question	**Response Distribution (No. of participants for each choice)**				
	(1-Strongly agree, 2-Agree, 3-Neutral, 4-Disagree, 5-Strongly Disagree)	(1)	(2)	(3)	(4)	(5)
Q1	**I think using the question answering tool supports the learning activity.**	2	2	1	1	0
Q4	**I felt that IPA gestures are helpful to the learning experience.**	0	2	3	0	1
Q5	**I thought that the voice capability of the pedagogical agent is important.**	2	1	2	1	0
Q6	**I felt that the pedagogical agent has some sort of intelligence.**	0	2	1	2	1
Q7	**I find the method of detecting avatar proximity is good to determine learner intention to run the activity.**	4	2	0	0	0
Q8	**The proximity scenario helps to increase learner attention to the learning activity in the virtual world.**	3	3	0	0	0
Q9	**In tutoring and activity feedback scenarios, the pedagogical agent increases learner attention to the learning task.**	1	4	1	0	0
Q10	**I felt that the IPA encourages me to interact more with it.**	1	3	1	1	0
Q11	**I felt the IPA encourages the learner user to interact more with the environment (learning object).**	1	4	1	0	0
Q12	**I think the tutoring scenario by the IPA contributes positively to the learning experience.**	3	2	0	1	0
Q13	**I think the observing and providing activity feedback scenario is important to the learning experience.**	4	1	1	0	0
Q14	**I think that the IPA support to learning by doing improves the learning experience in this virtual world setting.**	4	1	0	1	0

Q15	**Overall, the IPA contributes tactics that positively support the learning activity in a virtual world.**	2	1	3	0	0
Q16	**I felt that the IPA furnished guided instruction with the learning task, as an approach for enhancing the experience.**	1	3	1	1	0
Q17	**Through the task-completion support, the IPA helps improve learner motivation.**	1	4	1	0	0
Q18	**I learned something new about pedagogical agents.**	2	4	0	0	0
Q19	**I think the IPA is an essential learning component to an immersive learning environment.**	1	2	3	0	0
Q20	**The virtual world can become more interesting to the learner being more inhabited with pedagogical agents.**	3	3	0	0	0

Table 17: Mean, Standard Deviation (SD), and Mode values in a Likert scale as well as the Agree/Disagree percentages for all participants per question. (Q2, Q3, Q21 are none Likert scale based, handled separately).

	Question (1-Strongly agree, 2-Agree, 3-Neutral, 4-Disagree, 5-Disagree)	**Mean**	**SD**	**Mode**	**Distribution**	
					Agree	Disagree
Q1	**I think using the question answering tool supports the learning activity.**	2.17	1.17	1	67%	17%
Q4	**I felt that IPA gestures are helpful to the learning experience.**	3.00	1.10	3	33%	17%
Q5	**I thought that the voice capability of the pedagogical agent is important.**	2.33	1.21	1	50%	17%
Q6	**I felt that the pedagogical agent has some sort of intelligence.**	3.33	1.21	2	33%	50%
Q7	**I find the method of detecting avatar proximity is good to determine learner intention to run the activity.**	1.33	0.52	1	100%	0%
Q8	**The proximity scenario helps to increase learner attention to the learning activity in the virtual world.**	1.50	0.55	2	100%	0%
Q9	**In tutoring and activity feedback scenarios, the pedagogical agent increases learner attention to the learning task.**	2.00	0.63	2	83%	0%
Q10	**I felt that the IPA encourages me to interact more with it.**	2.33	1.03	2	67%	17%
Q11	**I felt the IPA encourages the learner user to interact more with the environment (learning object).**	2.00	0.63	2	83%	0%
Q12	**I think the tutoring scenario by the IPA contributes positively to the learning experience.**	1.83	1.17	1	83%	17%
Q13	**I think the observing and providing activity feedback scenario is important to the learning experience.**	1.50	0.84	1	83%	0%
Q14	**I think that the IPA support to learning by doing improves the learning experience in this virtual world setting.**	1.67	1.21	1	83%	17%
Q15	**Overall, the IPA contributes tactics that positively support the learning activity in a virtual world**	2.17	0.98	3	50%	0%
Q16	**I felt that the IPA furnished guided instruction with the learning task, as an approach for enhancing the experience.**	2.33	1.03	2	67%	17%
Q17	**Through the task-completion support, the IPA helps improve learner motivation.**	2.00	0.63	2	83%	0%
Q18	**I learned something new about pedagogical agents.**	1.67	0.52	2	100%	0%
Q19	**I think the IPA is an essential learning component to an immersive learning environment.**	2.33	0.82	3	50%	0%
Q20	**The virtual world can become more interesting to the learner being more inhabited with pedagogical agents.**	1.50	0.55	2	100%	0%
	Overall Average (with equal weights)	**1.95**	**Mode**	**2**		

Table 18: Responses by the participants to open questions.

Q22. What did you like about the tutoring learning scenario? (5 responses)

- Using voice and demonstration
- Very helpful for the student to learn new content. Also motivational to get immediate feedback.
- Voice
- Tutor (IPA) "weaves" and actively makes contact with you if you can come near, explains concepts that are unclear, helps with simulations
- The presentation of the simulation

Q23. What you did not like about the tutoring learning scenario? (4 responses)

- The relatively small amount of questions the IPA understands, explanations were quiet short and sometimes not really helpful
- Does not provide any new information. The IPA summarized /repeated what was already there
- Agent obscures the dummy panel

Q24. What do you think can be improved about the tutoring learning scenario? (6 responses)

- Providing help when formulating questions
- Make the agent more lifelike, let him point at objects he is explaining
- Maybe more interactivity & reactive behavior.
- The IPA should "tell a story" better than talking/repeating what was already written before
- Expand database, make the IPA understand more questions and use a fixed set of questions the user can choose from.

Q25. What did you like about the activity feedback learning scenario? (6 responses)

- Feedback helps during experiments
- Wrong answers (actions) gets corrected immediately
- Feedback is very important for the learner so that he does not get frustrated when learning new world. → Engaging
- Hints/Visual Hints (yellow marks) where was to focus
- The IPA telling me about right and wrong inputs
- Gestures

Q26. What you did not like about the activity feedback learning scenario? (3 responses)

- Not enough information when something was wrong
- Does not explain anything
- Sometimes I didn't know why the value I entered was wrong

Q27. What do you think can be improved about the activity feedback learning scenario? (4 responses)

- Explanation about the values, when they are wrong
- Better explanation why something is wrong
- Instead of a dialogue, the tutor (IPA) could offer different scenarios to show.
- Maybe some hints (Why & What)
- Not only "correct" vs. "incorrect": explain "what" and "why something is incorrect

Q28. What did you like about the proximity learning scenario? (6 responses)

- The response/greeting of the IPA motivates to learn.
- Agent weaves at you when you are approaching
- Tutor actively asks user if he needs help
- Good
- Very nice approach to make learners curious
- You feel personally involved when a chat starts

Q29. What you did not like about the proximity learning scenario? (2 responses)

- IPA may come to greet you not just stand there
- What if I don't walk there close enough?

Q30. What do you think can be improved about the proximity learning scenario? How can detecting learner intention to learning in Open Wonderland be better captured? (2 responses)

- Let the agent walk around to see if someone has problems in his proximity
- Maybe even more interaction & gestures to raise the attention of the user when he approaches (or voice?)

Q31. What did you like about the conversation scenario with the IPA? (5 responses)

- It is good that somebody can be asked
- Answering questions makes the IPA more lifelike
- Text Chat was easy to use
- "Very helpful to get information. Also fun for the user. Great training possibility"
- Open Response format (not redistricted such as 2D menu)

Q32. What you did not like about the conversation scenario with the IPA? (6 responses)

- It is difficult to formulate questions correctly
- The IPA sometimes gives answers that makes him look like a computer, like long explanations that usually not part of a conversation
- Limited amount of questions the IPA could understand
- A Little bit static
- Does not allow "typos"

Q33. What do you think can be improved about the conversation scenario? (5 responses)

- Giving help with the questions
- Extend database or provide user with fixed set of questions he can choose from
- More intelligence, Some hints as starting points
- Auto completion feature
- Building a conversation is a very hard task. I have never seen it running smoothly. Maybe a simpler approach is more user friendly.

about learning content

Q34. What did you like about IPA gestures? (4 responses)

- Clearly understandable
- They make him more "real"
- They make the avatar (IPA) more "human"-like
- Attracts user, also motivating fun part & playful. Makes IPA more human

Q35. What you did not like about IPA gestures, how it can be improved? (5 responses)

- Gestures maybe overlooked, like handshaking
- Limited set of gestures until now, could be extended
- Even more interactive
- Haven't seen that many
- I did not recognize gestures, gestures maybe to be put in the focus of the view (to give gestures a focus such as HUD)

Q36. How do you think the learning by doing approach suits the pedagogical agent in a virtual world? (6 responses)

- Fits very well, providing guidance, It is not forcing the learner
- Good, if the learner is good at learning by doing
- Very well. Frustrating moments can be avoided by tutoring
- By motivating and by giving hints & how to solve the simulation
- A good approach, Makes you feel more involved and personally supported.
- Good

Q37. What you did not like about the pedagogical agent learning by doing approach in a virtual world? What do you suggest as an alternative approach? And why? (0 responses)

None Provided

Q38. On what application types and subjects you find the IPA in the Virtual World useful for? Why? (5 responses)

- e-learning.
- Physics experiment simulations are a good example, because it is sometimes not clear what the user has to click. Generally speaking an IPA is useful for everything that needs explaining
- Subjects that need instructions and make automatic feedback to activities possible (Such as Simulation, also language learning)
- STEM/Simulation.
- Science experimentation, Medical and architectural

Q39. Overall, what did you like the most? Why? (6 responses)

- Somebody is here who helps and can be asked if needed, but does not force the help
- To be able to add new questions to the IPA through train feature
- The "active" help, not just text explaining what to do
- Activity feedback is very valuable & can help student seeing & learning from their mistakes by immediate feedback
- The general idea
- The Show case of the simulation (the general idea)

Q40. Overall, what did you dislike? Why, and what do you think can provide a remedy or a solution? (5 responses)

- It is too difficult to formulate questions
- That I didn't know what to ask and which keywords would start an experiment simulation. Provide user with sample questions or make agent more "intelligent"
- Even more interactions would be nice
- Auto-completion feature
- Open Dialogues if they are not natural

Q41. What tactics, methods, or functions you want to consider adding to IPA functions? (5 responses)

- "The IPA could give some general hints for learning. E.G. by pressing a ""hint"" button."
- Maybe provide the user with the chance to turn off activity feedback and give feedback at the end when the user fills everything.
- "Intelligent conversation, More interactive tutoring (which allows user to learn already by doing)"
- More gestures
- Putting the avatar geographically closer to the experiment

Q42. Please describe your suggestions for improvement. (3 responses)

- Probably use a different avatar for the IPA, because a human looking one fosters the expectation of a human being.
- "Help" button in Chat box.
- If you get feedback immediately, some users are prone to try all possible values without thinking until IPA says "correct"

9.4.7. Objectives and Hypotheses Testing

Three objectives are indicated in Section 9.4.2: hypotheses evaluation and validation, checking for the tools appropriateness to IPA, and general feedback. These objectives are discussed below.

O1. Hypotheses Testing

Each hypothesis (see Section 9.4.2) is measured by more than one question from the post-questionnaire in addition to input from relevant open questions. While individual questions are measured individually, an overall indicator is given per hypothesis assuming equal weights for the questions giving input on evaluating/validating the overall hypothesis.

H1: The IPA, in the provided setting, provides appropriate mechanisms for increasing learner engagement in the virtual world.

This hypothesis can be measured by Q8, Q9, Q10, and Q11 of the post-questionnaire (see Figure 78) in addition to obtaining input from open question responses.

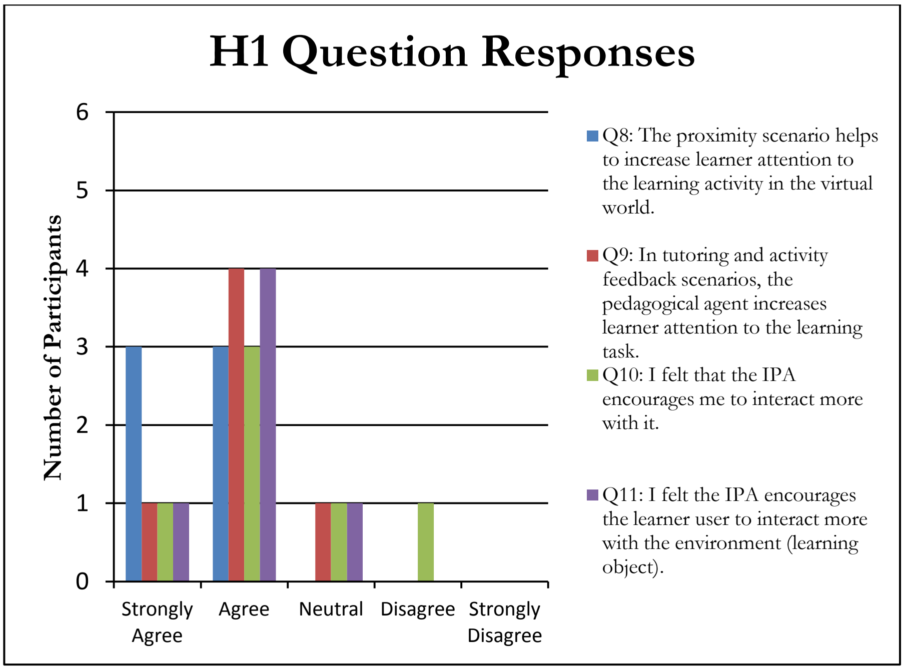

Figure 78: Responses summary for questions relevant to H1 (Q8, Q9, Q10, Q11).

- **Q8. The proximity scenario helps to increase learner attention to the learning activity in the virtual world.** In proximity Scenario (see Table 11), the IPA attempts to motivate, but not enforce, the learner in guiding to come closer and starting the experiment. The result is (M = 1.5, SD = 0.55, Mode = 2). 50% of the participants responded with *Strongly Agree* and 50% responded with *Agree*. In the Agree/Disagree calculation, 100% agree.

- **Q9. In tutoring and activity feedback scenarios, the pedagogical agent increases learner attention to the learning task.** This question checks for the learner attention as component to increase engagement checked in both scenarios (C,D). The result is (M = 2.0, SD = 0.63, Mode = 2). 16.67% of the participants responded with *Strongly Agree*, 66.67% responded with *Agree*, and 16.67% are *Neutral*. In the Agree/Disagree calculation, 83% agree while 17% are neutral.

- **Q10. I felt that the IPA encourages me to interact more with it.** This question checks for the appropriateness of the methods taken to encourage the learner for more interaction with the IPA. The result is (M = 2.33, SD = 1.03, Mode = 2). 16.67% of the participants responded with *Strongly Agree*, 50% responded with *Agree*, 16.67% are *Neutral,* and 16.67% *Disagree*. In the Agree/Disagree calculation, 67% agree, 17% disagree, and the rest are neutral.

- **Q11. I felt the IPA encourages the learner user to interact more with the environment (learning object).** This question checks for the increased interaction with the environment and the simulation. The result is (M = 2.0, SD = 0.63, Mode = 2). 16.67% of the participants responded with *Strongly Agree*, 66.67% responded with *Agree*, and 16.67% are *Neutral*. In the Agree/Disagree calculation, 83% agree while 17% are neutral.

- **Open Questions.** Some of the comments are also relevant to the observation of the immediate feedback to increase motivation and engagement (see Table 18). Comments in regards to Q28, *"You feel personally involved when a chat starts", "Very nice approach to make learners curious*" indicate the importance of the text chat and proximity scenario for increasing learner engagement.

- **Overall.** Participants agree on questions relevant to this hypothesis. A combined score of (M = 1.95, SD = 0.75, Mode = 2) is obtained combining questions Q8-Q11 with equal weights. On the overall 83.5% agree, 4% disagree, and 12.5% neutral. Accordingly, it is approximated to support this hypothesis with Agree.

H2: The IPA furnishes important guided instruction for enhancing the learning experience.

This hypothesis can be measured by Q12, Q13, Q14, and Q16 of the post-questionnaire (see Figure 79) in addition to particular open question responses.

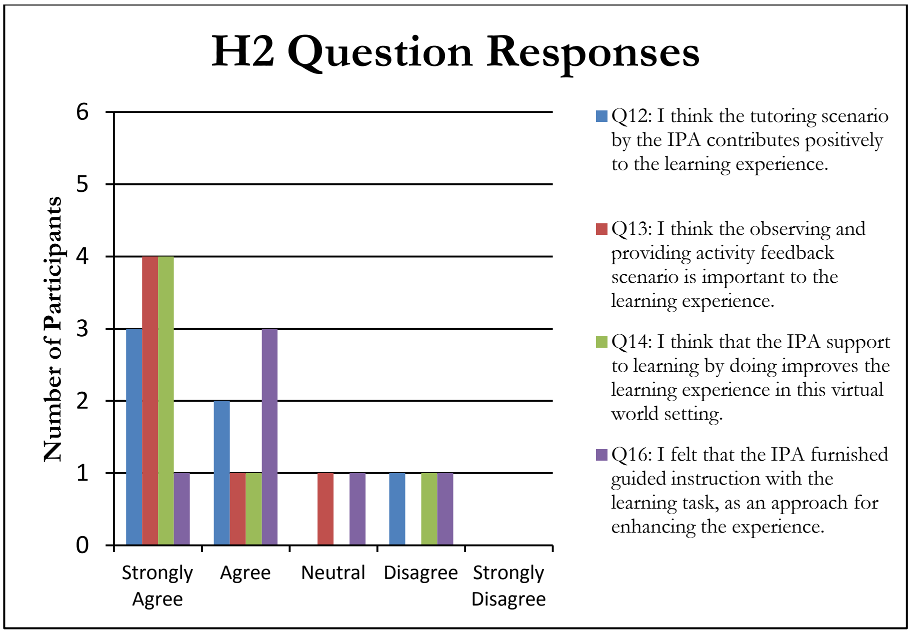

Figure 79: Responses summary for questions relevant to H2 (Q12, Q13, Q14, Q16).

- **Q12. I think the tutoring scenario by the IPA contributes positively to the learning experience.** This question checks whether the tutoring learning scenario (C) adds to enhance the learning experience. The result is (M = 1.83, SD = 1.17, Mode = 1). 50% of the participants responded with *Strongly Agree*, 33.3% responded with *Agree*, and 16.7% responded with *Disagree*. In the Agree/Disagree calculation, 83% agree while 17% disagree.

- **Q13. I think the observing and providing activity feedback scenario is important to the learning experience.** This question measures for the observing and providing feedback in relation contributing positively to the learning experience. The result is (M = 1.5, SD = 0.84, Mode = 1). 66.67% of the participants responded with *Strongly Agree*, 16.67% responded with *Agree*, and 16.67% are *Neutral*. In Agree/Disagree calculation, 83% agree while 17% are neutral.

- **Q14. I think that the IPA support to learning by doing improves the learning experience in this virtual world setting.** This question checks for the enhancing the learning experience through learning by doing. The result is (M = 1.67, SD = 1.21, Mode = 1). 66.67% of the participants responded with *Strongly Agree*, 16.67% responded with *Agree*, and 16.67% responded with *Disagree*. In the Agree/Disagree calculation, 83% agree while 17% disagree.

- **Q16. I felt that the IPA furnished guided instruction with the learning task, as an approach for enhancing the experience.** This question checks to validate if the approach is a guided and an enhancing approach to the learning experience. The result is (M = 2.33, SD = 1.03, Mode = 2). 16.67%

of the participants responded with Strongly Agree, 50% responded with agree, 16.67% are neutral, and 16.67% disagree. In Agree/Disagree calculation, 67% agree, 17% disagree, and the rest are neutral.

- **Open Questions.** Participant comments indicate favor of certain aspects of the learning object pointed by the IPA such as in the comment *"Hints/Visual Hints (yellow marks) where was the focus*", *"The IPA telling me about right and wrong inputs"* in response to Q25 of the open questions (see Table 18) Further detailed explanations was also suggested by several of the participants indicate the importance of this aspect also from their perspective.

- **Overall.** Participants agree on questions relevant to this hypothesis. A combined score of (M = 1.83, SD = 1.05, Mode = 1) is obtained combining questions Q12, Q13, Q14, and Q16 with equal weights. On the overall, 50% strongly agree, 29% agree, 8.3% are neutral, and 12.5% disagree in combining with equal weights. In Agree/Disagree calculation, overall 79% agree. Accordingly, it is approximated to support this hypothesis with Agree.

H3: The IPA contributes positively to learner motivation through guidance and task-completion support.

This hypothesis can be measured by Q8, Q17, and Q20 of the post-questionnaire (see Figure 80) in addition to particular open question responses.

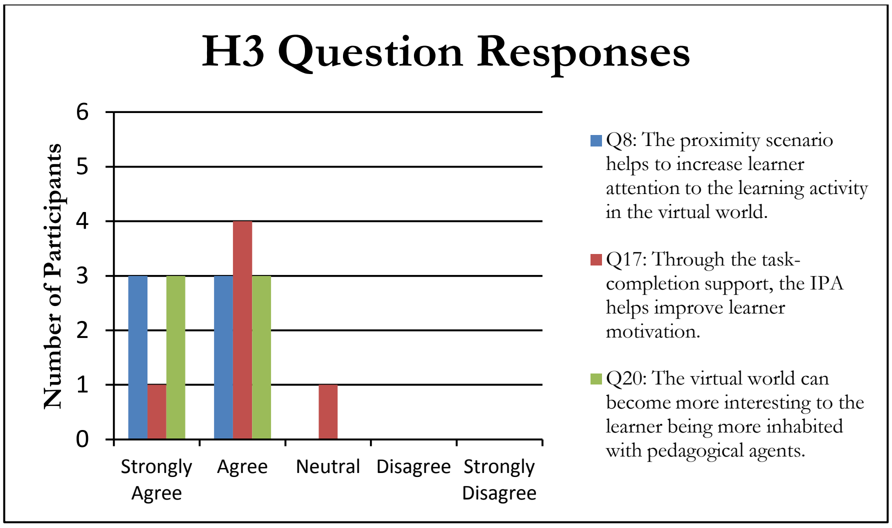

Figure 80: Responses summary for questions relevant to H3 (Q8, Q17, Q20).

- **Q8. The proximity scenario helps to increase learner attention to the learning activity in the virtual world.** In proximity scenario (see Table 11), the IPA attempts to motivate, but not enforce, the learner in guiding to come closer and starting the experiment. The result is (M = 1.5, SD = 0.55, Mode = 2). 50% of the participants responded with *Strongly Agree* and 50% responded with *Agree*. In the Agree/Disagree calculation, 100% agree.

- **Q17. Through the task-completion support, the IPA helps improve learner motivation.** This question checks for the importance of the IPA support to complete the task and its influence on learner motivation. The result is (M = 2.0, SD = 0.63, Mode = 2). 16.67% of the participants responded with *Strongly Agree*, 66.67% responded with *Agree*, and 16.67% are *Neutral*. In the Agree/Disagree calculation, 83% agree while 17% are neutral.

- **Q20. The virtual world can become more interesting to the learner being more inhabited with pedagogical agents.** This question is also relevant to learner motivation in a general support of the IPA influence on the learner perception of inhabitance of the virtual world. The result is (M = 1.5, SD = 0.55, Mode = 2). 50% of the participants responded with *Strongly Agree* and 50% responded with *Agree*. In the Agree/Disagree calculation, 100% agree.

- **Open Questions.** Several participants signified the importance of immediate feedback to learner motivation and preventing frustration. Several other comments indicate influence of IPA gestures, response of the proximity scenario to add to learner motivation (see Table 18, Q28). Another important factor is learning by doing and task completion support influence on the learner motivation (see Table 18, Q36).

- **Overall.** On the overall, participants agree on questions relevant to this hypothesis. A combined score of (M = 1.67, SD = 0.59, Mode = 2) is obtained combining questions Q8, Q17, Q20 with equal weights. On the overall 100% agree if excluding one neutral opinion. Accordingly, it is approximated to support this hypothesis with Agree.

H4: The IPA provides the learner with an appropriate feedback mechanism that is positive to the learning experience.

This hypothesis can be measured by Q9, Q13, and Q16 of the post-questionnaire in addition to particular open question responses as follows:

- **Q9. In tutoring and activity feedback scenarios, the pedagogical agent increases learner attention to the learning task.** This question checks for the importance of the feedback the IPA provides in relation to the learner attention. The result is (M = 2.0, SD = 0.63, Mode = 2). 16.67% of the participants responded with *Strongly Agree*, 66.67% responded with *Agree*, and 16.67% are *Neutral*. In the Agree/Disagree calculation, 83% agree while 17% are neutral.

- **Q13. I think the observing and providing activity feedback scenario is important to the learning experience.** This question measures for the observing and providing feedback in relation contributing positively to the learning experience. The result is (M = 1.5, SD = 0.84, Mode = 1). 66.67% of the participants responded with *Strongly Agree*, 16.67% responded with *Agree*, and 16.67% are *Neutral*. In Agree/Disagree calculation, 83% agree while 17% are neutral.

- **Q16. I felt that the IPA furnished guided instruction with the learning task, as an approach for enhancing the experience.** This question checks to validate if the approach is a guided and an enhancing approach to the learning experience. The result is (M = 2.33, SD = 1.03, Mode = 2). 16.67% of the participants responded with Strongly Agree, 50% responded with Agree, 16.67% are Neutral, and 16.67% disagree. In Agree/Disagree calculation, 67% agree, 17% disagree, and the rest are neutral.

- **Open Questions.** In the questionnaire questions of what you like, don't like or how to enhance, six participants responded with answers supporting strong aspects in the activity feedback learning scenario (see Table 18, Q25). In the what you didn't like types of questions and how to improve, the participants suggested enhancing the initial prototype feature building on it to give more detailed feedback that include what went wrong in an experiment step, and "How" to perform the step correctly. Giving such feedback support the observing scenario (Table 11, Point D) as mechanism to enhancing the learning experience.

- **Overall**. On the overall participants agree on questions relevant to this hypothesis. A combined score of (M = 1.9, SD = 0.87, Mode = 2) is obtained combining questions 9, 13, 16 with equal weights. On the overall, 77.78% agree, 5.56% disagree, and 16.67% are neutral/cannot judge in combining questions with equal weights. Accordingly, it is approximated to support this hypothesis with Agree.

H5: The pedagogical agent positively contributes to the learning experience in the virtual world setting.

This hypothesis can be measured by Q15 of the post-questionnaire in addition to particular open question responses. Given the generic nature of this hypothesis, it can be measured of a general score of the questionnaire (2 or agree result) or combining Q12-Q17.

- **Q15. Overall, the IPA contributes tactics that positively support the learning activity in a virtual world.** This question checks generally for the IPA tactics to support the learning activity. The result is (M = 2.17, SD = 0.98, Mode = 3). 33% of the participants responded with *Strongly Agree*, 17% responded with *Agree*, and 50% are *Neutral*. In the Agree/Disagree calculation, 50% agree while 50% are neutral (considering only those who provided a non neutral response, 100% agree).

- **Q12-Q14 and Q16-Q17.** Those questions (see Table 17) ask for specific tactic influence on the learning experience including tutoring, feedback, guided instruction, and motivation support. Hence they can be considered in relation to this hypothesis.

- **Open Questions.** As shown in Table 18**,** responses to Q22, Q25, Q28, Q31 provide input on the importance of these tactics contributing positively to the learner experience. As a general view of the expert's response to Q21, 100% suggest the learner to use the IPA in a virtual world for learning support. In detail, 83% suggest some of the time while 17% most of the time supporting the general idea of contribution to the learning experience.

- **Overall**. Combining questions Q12-Q17 give the result of (M = 1.91, SD = 0.97, Mode = 1) with equal weights. On the overall 41.67% strongly agree, 33.33% agree, 8.33% disagree, and 16.67% are neutral in combining questions with equal weights. Accordingly, it is approximated to support this hypothesis with Agree.

O2. Selected Tools Appropriateness to the Learning Activity

As for the objective of evaluating appropriateness of tools used, several questions are used in the post-questionnaire (Q1-Q5). Q2 and Q3 results are calculated separately from Likert type questions while questions Q1, Q4, and Q5 are Likert based. For the calculation of the result, a value in the 1 to 5 range can result.

- **Q1. I think using the question answering tool supports the learning activity.** This question checks for the importance of the question answering tool (linked through text chat). The result is (M = 2.17, SD = 1.17, Mode = 1). 33.3% of the participants responded with *Strongly Agree*, 33.3% responded with *Agree*, 16.7% are *Neutral,* and *16.7% disagree.* In the Agree/Disagree calculation, 67% agree while 17% disagree, and the rest are neutral.

- **Q2. Which tool is preferable for activating pedagogical agent functions and obtaining its responses?** There are three possible answers: Text Chat tool, Traditional 2D menu or other. The answers of those questions are 5 opting Option 1 (Text Chat tool) and 1 participant selected *"Other"* (indicating some sort of variation needed). This calculates to 83% of participants view the appropriateness for the *Text Chat tool* for the pedagogical agent.

- **Q3. Having both the text and voice chat options are important to the system user (learner).** There are two possible answers: *"Yes"* or *"No, One is enough"*. Four of the six participants selected *"Yes"* while two selected *"No"*. This calculates to 67% of the participants believe that both the text and voice options are important while only the text chat option is enough for 37% of the participants.

- **Q4. I felt that IPA gestures are helpful to the learning experience. (Gestures).** This question checks for the importance of gestures. The result is (M = 3.0, SD = 1.1, Mode = 3). 33.3% of the participants responded with *Agree*, 50% are *Neutral*, and *16.7% Disagree.* In the Agree/Disagree calculation, 33% agree, 17% disagree, while the rest are neutral. This can indicate the gestures less relative influence or it can be noted the quick occurrence of the gesture (see Table 18, Q34).

- **Q5. I thought that the voice capability of the pedagogical agent is important.** This question checks for the importance of the Text to Speech tool demonstrated in the tutoring scenario. The result is (M = 2.33, SD = 1.21, Mode = 1). 33.3% of the participants responded with *Strongly Agree*, 16.7% responded with *Agree*, 33.3% are *Neutral,* and *16.7% disagree.* In the Agree/Disagree calculation, 50% agree, 17% disagree, and the rest are neutral.

- **Open Questions.** In what you like questions, participants highlighted certain features and recommending certain extensions on available ones. The ability to add more questions, the voice feature, and the text chat have shown importance. Suggested improvement include the IPA to be actively moving to give be more lifelike and adding more gestures. An important enhancement suggests the text chat to add an auto-complete feature. This solves a problem of that the user is unable to determine if there is an answer available to his question or not or thinking of what can be possible questions given the artificial chat bot.

- **Overall.** On the overall, participants support appropriateness of certain tools for the IPA. In particular, they support the question answering tool for conversation, and the text chat tool for activating IPA functions, and relative importance of the voice function. Combining a score for questions Q1-Q5 result in a score of 60% overall agreement, 20% neutral and 20% disagreement.

O3. How the Prototype Supports the IPA concept

Measuring this objective is performed through questions Q19, Q20, and Q21 in addition to open responses and comments of the post questionnaire as follows:

- **Q19. I think the IPA is an essential learning component to an immersive learning environment.** This question attempts to gain a general perception of the participants of the importance of the IPA in relation to immersive learning in general. The result is (M = 2.33, SD = 0.82, Mode = 3).

16.7% of the participants responded with *Strongly Agree,* 33.3% responded with *Agree,* and *50%* are *Neutral.* In the Agree/Disagree calculation, 50% agree and the rest are neutral or to 100% agree excluding neutral responses.

- **Q20. The virtual world can become more interesting to the learner being more inhabited with pedagogical agents.** This question is also relevant to learner motivation in a general support of the IPA influence on the learner perception of inhabitance of the virtual world. The result is (M = 1.5, SD = 0.55, Mode = 2). 50% of the participants responded with *Strongly Agree* and 50% responded with *Agree* (see Figure 81). In the Agree/Disagree calculation, 100% agree.

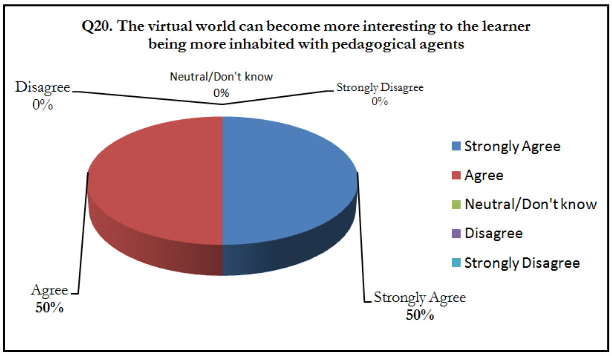

Figure 81: Can the virtual world become more interesting to the learner with utilization of pedagogical agents? Summary of six expert responses.

- **Q21. I view that the virtual world learner user will prefer to learn with a similar pedagogical agent** *(None of the time, Some of the time, Most of the time, or All of the time).* Five of the six participants have chosen *"Some of the time"* option while one have chosen *"Most of the time"* option. This translates to 83% find learners in virtual world prefer to learn with a similar pedagogical agent some of the time but not most or all of it.

Further Study Conclusions and Outlook

Comparing individual response statistics among the questionnaire can also give indication of strong features, and conversely features for improvement. It can be shown that Q7 gives a high statistical indication of the proximity scenario importance to capturing user intention to learn the activity (M = 1.33, SD = 0.52, Mode = 1) with strong agreement (66.7%) and 100% either agree or strongly agree. There is also strong support to the assertion that more IPAs inhabiting a virtual world makes it more interesting to the learner (Q20) having results of (M = 1.5, SD = 0.55, Mode = 1) with 100% agreement. Also it shows the importance of the activity feedback scenario (D, Q13) having results of (M = 1.5, SD = 0.84, Mode = 1) with 83% agreement (rest are neutral). On the other hand, question Q6 of IPA perceived intelligence by the user scores higher disagreement 50%, (M = 3.3, SD = 1.21, Mode = 2) can be attributed to the need for more human like behavior such as being more active as indicated of some experts feedback. However, it is an interesting observation in comparison to the other scores of the learning support the IPA can provide and the checked hypotheses for learning enhancement. It might support the analysis (direction) of the potential importance of learning support strategies and methods of the IPA regardless of having a more imitating human behavior. Inspecting the Open questions part of the questionnaire shows a response suggesting giving the IPA an embodiment that is not necessarily human to isolate the expectations of the human being (see Table 18, Q41), stating *"Probably use a different avatar for the IPA, because a human looking one fosters the expectation of a human being"*[1]. A Similar conclusion can be drawn given the relatively lower importance of gestures in relation to question answering for example.

Through the open questions, participants indicated support to different features. On a top importance is the conversation text chat feature as a main method to trigger IPA functions and to provide conversations and the proximity scenario (Q28). Experts also indicated the value of the learning by doing approach through comments like *"Fits very well, providing guidance, it is not forcing the learner", "Good",* "A *good approach, Makes you feel more involved and personally supported.*" In the question of what did the participant like the most, the answers indicate the general idea of the showcase as of general domination (see Table 18, Q39), availability of a support entity of the IPA, and providing active help and feedback. Also the participants positively responded on various suggested application types the approach can be useful for (Q38) including *physics and science experiments simulation, medical, architectural, STEM, language learning*, and for any user application that requires explanations in a virtual world in general.

While the questionnaire obtained opinions of strong features to keep such as in Q22, Q25, Q28, Q31, and Q34, it also seeks to obtain areas of deficiencies in Q23, Q26, Q29, Q32, Q35, and Q37 and suggestions for improvements in Q24, Q27, Q30, Q33, and Q36 (see Table 18). An important opinion and suggestion repeats in relation to the conversation scenario that is related to the open question and conversation nature with the IPA, is how can the user form the question. While variations are allowed in the AIML approach, still it is relatively not compared to human open conversation ability, especially at a teacher level. Also, to enable wider possibilities of conversation flexibility, further question sets can be loaded to the AIML module. The suggested approach to overcome this obstacle is formed, through discussions to become interesting. It is suggested to use an auto-complete feature of the questions to give hints and support of the

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[1] To inspect the effect of this suggestion, a future study can have a control group with the different embodiment while pursuing similar learning support strategies to compare the results. It also desirable to study how future enhancements, through the intelligent agent paradigm, can influence scoring this factor give taking given that the proximity learning scenario is intelligent agent supported.

possible questions, or alternatively enable the learner user to query what the available questions are. A similar approach is suggested by one of the experts is to provide recommendations of possible actions to do as a cognitive support method to what is already available to learning relevant tasks, and not performed previously. Considering this aspect can be related to the discussion of learning activities design with the pedagogical agent shown in Figure 53 in relation to completing recommended learning tasks. An important observation was about limited possible supporting explanations and for feedback in relation to the tutoring and activity feedback scenarios. More feedback is required including what the sub-task is, how to perform it, as well as expanding the question-answer pool while keeping the approach as an appropriate method.

From the study, it can be concluded that the provided scenarios are key to IPA in virtual worlds highlighting the proximity scenario importance, the text chat feature in particular and the tutoring and feedback scenarios in general with positive contributions to the learning experience. The prototype along with the experts second perspective, give an input to provide future enhancements and additions to pedagogical agents for enhanced learning in immersive virtual learning environments.

9.5. Conclusion

The Chapter discussed learning scenario architecture and implementation of intelligent pedagogical agents (IPAs) in the virtual world of Open Wonderland. The focus is fostering learning with experiments in the environment by means of the IPA. The IPA chats with the learner to answer questions, provides demonstrations, and gives support through gestures. The objective is to autonomously support the learner in the immersive environment. In order to realize those features along with desired reasoning abilities, an NPC module in the Open Wonderland environment has been utilized with adding features in addition to supporting its decision abilities by interfacing with the Jadex intelligent agent platform.

A multi-modal communication module is central to the IPA since IPA is the focal point of interaction with the learner and helps in improving engagement, believability, and more. Question answering through a text chat feature is implemented by adopting the Artificial Intelligent Markup Language (AIML). It also allows training the pedagogical agent to update the question and answer knowledge base. Converting to voice is enabled by a Text-To-Speech (TTS) engine. The IPA aware of knowledge of the learning experiment in addition to be able to communicate with the learner provides an unconventional user interface.

With this implementation tools, several learning scenario patterns are achieved. The avatar learner can ask the pedagogical agent questions in the scope of an experiment, obtains information about the experiment, listens to and watches a demonstration to running an experiment visually. The IPA has the ability to observe learner actions versus expected ones to run the experiment. Upon errors, the IPA provides feedback and corrects errors. In order to capture learning interest and engage the learner, a proximity scenario based on two zones of interest is adopted.

Assessing the approach and the prototype gives input to further improvements and to allow knowing information about their impact.

A discussion of the approach and prototype fitness, what is included, and enhancement possibilities are discussed in the Chapter. Based on the provided learning scenarios in relation to approach and the prototype, it is possible to enrich pedagogical agent functions through a provided an incremental and iterative manner. While the prototype followed the conceptual model, it didn't implement all supporting models. Incorporation of the supporting models building not only leads to new possibilities, but also enables effective learning methods in the immersive environment.

This Chapter includes the analysis of results a qualitative evaluation study experiment. The objective of the evaluation is to obtain opinions and evaluation information with a second perspective on three objectives: evaluating hypotheses relevant to the provided learning scenarios impact on learning in a virtual world, evaluating the appropriateness of the prototype tools, and to check for its importance as an apparatus for providing input to pedagogical agents' research. On the overall, the result indicated agreement on the importance of the specific scenarios with emphasis on the proximity scenario, tutoring, and observation. The evaluation also supports the prototype contribution to increased engagement, guided instruction support, motivation through task completion, and enhancing the learning experience. Furthermore, the study showed preference for the conversation tool and its importance for interaction with a pedagogical agent. The prototype, along with the experts' second perspective also give input to provide future enhancements and additions to pedagogical agents for enhanced learning in immersive virtual learning environments.

10. Conclusions and Outlook

This Chapter aims to provide a summary of experiences and findings of the thesis. It discusses research questions, results, and conclusions based on research findings and studies. It also aims to provide a future outlook for a view and input for future work with intelligent pedagogical agents in immersive virtual learning environments. Thus, this Chapter is organized as follows. Section 10.1 provides a summary of the work done. Section 10.2 gives conclusions and findings. Section 10.3 gives perspectives, future directions, and outlook for pedagogical agents in immersive learning environments.

10.1. Summary

The thesis targeted the problem of adopting intelligent pedagogical agents in immersive learning environments. The thesis presented literature surveys, studies, conceptual model, and proof of concept prototype relevant to intelligent pedagogical agents focusing on 3D immersive virtual learning environments. It studies characteristics and methods of learning in immersive learning environments in general and with pedagogical agents in those environments in particular. Intelligent methods are studied in relation to what can be potential learning support with pedagogical agents. Forming the requirements of pedagogical agents in a virtual world was an objective to enable proceeding with a conceptual model then a proof-of concept prototype. A conceptual model was depicted to illustrate the view of pedagogical agents operation to advance learning in those environments with pedagogical intelligence. The developed prototype of a pedagogical agent in the Open Wonderland virtual world environment was created to be further used to study aspects, interaction patterns with the pedagogical agents and provide potential supporting tools.

The thesis and work include: a) literature surveys on pedagogical agents, immersive learning environments, and supporting intelligent methods for learning, and b) a solution approach comprising requirements definition and analysis, a conceptual approach definition stage, and design and pre-implementation studies, and c) a prototype implementation, assessment, and evaluation.

The survey on relevant educational theories and aspects (see Chapter 2) form necessary knowledge to consider from the learning aspect in general and in virtual learning environments in particular. The survey on pedagogical agents (see Chapter 3) studies and inspects the different aspects of pedagogical agent relevant concepts revealing its importance to engaging learners and sheds light into what IPAs can offer in learning environments. The survey on immersive environments for learning (see Chapter 4) focused on characteristics and fitness for learning support. It strongly suggests learning by doing pedagogical approach that is taken, to suit learning in those environments and gives details of how pedagogical agents fill gaps in learning support demands. Intelligent pedagogical functions can thus have good impact to improve learning in those environments and add to their learning affordances. The survey on the supporting intelligent methods for learning show how different functions can support learning in artificial environments. It highlights different AI methods for learning support that can be useful for intelligent pedagogical agent realization. The intelligent agent AI approach strongly provides different pedagogical support methods realization. Important properties include autonomy, goal directed behavior, reasoning, collaborative support, and more given the nature of the research field.

Identification of the requirements, discussed Chapter 6, is based on the performed literature review results and in the direction of shaping a solution approach. The requirements for the pedagogical agent in relation to the learning environment included the need for embodiment, a practical immersive environment for experimentation, and a pedagogical approach. The pedagogical goals of the pedagogical agent was better formed to add learner engagement and learning support through better interaction and intelligence abilities. The intelligent agent properties add to the autonomy, goal directed behavior and provide cognitive realization support to pedagogical agent intelligence in relation to desired lifelike and pedagogical orientation. In order to get into further details, and combine the various requirement views, an overall conceptual view and a prototype implementation are needed. Given the several unknowns in the environment and with the pedagogical agent, an iterative approach was taken to perform development activities in parallel to conceptualizing the view. The objective was to allow answering the unknowns, use answers to improve the view and the prototype through the iterative stages.

The conceptual model (see Chapter 7) is depicted after visiting relevant conceptual models in literature with detail, and after experimentation. The purpose was to identify possible ways of learning support to provide an integrated and consistent view of learning with pedagogical agents in immersive environments while considering the methods and findings of the literature review. Several supporting models are suggested in the conceptual view to support pedagogical agent functions including learner models, task models, etc. Special importance was given to the learning object at the time when experimenting with the immersive environment implementations of virtual worlds since it provides a fundamental building block to learning activities. Thus it is essential for the pedagogical agent interaction.

The question of how interaction should be shaped with the learner, the pedagogical agent, and the environment is answered in two strands. First, details of interaction among the pedagogical agent, the learner, and the learning object were simulated in an intelligent agent platform. The simulation of this interaction helped to detail the distribution of control and the roles of the learner, the IPA, and the learning object. Second, the simulation and the approach gave input to a prototype implementation that requires IPA realization with multi-modal communication abilities with the learner in a virtual world example implementation.

To realize an IPA in the prototype, and according to the conceptual model and the requirements, the Non-Player Character (NPC) cell is used in Open Wonderland virtual world that is required to be amended with tools and methods, especially for the lifelike nature of the IPA. An important aspect of realization to the prototype is the interaction aspect, either with the learner or with the environment to enable to the IPA to perform tutoring and activity feedback to the learner and to control the virtual world simulation object and increase engagement. The lifelike nature required several functions including the ability for automated question answering, text to speech synthesis, gestures, in addition to integration to an intelligent agent platform. A text chat tool was developed in the Open Wonderland virtual world that both allows the IPA to give answers to questions in different topics and to perform action requests to the IPA, such as instantiating or terminating a learning object cell. Automated answers were possible with the aid of an AIML Bot Chat module. Since the intelligent agent paradigm integration was important, Chapter 8 illustrated a two stages selection process of an agent platform and shows how it contributed to pedagogical goal oriented behavior for the pedagogical agent design. To test the importance of the approach, an interface is achieved and provided in the proximity scenario prototype (see Section 9.2.1). The prototype enabled creating various episodic interactions that support the learning experience while providing new patterns of interaction with the virtual world.

Assessing the approach shows its fitness of extensibility to various settings and further research extensions. Adding further learning scenarios with the pedagogical agents, through an incremental process can contribute to further effective pedagogical agent functions. Assessing the prototype shows important functions that are possible and new ones that can be extended to enable applying new features. To test the impact of the developed scenarios and the elements of the prototype on the learning experience, a qualitative evaluation experiment was conducted by six field experts (see Section 9.4). The study experiment was composed of filling pre-questionnaire, have information about the design elements, experience four learning scenarios with the IPA in the virtual world, and fill a post-questionnaire. The four learning scenarios were an apparatus to evaluate and test hypothesis of the IPA and the prototype impact on learning experience.

10.2. Conclusions

The importance of pedagogical agents is studied in relation to the immersive learning environment that has shown affordances for learning. Pedagogical agents are found to fill a gap of the learning support needed to be available, scalable, and provide new methods of learning that can take ICT advancements into application in the environment by being a central point of interaction between the learner and the immersive environment.

In conceptual model establishment, an immersive and intelligent learning layer is proposed to support the pedagogical agent intelligent learning service provisioning. This learning layer as studied in Chapters 5 and 7 is proposed to be based on an intelligent agent framework and its design perspective impact on the pedagogical agent is provided in Chapter 8. The adoption of an intelligent agent platform paves the road towards intelligent functions including autonomy with goal directed behavior and cooperative behavior among multi-pedagogical agents.

An evaluation provided input on the importance of the IPA to be available in the virtual world for learning support to help to learn. The IPA increases engagement, provides guidance, support motivation and task completion, provide feedback, and other methods that improve the learning experience. The evaluation study experiment tested the following hypotheses:

H1: The IPA provides appropriate mechanisms for increasing learner engagement in the virtual world.

H2: The IPA furnishes important guided instruction for enhancing the learning experience.

H3: The IPA contributes positively to learner motivation through guidance and task-completion support.

H4: The IPA provides the learner with an appropriate feedback mechanism that is positive to the learning experience.

H5: The pedagogical agent positively contributes to the learning experience in the virtual world setting.

The evaluation study supported the above hypotheses and showed that the pedagogical agent, with the tools and methods contributes positively to the learning experience in the virtual world setting. Furthermore, the study supports the premise of the input and potential enhancement of the developed tools to contribute to pedagogical agents' further development and research.

Based on assessment and evaluation of the approach and prototype, it is possible to extend the prototype to enhance available features and to cover more learning scenarios to enhance and enrich the learning experience in the immersive environment.

10.3. Outlook

It is viewed that IPAs are equipped with intelligence abilities with focus of utilization for pedagogical objectives to act as a central point of interaction between the learner and the environment in way that delivers smart services to the learner. The ability to integrate an intelligent agent platform to a virtual world gives the possibility to bring new intelligent functions for learning to pedagogical agents. Once the integration is achieved, the intelligent agent approach, supported by the vast problem domains it can solve, acts as an umbrella to combine different appropriate methods from learning modeling, emotions modeling, and more depending on the problem.

For constructivism in the visual and immersive domain, the IPA can further construct a visual scene that is suitable to pedagogical objectives and learner abilities and needs. Consideration of pedagogical strategies can gain attention and use of the conceptual model and the prototype. For example, extending the learning scenarios to add collaborative learning possibilities can add to learning benefits in immersive environment when the distribution of control among different learners is mediated by the pedagogical agent according to the conceptual model.

An important view is that the IPA acts in a virtual learning environment not only as absorbing services from the environment providing them to the learner, contributing to a broader scope to the environment of other learners and management services. Taking *learning analytics* as an example (Fernández-Gallegoa et al., 2013), pedagogical agents not only contribute, but also reason and present results in the immersive environments to the learning community. In the design of future virtual learning environments, the intelligent pedagogical agent is an important component.

Further learning scenarios can be further added enriching the pedagogical agent offering to provide broader services that can be built based on the provided prototype. Section 9.3 showed an incremental method to enrich pedagogical agent abilities with further learning scenarios through an incremental approach. Also, further features could be enhanced based on the provided evaluation, to enable the learner with the pedagogical agent know in advance what interaction possibilities are available, and possible actions the pedagogical agent supports in the virtual world. Extending the question answering, for example, by auto complete feature and task recommendation can facilitate question answering and possible task approaching. Integrating the pedagogical agent into a broad learning design path can be better considered, especially in practical offerings. Utilization and implementation of supporting models of the IPA conceptual model (see Section 7.3) further enables such disciplined learning design while targeting pedagogical objectives. The pedagogical agent prototype can thus be extended to provide learning support to *physics and science experiments simulation, medical, architectural, STEM, language learning*, and for any user application that requires explanations in a virtual world in general.

With promising trends in employing immersive education for different educational application types, the intelligent pedagogical agent adds to enrich the learning experience.

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