The Non-invasive Personalisation of Educational Video Games

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Declaration

I, the undersigned, declare that this work has not been previously submitted as an exercise for a degree at this or any other University, and that, unless otherwise stated, it is entirely my own work.

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Abstract

Educational video games present a progressive approach to technology enhanced learning that offer intrinsically rewarding experiences, high interactivity, an environment with low-risk of failure, and the freedom and flexibility to illustrate educational concepts. In addition to the benefits of game-based learning the consideration of varying abilities and preferences has long been recognised as a significant factor in learning. In addressing this, the use of personalisation that tailors the learning to the individual, has been extensively used within Intelligent Tutoring Systems, and Adaptive Hypermedia. The incorporation of personalisation into educational video games presents the possibility of an intrinsically motivating learning experience that is also tailored to each individual learner. However, this integration presents considerable design challenges as there emerge potentially conflicting objectives. Most notably the desire to maintain an engaging game can conflict with the desire to adapt the game to benefit learning. In order to preserve the benefits of game-based learning the personalisation must be considerate of the game's storyline, character consistency, and character plausibility. In essence the personalisation must be non-invasive to the gaming experience. This thesis proposes a novel four-stage approach to the non-invasive personalisation of educational video games. This approach not only ensures that are all adaptations are non-invasive to the game being adapted it also achieves this in a flexible and reusable manner. Through loosely coupling the video game with the personalisation that adapts it, the Adaptive Learning In Games through Non-invasion (ALIGN) system facilitates the independent authoring of the game and the personalisation strategies. This separation further enables the reuse of ALIGN across multiple games effectively reducing the development costs of personalised games. To evaluate and validate this research the ALIGN system was trialled with contrasting games both in terms of their game style and learning content. Through the use of authentic user trials the ALIGN system was shown to represent a progression towards the effective reuse of personalisation across adaptive educational games.

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Abbreviations

AE	Adaptive Element
AH	Adaptive Hypermedia
AI	Artificial Intelligence
BN	Bayesian Network
CAI	Computer Aided Instruction
CbKST	Competence-based Knowledge Space Theory
CSCL	Computer Supported Collaborative Learning
HCI	Human Computer Interaction
ITS	Intelligent Tutoring System
JVM	Java Virtual Machine
KST	Knowledge Space Theory
LIP	Learner Information Packaging
LMS	Learning Management System
LO	Learning Object
NPC	Non-Player Character
OWL	Web Ontology Language
PBL	Problem Based Learning
SCORM	Shareable Content Object Reference Model
SD	Standard Deviation
SPARQL	Simple Protocol and RDF (Resource Description Framework) Query Language
VLE	Virtual Learning Environment
W3C	World Wide Web Consortium
XML	Extensible Markup Language

1 Introduction

1.1 Motivation

The rise of the computer games industry began largely in the 1980s with the proliferation of personal computers and the growing popularity of video game consoles. Throughout the 1990s as the video game industry matured there was a growing interest in the use of video games for educational purposes. Although the transition of non-digital educational games into this new medium seemed like a natural progression, the novelty of this new medium resulted in numerous attempts to thrust learning content into games, often with detrimental effects (Kirriemuir & McFarlane, 2004; K. Squire & Jenkins, 2003; Van Eck, 2006). Whereas pedagogical experts and commercial eLearning practitioners were quick to identify the engaging and motivating potential of video games, the subtleties that made the medium so immersive were often overlooked. In the worst examples educational content was effectively interleaved between bouts of unrelated game play. The results were to be ‘Shavian reversals’ (Papert, 1998), essentially learning experiences that were fragmented by irrelevant game play, and a game that was marred by bouts of learning content that were of little significance and slowed progress. Throughout the late 1990s and up to the present day, research into the design of effective educational games has been publicised through the work of authors such as Marc Prensky (Prensky, 2001), James Paul Gee (Gee, 2004), Clark Aldrich (Aldrich, 2004), Katie Salen, and Eric Zimmerman (Salen & Zimmerman, 2003). Of the many factors involved in the design of educational games, these authors have shown that of particular significance are the tight integration of game play and learning content, the maintenance of the fun aspects within the game, and the selection of an appropriate game genre for the learning content.

With the gradual emergence of best practices in educational game design this area of research became subsumed under the broad ranging banner of Serious Games, in essence games whose primary objective is one other than entertainment.

The popularity of game based learning burgeoned in the serious games market, in part due to the mass market appeal of commercial games such as Nintendo Brain Age™[1] and Wii Fit™[2]. In parallel to the emergence of serious games the video games industry was evolving to embrace a new market, that of the so-called casual gamer. The casual games industry delivered accessible, fun, periodic games that have a minimal learning curve and a broad appeal across demographics (Juul, 2009; Kuittinen, Kultima, Niemelä, & Paavilainen, 2007).

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[1] http://www.brainage.com

[2] http://wiifit.com/

[3] http://www.darfurisdying.com/

[4] http://www.globalconflicts.eu/

In response to the growing recognition of the educational potential of video games, the instances of high quality educational games began to rise. Games such as ‘Darfur is Dying’[3], ‘Global Conflicts Palestine’[4], and ‘Innov8’[5] clearly demonstrate the potential of educational games. Overcoming the integration of education into video games can bring educational benefits through the inherent motivation of the game environment, the freedom and flexibility to illustrate educational concepts, a low risk of failure, and the engaging interactive worlds to which 21st century learners are increasingly accustomed. However, learning is a multi-faceted process that is influenced by many factors, and not solely those provided by contemporary educational games. Non-game based eLearning has notably been progressed through interactive tutoring as found in Intelligent Tutoring Systems (ITSs) (Koedinger, Anderson, Hadley, & Mark, 1997; Lesgold, Lajoie, Bunzo, & Eggan, 1992) and through personalising the learning experience as is common within Adaptive Hypermedia (AH) (Brusilovsky, 1996; De Bra & Calvi, 1998; De Bra & Ruiter, 2001). The process of tailoring a learning experience to the learner has been shown to be beneficial by such early proponents as Benjamin Bloom (Bloom, 1984). However, the potential to personalise the learning experience within an educational game has received little attention, yet could provide great benefits. The personalisation of educational games presents a range of challenges due to the game-based nature of the medium, such challenges that are atypical to ITS and AH applications.

The highly-crafted immersive nature of video games is testament to the significance of player experience. Although commercial video games have begun to adopt AI techniques in order to automatically adapt game difficulty, this is only a more modern recognition of varying player ability. The concept of a game having various difficulty levels is a common, almost ubiquitous feature of modern video games. Evidently a player’s experience is highly influenced by the matching of their skills with the difficulty of the game presented. In the case of educational video games the tight integration of the gaming and learning content requires that the difficulty of the learning content must similarly be matched to the skills of the learner in the learning content addressed.

In considering this personalisation challenge, one must acknowledge the best practices in educational game design, i.e. to blend gaming and learning, to maintain fun, and to select an apt game genre. Due to the tight integration of gaming and learning, any change to learning content also affects the game play, additionally all changes must not be detrimental to the fun, and finally all adaptations must be achieved in a manner befitting the game genre. As is common with any

[3] http://www.darfurisdying.com/

[4] http://www.globalconflicts.eu/

[5] http://www-01.ibm.com/software/solutions/soa/innov8/index.html

personalisation system, a model of the learner must be developed constituting their skills, abilities, characteristics, preferences, and context. An architecture to support these requirements would be required to be flexible to the game genre and learning content dealt with, able to model the learner involved without interfering with the game being played, and to deliver personalisation of the learning content that is non-invasive to the game play and the learners understanding of the game world. The notion of non-invasive personalisation considers that changes to the game world made for learning benefit should not adversely affect or disrupt the entertaining value of the game through changing the game storyline or game character consistency.

Whereas examples of tightly integrated adaptive educational games have shown to be effective, e.g. *Tactical Language and Cultural Training Systems (TLCTS)* (Johnson et al., 2004) these games utilise a game-specific architecture and have limited reuse across multiple game genres. In consideration of the rise in popularity of online casual games, the single-use, standalone nature of the adaptation employed by such games appears restrictive. A more generic approach to personalising educational games needs to consider the diversity of game platforms and technologies in use as well as the growing popularity of online and network enabled games. In this thesis we introduce the ALIGN (Adaptive Learning In Games through Non-invasion) architecture and its implementation as a flexible network-enabled, learning personalisation system. As well as being game genre and learning content agnostic, the ALIGN system provides all adaptations in a manner which is non-invasive to the game being adapted. These adaptations are considerate of the game's storyline and what are sensible actions for game characters to perform, so as to ensure the game remains fun and entertaining.

Although a number of examples of effective adaptive educational games exist (Johnson et al., 2004; Mateas & Stern, 2003; Moreno-Ger, Burgos, Sierra, & Manjón, 2007; Zhao, 2002) this thesis approaches the problem of instrumenting a generic architecture that is capable of adapting educational games whilst maintaining a degree of logical separation. Through loosely coupling the educational adaptation and the game logic, the architecture facilitates the independent authoring of game design and pedagogical strategies. Moreover, it enables the potential for the reuse of adaptation strategies. In this thesis the benefits of this architecture are elicited and the advantages of the approach over single-use adaptive educational games are presented.

1.2 Research Question

The research question posed in this thesis is *what are the benefits – with respect to the learning experience, the ease of reuse, and the independent authoring of games and personalisation systems – of a non-invasive approach to loosely coupling video games and adaptive systems?*

This research is focused on the design and development of a system to allow the non-invasive personalisation of learning experiences within educational video games. The non-invasive nature of the personalisations refers to how all adaptations performed are chosen in such a way as to not negatively disrupt the gaming experience of the learner. An invasive adaptation is defined as an adaptation that disrupts the game narrative, character consistency, or character plausibility, and as such negatively impacts the engaging nature of the game. Examples of non-invasive adaptation can be found in (Katsionis & Virvou, 2007; Si, Marsella, & Pynadath, 2005; Spring & Ito, 2007) whereby user modelling techniques and narrative modelling have been used to support non-invasion.

The aim of this system is to continually receive evidence of a learner’s interactions within an educational game, infer and identify the significance of these actions in terms of the learning experience, and consequently adapt the game to improve the learning experience but without sacrificing the fun and engaging nature of the game. A secondary focus of this system is to demonstrate how the flexible nature of the developed system can accommodate varying game styles and educational content due to the loosely coupled service oriented nature of the system.

Of the few examples of adaptive educational games in this emerging research area, virtually all of them tightly couple the game and personalisation system. This is evident in (Johnson et al., 2004; Mateas & Stern, 2003; Zhao, 2002). This tight coupling has effectively limited the reuse of the personalisation components and as such has required each adaptive educational game to custom develop a personalisation system. In consideration that personalisation systems can be similar or even identical across varying learning content, there evidently remains scope for the reuse of personalisation components.

The emergence of adaptive educational games as a research area has drawn significant attention to the conflict that can exist between designing an engaging game and adapting educational game content (Conati & Manske, 2009). Whereas good educational game design can blend the boundaries between learning and gaming, adaptive game design must further maintain the engaging nature of the game whilst also targeting a learning goal. Successful adaptive educational games ensure the tailoring of the learning is not to the detriment of the game, in effect the adaptations performed are non-invasive to the gaming experience. This research explores the potential to non-invasively personalise an educational game in order to create a tailored, inherently motivating learning experience whilst also facilitating the reuse of such personalisation systems across diverse games and learning content.

1.3 Objectives and Goals

In answering the research question posed, the objective of this thesis is to propose and evaluate an architectural approach to delivering non-invasive personalised learning experiences, which is flexible to accommodate diverse game genres and platforms as well as varied learning content. The architecture should be capable of catering for a variety of pedagogical approaches to personalisation, be this through content adaptation, feedback, or by other instructional means. This overarching objective can be further disaggregated into the following set of objectives:

1) To research and identify strategies that can effectively combine educational games and adaptive instructional systems.

2) To develop a flexible game agnostic personalisation software system that can non-invasively personalise the educational experience within an educational video game.

3) To develop contrasting educational video games that can be integrated with the developed personalisation system in order to enable a real world evaluation of the software system.

4) To evaluate the ability of the developed system to provide non-invasive personalisation that benefits the learning experience, facilitates the independent authoring of games and personalisation systems, and eases the reuse of these systems across contrasting educational games.

1.4 Research Contribution

This thesis proposes a novel four stage approach for the non-invasive personalisation of educational video games. Within this approach each stage is concerned with a different aspect of providing non-invasive personalisation for educational games. One of the key contributions arising from this approach is the identification of the requisite steps to enable non-invasive personalisation. These steps consist of (i) the use of rules and statistical modelling through Competence based Knowledge Space Theory (Heller, Steiner, Hockemeyer, & Albert, 2006) and linear modelling that enable non-invasive user modelling, (ii) the accumulation of game context and the use of fact pruning rules to make informed adaptations, (iii) the constraint of the adaptations performed, based on annotated adaptations and reusable constraint rules, to minimize their invasiveness, and (iv) the simplified rule based selection of personalisations. The design of these steps is strongly influenced by the desirability of separating game logic and educational personalisation to enable reuse and independent authoring. The feasibility of performing this separation and still enabling effective personalisation is another of the key contributions of this thesis. This separation allows not only for the independent authoring of the diverse areas of game design and personalisation strategies, it also allows for the reuse of educational personalisation systems across multiple games with the benefit of both increased usage of personalisation techniques and reduced development overhead.

The following are the publications associated with the research contribution:

- **Peirce, N**., & Wade, V. (2010). Personalised Learning for Casual Games : The ' Language Trap ' Online Language Learning Game. *European Conference on Game Based Learning (ECGBL 2010)*. Copenhagen, Denmark.
    - This paper was additionally one of 11 papers selected for publication in: *Leading Issues in Games-Based Learning Research*, edited by Thomas Connolly, 159-177. Reading, UK: Academic Publishing International Ltd, 2011.

- Conlan, O., Hampson, C., **Peirce, N.**, & Kickmeier-Rust, M. (2009). Realtime Knowledge Space Skill Assessment for Personalized Digital Educational Games. *2009 Ninth IEEE International Conference on Advanced Learning Technologies* (pp. 538–542). Riga, Latvia: IEEE. doi:10.1109/ICALT.2009.150

- **Peirce, N.,** Conlan, O., & Wade, V. (2008). Adaptive Educational Games: Providing Non-invasive Personalised Learning Experiences. *Digital Games and Intelligent Toys Based Education, 2008 Second IEEE International Conference on* (pp. 28–35). doi:10.1109/DIGITEL.2008.30
  [Awarded Best Full Paper]

- Albert, D., Hockemeyer, C., Kickmeier-Rust, M. D., **Peirce, N.,** & Conlan, O. (2007). Microadaptivity within Complex Learning Situations – a Personalized Approach based on Competence Structures and Problem Spaces. *Proceedings of the International Conference on Computers in Education (ICCE 2007).*

- Kickmeier-Rust, M., **Peirce, N.**, Conlan, O., Schwarz, D., Verpoorten, D., & Albert, D. (2007). Immersive Digital Games: The Interfaces for Next-Generation E-Learning? *Universal Access in Human-Computer Interaction. Applications and Services* (Vol. 4556, pp. 647–656). Springer Berlin / Heidelberg. doi:10.1007/978-3-540-73283-9_71

1.5 Research Methodology

This research uses an Action Research (Lewin, 1946; Susman & Evered, 1978) methodology as both a structure for the research undertaken and for the structure of this thesis. The Action Research methodology is a progressive approach to research that takes place in real world situations and aims to solve real problems. It is characterised by a continuous cyclical process of Analysis, Planning, Action, Observation, and Reflection (Dickens & Watkins, 1999) as is shown in Figure 1 below. The cyclical nature of this approach dictates that the outcomes of experiments are reflected upon and directly influence subsequent experiments.

Figure 1. Spiral Process of Action Research

In line with this methodology the structure of this thesis reflects the progressive series of experiments undertaken. The design of each experiment represents the Analysis and Planning phases of the process, the technical implementation and user trials represent the Action phase, and the final Observation and Reflection phases being addressed in the experiments' evaluations and in the final conclusions. The structure of this thesis corresponds to the research undertaken as it progressed through two Action Research cycles beginning with a state of the art review and progressing through two experiments and ending with the concluding chapter of this thesis. A more detailed introduction to Action Research and its application in this research is given in section 4.2.

1.6 Thesis Overview

This thesis begins with an analysis of current research in personalised educational video games. As an emerging research area it bridges both research in educational video games, and adaptive instructional systems. For this reason the state of the art review is accordingly split across the second and third chapters of this thesis. The second chapter examines issues in the creation of educational video games from the perspectives of the pedagogical approaches employed, the design theories applied, the challenges of integrating learning content, and nature of learners currently being targeted by game based learning.

The third chapter focuses on adaptive instructional systems and charts the progression of research in this area. Through analysing the origins of such systems in Intelligent Tutoring Systems (ITSs), the key features of learner modelling and personalisation are examined. The progression of this research area is continued through advances in Adaptive Hypermedia and into the emerging research area of adaptive educational games. This chapter concludes with a review of prominent adaptive educational games and comparison of their diverse feature sets is presented.

The fourth chapter represents the initial planning phase and introduces the novel four-stage approach to non-invasive personalisation proposed by this thesis. The implementation of this approach, in the form of the Adaptive Learning In Games through Non-Invasion (ALIGN) system, is then presented. The chapter then continues into the first action phase with the technical implementation of ALIGN in the context of the first experiment using the ELEKTRA game. The design of the experiment with the ELEKTRA game addresses the initial objective of evaluating the feasibility of separating the ALIGN system from an educational game whilst still enabling the varied personalisation of the game.

The fifth chapter of this thesis examines and evaluates the experiment undertaken with the ELEKTRA game. The objectives of this experiment are to examine the feasibility of separating ALIGN from the ELEKTRA game, determine the variety of personalisations possible, and to determine the effectiveness of the personalisations performed. This chapter represents the action, observation and reflection phases of the first cycle with the reflection focussing on the outcomes of the experiment and on the refinements necessary to progress the ALIGN system. This chapter marks the end of the first action research cycle with the outcomes of the experiment directly influencing the subsequent cycle.

The sixth chapter builds upon the ELEKTRA experiment to investigate the potential benefit of the non-invasive personalisation, and the reusability of the ALIGN system across diverse games. This chapter reflects the beginning of the second action research cycle and consists of analysis and planning phases beginning with the refinement of the ALIGN system following the ELEKTRA experiment, and its integration with a second diverse game called Language Trap. The design of the Language Trap game is detailed with its differing storyline, style, and learning content compared to ELEKTRA.

The seventh and penultimate chapter progresses the second action research cycle and consists of the action, and observation phases surrounding the experiment conducted with the Language Trap game. The details of the experimental setup are presented, and in line with the action research methodology consists of a real world evaluation with appropriate learners. The results of the experiment are presented and a reflection of their significance in terms of this thesis's objectives is given. This chapter concludes with an evaluation of how ALIGN facilitates reuse of personalisation across the contrasting ELEKTRA and Language Trap games.

The eighth chapter concludes the second action research cycle and this thesis with a final reflection and a summary of how this thesis has addressed the research question posed, and the derived objectives. The significant contributions to the state of the art made by this research are highlighted, and a short discussion on future directions for this research concludes this thesis.

2 Analysis - Educational Games

"Let my playing be my learning, and let my learning be my playing"

- Johan Huiziunga, Homo Ludens

2.1 Introduction

The development of educational video games began in the 1960s and slowly developed in parallel with the growth of the entertainment video game industry. Although examples of educational video games were to be found throughout the 1970s and 80s (Malone & Lepper, 1987), it wasn't until the massive growth of personal computers and game consoles in the 1990s that research into educational computer games became established. Whilst instructional designers were quick to identify the educational potential of this new medium, little research was established into the development of effective educational games. As a result the emergence of so called 'edutainment' titles, and the Shavian reversals (Papert, 1998) (see section 2.5.1) they are commonly associated with, hindered the acceptance of video games as legitimate learning tools.

The continued growth of the video games industry from 2000 onwards and the growing research area of Technology Enhanced Learning stimulated research into the design of effective educational games. The research of Marc Prensky (Prensky, 2001) on matching game genres and learning content as well as the emerging Digital Natives, James Paul Gee (Gee, 2004) on the learning principles that games incorporate, Clark Aldrich (Aldrich, 2004) on the design of educational games and simulations, Richard Van Eck (Van Eck, 2006) on the effectiveness, sources, and institutional usage of games, Katie Salen, and Eric Zimmerman (Salen & Zimmerman, 2003) on the design of meaningful play in games, has aided in highlighting the key constituents of educational games and presented a progression away from so called 'edutainment' titles. In this movement away from edutainment, the issue of effective integration of learning content and gaming proved to be of paramount importance.

This chapter will examine the existing approaches to education within video games, the effective design of educational games, the challenges surrounding integrating learning content, and the aptness of educational games for an increasingly technically aware learner. This chapter will conclude with a summary of the state of educational games research and a discussion on the future of the medium for education.

2.2 Video Games as Learning Environments

The motivation to use video games as learning environments is both a natural elaboration of play as a learning method and also a realisation of the unique properties video games possess for education. One only has to investigate the evolution of human culture to identify the significance of play as a learning mechanism. This was a key feature in the seminal book *Homo Ludens* (Huizinga, 1949) that extols the significance of play in shaping our culture and progressing our shared knowledge. Through study of the use of word play and riddles the significance of play in learning and conveying knowledge has been observed.

As play is an instinctive learning activity pursued by humans (and indeed most mammals), it is an activity that comes naturally and involves experimentation, exploration, and self-direction. To observe the instinctive human tendency to play, and to learn through play, one must only observe the inherent progress made by infants and young children, a phenomenon supported in the Montessori method (Montessori, 1912). Although playfulness is most often associated with children, it is practiced amongst all age groups, albeit more often in the form of games. This progression from imaginative playfulness to games with explicit rules has been highlighted by (Vygotsky, 1978).

> *"The development from games with an overt imaginary situation and covert rules to games with overt rules and a covert imaginary situation outlines the evolution of children's play."* (Vygotsky, 1978)

Within the realm of play and playful activities as explored by (Salen & Zimmerman, 2003), games emerge as play governed by rules, directed by goals, allowing self-governance, and supporting immersion. Whereas there exist many definitions of what a game is (Akilli, 2007; Caillois, 2001; Prensky, 2001; Suits, 1978) the following definition covers the key constituents of conflict, rules, and goals.

> *"A game is a system in which players engage in an artificial conflict, defined by rules, that results in a quantifiable outcome."* (Salen & Zimmerman, 2003)

To begin to look at the naturalness of games as learning environments one only has to consider their goal oriented nature. As a goal directed pursuit they inherently involve problem solving, and consequently planning, theorising, and experimenting. As immersive worlds where a learner can assume an alternate identity, games can support "exploration, hypothesis testing, risk taking, persistence past failure, and 'seeking' mistakes as new opportunities for progress and learning."(Gee, 2004).

Whereas games are not the only form of goal directed learning, they are actively pursued activities for their entertaining nature. One of the key benefits of using games as a learning environment is that they are inherently motivating. Further to this they are regarded as providing an autotelic[6]

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[6]Autotelic, *a.*, having or being an end or purpose in itself. Source: Oxford English Dictionary

experience whereby they are sought out for their inherently rewarding nature (Salen & Zimmerman, 2003).

2.2.1 Video Games

Video games are the natural progression of games onto computers and digital platforms. The term ‘video game’ refers to games played on digital platforms featuring a visual display. This broad category of games includes, but is not limited to, games played on arcade machines, games consoles, personal computers, mobile phones, and handheld digital devices. Within this thesis the term video game will be used in preference to computer game. This is in consideration of the premise that computer games (played on a personal computer) are a subset of video games and have particular characteristics that limit their usage and variety.

The origination of video games can be traced back to some of the first computers featuring a visual display unit (VDU). One of the more notable first computer games was Spacewar![7] which ran on a DEC PDP-1[8] in 1962. However, due to the cost ($120,000 in 1960), size (8ft. x 2ft. x 6ft.), and weight (1,200lb) of the computer it would be many years until computer games achieved mainstream availability. The emergence of home computers in the early 1980s such as the ZX Spectrum and the Commodore 64, and game consoles such as the Atari 2600, heralded the start of the home video game market.

The growth in popularity of video games in the 1980s gained significant interest from instructional designers and pedagogues for the highly engaging and motivating traits of this new medium. In parallel with the growth of the entertainment video game industry, a significant body of research was emerging around the educational benefits of educational video games.

The work of (Malone & Lepper, 1987) was pioneering in identifying the educational benefits of motivational video games. In drawing the distinction between how video games present intrinsic motivation over extrinsic motivation, the potential benefits of educational video games became apparent. Through the use of appropriate challenge, curiosity, control, and fantasy, to foster intrinsic motivation, both higher sustained interest and improved learning were observed in comparison to extrinsic motivation alone. The ability for video games to present worlds with suitably difficult tasks, interesting curios, self-governance, and visually stimulating experiences evidently aids their educational potential.

In line with the growing availability of computers and the ever increasing quality of video games, more in depth research began to elicit the many educational factors inherent to games. Drawing on

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[7] Details available at: http://pdp-1.computerhistory.org/pdp-1/?f=theme&s=4&ss=3
[8] Details available at: http://pdp-1.computerhistory.org/pdp-1/index.php?f=theme&s=2&ss=3

the fields of psychology and anthropology, the theoretical frameworks of constructivism as proposed by Jean Piaget, and flow theory (Csikszentmihalyi, 1990) began to emerge as exemplary methods of understanding learning in video games (Rieber, 1996).

2.3 The Pedagogy of Educational Video Games

Play is a natural phenomenon and arguably the original form of learning (Huizinga, 1949). However, playfulness as an unguided pursuit is often considered an activity of children and so begins to wane in more structured formal education and entertainment.

Video games have evidential benefits as learning environments; however their characteristics of inherent motivation, low risk of failure, and rich visual environments do not impose a pedagogy per se, as to how they are used. As flexible software and hardware systems they can accommodate varying learning theories and approaches. The most common pedagogical approaches involve experiential learning, discovery learning, situated cognition, and constructivist learning (Kebritchi & Hirumi, 2008), a position also emphasised by (Rieber, 1996).

2.3.1 The Constructivist Perspective

As an over arching perspective on learning in video games, constructivism is one of the predominant means used to both understand and design for learning in video games. The theoretical basis for constructivism proposes that learners construct new knowledge through their experiences, and incorporate this new knowledge into a pre-existing framework. Applied to educational video games there are evident synergies with the design process of video games (Dickey, 2006a) whereby conveying meaning through game experiences is the key aim. The highly crafted experiences created by game designers lend themselves to immerse and engage a learner, to the extent where they are engaging in meaningful play (Salen & Zimmerman, 2003).

The work of Jean Piaget has arguably had the greatest impact on constructivist learning theories. Although Piaget's theory of constructivism is not a learning theory per se, his fundamental ideas have been adopted and refined into concrete theories such as experiential learning, problem-based learning, situated cognition, and constructionism. As tenets of constructivism, emphasis is placed on learning being an active process, a process involving the creation of one's own schemata, an inherently desirable subjective activity, and a process that may involve a teacher but only in a facilitatory role.

The work of Lev Vygotsky drew on many of the principles of constructivism but placed greater emphasis on the impact of society, culture, and the role of the teacher. Vygotsky was also significant in identifying the importance of play in childhood development (Vygotsky, 1978). Whereas Vygotsky identified the developmental benefits of childhood play, he also noted how it is a natural progression for children to move away from imaginary play towards the play of games with explicit rules. The intricate and complex relationship between learning and development is consistently emphasised. Of particular importance to this relationship is the social context in which learning occurs. Following from this, the theory of the Zone of Proximal Development (ZPD) (Vygotsky, 1978) emphasises that an individual has two developmental levels, firstly their actual independent developmental level, as assessed by problem solving tests, and the developmental level they can potentially reach through adult guidance or in collaboration with capable peers. The ZPD is the area between the actual and potential developmental levels, and is an indication of the potential developmental effect of social guidance and collaboration. The significance of this to educational games is that through play, and consequently through games, the ZPD is created. In effect it is the social dimension of games, either virtual or physical, that can provide significant developmental benefits.

> *"In play a child always behaves beyond his average age, above his daily behaviour; in play it is as though he were a head taller than himself. As in the focus of a magnifying glass, play contains all the developmental tendencies in a condensed form and is itself a major source of development."* (Vygotsky, 1978)

The strong emphasis placed on the importance of the instructor in learning differentiates Vygotsky's work from more classical constructivism. However, Vygotsky was clear to emphasise that the activity of the learner was central to education, and that the social interaction with other learners was also significant. From this, Vygotsky's view of the teacher was more interventionist as opposed to the purely enabling role advocated by Piaget.

2.3.2 Experiential Learning

Linked closely with constructivism is the pedagogy of experiential learning that attests that learning occurs through exploring and experiencing authentic situations and discovering a personal meaning from the experience.

> *"education is not an affair of 'telling' and being told, but an active constructive process"* (Dewey, 1916)

Although this is a more general constructivist viewpoint, the work of John Dewey, as well as Jean Piaget, strongly influenced the formalisation of experiential learning by (Kolb, 1984). The four stage experiential learning cycle devised by Kolb comprises of the following:

1. Concrete Experience (Experiencing)
2. Reflective Observation (Processing)
3. Abstract Conceptualization (Generalising)

4. Active Experimentation (Applying)

As a theory to describe learning in video games, experiential learning is well suited to the rich multi-modal worlds that games can provide. The highly interactive nature of video games is a key factor as to why constructivist and experiential learning theories are so readily applied to game based learning. In terms of providing an engaging experience video games are unique in their ability to provide timely feedback, a low-risk of failure, and alternative perspectives of problems encountered. Whilst the activities pursued during game play can take place in any world conceived by the game designer, the abstract conceptualisation and reflection that accompany this are key to Kolb's four stage cycle. The ability of video games to accommodate these processes is crucial in realising effective experiential learning. The realisation of this may involve other non-game based activities as would be encountered in a conventional curriculum, and can cast video games as complementary to existing curricula.

> *"Learning occurs not just in the game play but as players move back and forth between games and other kinds of activities;"* (K. Squire & Jenkins, 2003)

2.3.3 Problem Based Learning & Situated Cognition

The act of playing a game is an inherent problem solving activity due to the goal directed nature and the artificial conflicts that are encountered. As such, video games are not created to explicitly promote problem based learning (PBL), as much as it is the nature of the game that implies it. In line with the constructivist perspective of learning, problem based learning emphasises that understanding emerges from interactions within environments, and it is cognitive conflict that acts as both the stimulant and the determinant of what is learned (Savery & Duffy, 1995).

A distinction that separates PBL from other constructivist theories is the emphasis on how knowledge evolves through social negotiation. In essence it is through the challenges and tests provided through group interaction that understandings are enriched and expanded. The realisation of this social dimension is catered for in educational video games through either multiplayer games or through socially interactive Non-Playing Characters (NPCs). Whereas the physical group-based origins of PBL can have practical limitations logistically, within educational games PBL can be achieved with potentially remote learners and conceivably with game driven facilitators.

From an instructional perspective PBL outlines a number of principles that can be employed in the design of educational games (Savery & Duffy, 1995). Many of these principles are widely regarded as beneficial to educational games design such as the authenticity of the task, relevance of the learning environment to the end use environment, encouragement of experimentation, the support of reflection on the learning content and process, and encouraged ownership of the learning task.

Although these principles can be useful guides in the design of educational games it must be considered that not all game genres can suitably integrate these principles. In particular it is claimed that PBL is most suited to adventure and role-playing style games (Dickey, 2006a; Prensky, 2001; Van Eck, 2007). The issue of matching learning theories to game genres is a considerable factor in effective game design and is an issue addressed in section 2.4 on educational game design.

Whereas PBL proposes the instructional principles of task authenticity and a relevant learning environment, the theory of situated cognition (J. S. Brown, Collins, & Duguid, 1989) holds these principles at its core. In essence, situated cognition emphasises the importance of context, and how knowledge is acquired through authentic activities in specific contexts. Further to this, the knowledge that can be learned is determined by the context, and so will vary with varying contexts. In fact emphasis is placed on varying contexts to improve the understanding of a piece of knowledge.

Although the emphasis on authentic activities would seem to be at odds with learning within video games, the definition of authentic employed, that the activities be "coherent, meaningful, and purposeful" (J. S. Brown et al., 1989) is in line with the design of educational video games. Through the use of interaction design, the objective of meaningful play, and the goal directed nature of games, video games can be designed to effectively cater for situated cognition (Kiili & Lainema, 2008; Van Eck, 2007). However, in a similar manner to PBL based games, certain game genres are more suited to supporting situated cognition such as simulation based, adventure, and role-playing games.

2.3.4 Further Learning Theories

The varied nature of educational video games lend themselves to accommodating a broad variety of learning theories. Amongst the further constructivist theories employed in educational games are 'learning by doing' or active learning (Gee, 2004), discovery learning (Leutner, 1993), and enquiry-based learning (Cher P. Lim, Nonis, & Hedberg, 2006). As a derivative of constructivism, the theory of constructionism proposes that learning occurs through the process of creating an entity (Papert, 1991). Applying this theory to educational video games, learning can be seen to occur either through engaging students in the design of educational games (Papert, 1998; Prensky, 2008) or through creating entities within game worlds such as game characters (Kelly et al., 2007). In Seymour Papert's book *Mindstorms* (Papert, 1980), the construction of virtual entities in the form of LOGO programs are used as an example of constructionism in practice.

"…the computer allows, or obliges, the child to externalize intuitive expectations. When the intuition is translated into a program it becomes more obtrusive and more accessible to reflection." (Papert, 1980)

In essence microworlds or game-based environments facilitate exploration and experimentation in a low-risk environment, whereby alternative theories and approaches can be triaged in pursuit of an optimal solution.

The inherent visual nature, and highly crafted experiences commonly found in video games has resulted in largely constructivist theories being applied to educational video games (Kebritchi & Hirumi, 2008). However, there are examples of behaviourist learning theories being employed where the games form part of an Intelligent Tutoring System (ITS) (Katsionis & Virvou, 2004; Virvou, Katsionis, & Manos, 2005). The premise of behaviourist learning is that learners are entirely 'stimulus response' systems that have no free-will. It is assumed that learning is a process of habit forming where through repeatedly presenting the same set of stimuli the desired response can be attained. In line with this, the use of rote learning is a common feature of behaviourist learning. Under this theory as learning is formed by repeated stimuli the learning content is often linear in nature, a condition this is often at odds with the non-linear nature of games. However, similarities do exist in considering the emphasis on self-pacing and individualised learning advocated by this theory. Despite the criticisms of behaviourist education (Sutherland, 1992), the tailored learning experiences advocated by behaviourism remain attractive considering the potential benefits of personalisation in both eLearning and video games.

Within educational video game research, there is a propensity for games to be developed that either do not use an explicit learning theory or in the least do no declare it. The survey by (Kebritchi & Hirumi, 2008) highlighted this issue whereby the majority of the games surveyed lacked explicit pedagogical foundations. Although this would seem to be alarming in consideration that educational video games are still vying for acceptance, it is a consequence of the field's origins in video games. The act of playing a conventional entertainment video game is in itself an inherent learning experience. Through aspects of mastering controls, understanding game mechanics, and discovering rules, to investigating, exploring, and engaging in a game's narrative, every game involves a certain degree of learning. In consideration of how games are designed from the perspective of the experience obtained as opposed to the learning outcome desired, it becomes apparent that educational video games are being designed from two separate perspectives, that of the educator, and of the game designer.

The concept of designing educational games from the perspective of a game designer is supported as it ensures that an educational game is a game first and a learning tool second (Prensky, 2001;

Van Eck, 2007). Accompanying this game design perspective, the areas of motivation and feedback are emphasised as contributing to effective learning. Although the benefits of motivation in games has been identified by (Malone & Lepper, 1987) there remains little consensus over mechanisms to achieve it. Whereas Malone & Lepper identified intrinsic motivations as coming from challenge, curiosity, control and fantasy, the additional factors of rules, sensory stimuli, and mystery were added by (Garris, Ahlers, & Driskell, 2002). The importance of feedback in stimulating motivation was further identified by (Rieber, 1996), as were choice, collaboration, and narrative by (Dickey, 2006a). Despite the disparate factors associated with stimulating motivation in games it remains a common priority in the design of educational games. In particular, learning benefits have been associated with improving motivation for weaker or low-interest learners (Virvou et al., 2005).

Although considering motivation as the key benefit of games is disputed by some researchers (Whitton, 2007) it is none the less an important benefit of game based learning, and particularly relevant considering the decline of intrinsic motivation within formal education that has been observed by (Lepper, Corpus, & Iyengar, 2005).

2.3.5 Learning Outcomes

The learning outcomes from educational video games have conventionally surrounded knowledge gain and skill acquisition. However, the variety of game genres and learning theories that are used in educational video games offers a broad scope for learning outcomes beyond knowledge and skill acquisition. An analysis of the learning outcomes from educational games and simulations by (Garris et al., 2002) identified outcomes that were skill-based, cognitive, and affective as is shown below in Table 1. These outcomes are evidently influenced by the three forms of learning outcomes – cognitive, affective and motor-skills - described in Blooms taxonomy (Bloom & Masia, 1956).

Table 1. Learning Outcomes from Educational Video Games, adapted from (Garris et al., 2002)

		Cognitive			
	Skill-Based	*Declarative*	*Procedural*	*Strategic*	***Affective***
Descriptors	Performance of technical or motor skills	Knowledge of the facts and data required for task performance	Knowledge about how to perform a task	Ability to apply rules and strategies to general, distal, or novel cases	Beliefs or attitudes regarding an object or activity

In addition to declarative, procedural, and strategic knowledge being learning outcomes of educational games, meta-cognitive knowledge was further identified by (Dickey, 2006a) as a potential outcome. In particular games can encourage the reflection on past game tasks in order to improve upon the approaches taken to complete future tasks.

The use of video games to foster non-knowledge based outcomes is rarely triumphed due largely to pressures to conform to knowledge assessed curricula. However, it has been proposed that video games can affect "locus of control (the perception that outcomes are a result of one's own control), self-efficacy (perceptions of competence and mastery), and valence (the value placed on the activity)." (Garris et al., 2002). Further to this, positive effects on self-esteem have been observed by (Miller & Robertson, 2010). In consideration that motivation, attitude towards the learning content, ownership of the learning experience, and perspectives over the learning tasks are all relevant to an effective learning experience to solely focus on skills and knowledge acquisition would seem naïve. Although games can present a motivating experience whilst they are being played, the resultant impact of the experience on subsequent classroom learning may be considerable and is an aspect of educational games seldom studied (Cordova & Lepper, 1996).

The unique perspectives on learning content that video games allow can be seen as one of their educational benefits. Through allowing interaction in dangerous environments ('HazMat: Hotzone' (CMU, 2005)), to interacting in historical contexts ('Revolution' (EducationArcade, 2004)), to engaging in political conflicts ('PeaceMaker' (ImpactGames, 2005)), video games can uniquely situate learners in environments that support "exploration, hypothesis testing, risk taking, persistence past failure, and 'seeking' mistakes as new opportunities for progress and learning."(Gee, 2004). Not only does the video game medium afford these varying viewpoints, it can seamlessly integrate feedback and demonstration through natural social and emotional means. In achieving this social interaction, the use of interactive pedagogical agents have been shown to foster social interactions between learners and AI driven game characters (Johnson, 1995). The manner in which learners interact socially within games can in part be explained by the media equation theory (Reeves & Nass, 1996), wherein the same real world social rules are applied within the game world. In effect through the ability to create meaningful social interactions within video games, the medium becomes inherently more suited to social and collaborative learning. A further discussion on the design of these social interactions is given in the following section.

2.4 The Design of Educational Games

> *"In anything but a game the gratuitous introduction of unnecessary obstacles to the achievement of an end is regarded as a decidedly irrational thing to do, whereas in games it appears to be an absolutely essential thing to do"* (Suits, 1978)

The design of educational games draws equally from the fields of game design and learning theory. One notable characteristic of contemporary educational video games is the emphasis placed on maintaining an enjoyable gaming experience, which is often prioritised over the regularity and frequency of learning content. Whereas this may initially seem a misguided approach when a positive learning outcome is the ultimate goal, one must consider that the effect of doing the opposite, i.e. prioritising learning content over gaming, is considerably worse. In a scenario where the presentation of the learning content is prioritised over the gaming experience, the possibility of the gaming experience being negatively impacted increases significantly. Without a positive gaming experience the benefits of using games as a motivational vehicle for learning becomes compromised, an argument supported by (Prensky, 2001; Van Eck, 2007).

Although initial attempts to design educational video games were content driven and involved applying game aspects to traditional learning content, these approaches resulted in so called 'edutainment' titles and were poor examples of educational games. These games often referred to as 'Shavian reversals' (Papert, 1998) lacked both the motivating features of games and the educational benefit of the learning content.

In an attempt to avoid the pitfalls of edutainment titles one would expect to be able to follow established models and guidelines. However, despite the increasing incidents of effective educational games there is a noticeable lack of established theories and models for both game design and educational game design (Moreno-Ger, Burgos, Ortiz, Sierra, & Manjón, 2008; Van Eck, 2007). The varied nature of video games in terms of genre, style, and game mechanics means that it is not surprising that game design has been approached from varying perspectives.

The following table aims to highlight the variety and co-occurrence of game design aspects across a number of influential authors. Although game design can be viewed from many perspectives such as rules, play, or culture (Salen & Zimmerman, 2003); competition, chance, simulation, or physical sensation (Caillois, 2001); pedagogy/instructional design, user modelling, learning context, or interaction modality (de Freitas & Oliver, 2006); these classifications typically have an associated design methodology. As no methodology per se is being proposed, the table categories are chosen as broad themes that emerge from the work of these authors. The chosen categories in Table 2 below highlight the more commonly considered design aspects and are indicative as opposed to being exhaustive and all encompassing. The game design aspects of goals, rules, and conflict have been omitted as they are considered to be prerequisites of video game design. An extended version of the this table featuring contributions from 22 authors is available in appendix B to this thesis.

Table 2. Game Design Aspects by Thematic Area and Author

	Challenge	**Context**	**Ownership, Control**	**User-centric**	**Environmental Support**	**Social**	**Uncertainty**
(Gee, 2005)	Progressive difficulty	Low risk of failure, relevance to overall system	Identity through character building	Co-design, customized gameplay	Movement and world interaction		

(Caillois, 2001)		Separate, unproduc-tive (not work), make believe	Freedom to act within the game				Uncertainty as an important component of games
(Dickey, 2006a)	Character design & narrative		Character design, quest selection	User as the co-creator in the game	Narrative	Chat, collabora-tive quests	
(Kiili & Lainema, 2008)	Flow theory and balancing challenge	Situated challenges			Importance of playability, ease of interaction		
(McGinnis, Bustard, Black, & Charles, 2008)	Appropriate challenge and flow theory	Clearly situated in overall learning material	Empower-ment, control	User-centred design	Structure environment	Social Identity	Interactive-feedback loop for coping with uncertainty
(Rieber, 1996)	Importance of Flow theory, progressive difficulty		Ability to reshape the world, 'learning by designing'	Support self-regulated learning, learners as designers	Emphasis on the complete-ness of the game world	History of games in culture and as socio-logical agents	
(K. Squire et al., 2003)		Knowledge is contextual, importance of narrative contexts	Provide choices within simulated worlds		Simulated environments to support experiment-ation	Differing roles and distributed expertise, collabora-tive play	
(Van Eck, 2006)	Importance of flow experience	Importance of situated learning			Provide alternative viewpoints		
(Hong et al., 2009)	Game complexity and the effect on playfulness	Equal opportune-ties for fair play	Flexibility in making decisions	User friendly systems reduce confusion and frustration		Competitio n and cooperation	Importance of uncertainty but not outcomes by chance
(Prensky, 2008)			Engaging nature of decision making	Personalisa-tion and meeting the student's needs, students as game designers	Fun game world	Cooperatio n and competition	
(Ang & Rao, 2008)	Ludus[9] rules to provide challenge and goals		Paidea[10] rules to provide control		Narrative to provide fantasy and curiosity		
(Garris et al., 2002)	Optimum level of difficulty		Active learner control	Importance of supporting self-directed learners	Importance of fantasy and mystery		Importance of uncertain goal attainment
(Amory,	Importance of		Manipulation and		Importance of exploration and	Significanc e of	

[9] ludic, *a*, Of or pertaining to undirected and spontaneously playful behaviour. Source: Oxford English Dictionary

[10] paideia, *n*, Education, upbringing; spec. an Athenian system of instruction designed to give pupils a rounded cultural education, esp. with a view to public life. Source: Oxford English Dictionary

Naicker, Vincent, & Adams, 1999)	challenge		exploration		discovery	competition	

As is evident from Table 2, there are both a wide variety of factors considered important to educational game design, and a certain degree of consensus. The following sections elaborate on three of the key thematic areas that are commonly identified as being significant to educational game design and game design in general.

2.4.1 Flow Theory and Challenge

Among the key game design aspects that are regularly identified by varying authors (Kiili & Lainema, 2008; McGinnis et al., 2008; Rieber, 1996; Van Eck, 2006) is the importance of the *flow* experience (Csikszentmihalyi, 1990). At the core of flow theory is the belief that through balancing a person's skills and abilities with the challenges presented, a person can experience an exhilarating, positive, and engaging state of mind. Although the balance of skills and challenges is an important aspect of attaining a flow experience, Csikszentmihalyi identified the following eight factors that contribute to a flow experience.

- Being confronted with a task that is feasible to complete
- The ability to concentrate on what one is doing
- Clear goals are provided
- Immediate feedback is provided
- Deep but effortless involvement that removes one from everyday life
- Sense of control over one's actions
- Concern for one's self disappears during the activity
- One's sense of the duration of time is altered

The concept of a 'flow channel' in which a person's skills are matched with the challenges presented was proposed by (Csikszentmihalyi, 1990) and can act as a useful guide for the game designer in how to avoid anxiety and boredom in players through the appropriate challenges (see Figure 2). When considering flow in the design of educational games, learning is considered to occur just above the flow channel, where a learner's skills do not meet the challenges presented and so new skills must be acquired (Figure 3). The role of learning in flow theory has relevance to Vygotsky's Zone of Proximal Development (ZPD). In Vygotsky's terminology the ZPD is deemed to occur just above the flow channel.

However, flow theory does not dictate how these new skills are acquired, according to Vygotsky, new skills are acquired through social interaction with experts or collaboration with capable peers.

Evidently although an overlap is clear, the ZPD presents a much more concrete distinction as how learning occurs, as opposed to the more generic approach proposed by flow theory.

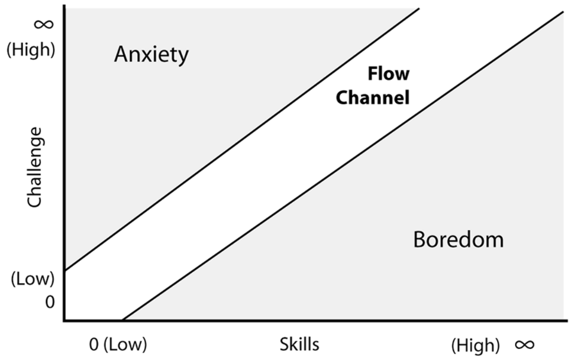

Figure 2. The Flow Channel

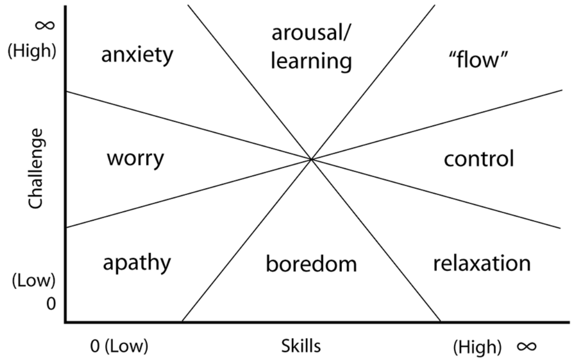

Figure 3. Emotional reaction with varying challenges and skills

The experience of flow is not bound by social class, wealth, or education and has been recorded as occurring in work, leisure, and learning activities. Whereas the intrinsically rewarding nature of the flow experience makes it appealing from an educational perspective, traditional classroom and lecture based tuition often fails to cater for it (Shernoff, Csikszentmihalyi, Schneider, & Shernoff, 2003). As the economic and practical considerations of catering for flow have thus far limited its uptake in classrooms, eLearning and in particular educational games present opportunities to cater for the flow experience. The affordances of video games to support flow, and techniques to design flow experiences have been suggested by (Cowley, Charles, Black, & Hickey, 2008)

Although flow can act as a guide to designing intrinsically rewarding learning experiences, it must be considered that flow is not a universal phenomenon with 15% of people reporting never having experienced a flow like state (Csikszentmihalyi, 1997). Despite this lack of universal applicability, many of the factors involved in a flow experience have commonality across both game design and constructivist learning theories. In consideration of this, the design of an educational game around the principle of flow, can accommodate both good game design and sound learning theories, even if the targeted flow experience is not experienced by all learners.

Despite the benefits of designing games around the theory of flow it must be considered that the theory itself does not have scope for self-scrutiny and reflection (Kiili & Lainema, 2008), an important activity in learning theories such as experiential learning (Kolb, 1984).

2.4.2 Sociality and Narrative

The social nature of play, the importance of social interaction in learning, and the numerous authors supporting sociality in game design, indicates the importance of social interaction within educational games (Ang & Rao, 2008; Coyle, Matthews, Sharry, Nisbet, & Doherty, 2005;

DiPietro, Ferdig, Boyer, & Black, 2007; Shaffer, Squire, Halverson, & Gee, 2005; K. D. Squire, 2008; Sweetser & Wyeth, 2005).

As a medium for social interaction video games can allow for social experimentation and can act as a low-risk testing ground for social interactions. Whereas prejudices, stereotypes, and social taboos govern social interactions in the real world, within games these constraints are relaxed due to limited social penalties and anonymity (DiPietro et al., 2007; Shaffer et al., 2005) . Games such as PeaceMaker (ImpactGames, 2005) have shown how through social interaction, games can provide beneficial alternative social perspectives, in this case about the political Israeli-Palestinian conflict.

As well as allowing for social experimentation, games can allow for social interactions that can be contentious or difficult to realise in reality. One example of this can be found in the work of (Coyle et al., 2005) that used socially interactive game characters as a therapeutic means to address adolescent mental trauma. In this case therapeutic social interactions were possible that would otherwise have been hindered by existing social pressures, shyness, and stigmas.

As well as social interactions with other players, video games can cause para-social relationships to emerge between players and NPCs. A para-social relationship in effect occurs when a person subjectively believes they have a social relationship to another individual where objectively this relationship exists only for the beholder (Horton & Wohl, 1956). The most common occurrence of para-social interaction is where audiences or fans believe they know a particular media-exposed celebrity, whereas in reality this relationship is entirely one-sided. Within educational video games, the development of para-social relationships can be an effective means to present meaningful and appropriate challenges (Linek, 2007). Further to this, as a means for fostering sociality in games, the design of para-social relationships can be seen as a further step in creating a social context. As social context and experiences within games can aid in comprehending learning content (K. D. Squire, 2008), it is evidently an important consideration for the design of educational video games.

2.4.2.1 Sociality and Gender

In considering social interaction within video games the issue of player gender is considerable. Whereas traditionally video games have largely been created by males, there was resultantly an abundance of games appealing to male game players. The characteristics of such games, with high action content and violence, limited the appeal of video games to female players. Although these games are not solely appealing to males, the preference of many female players for games featuring more creativity and social interaction is significant.

In line with the growth of female targeted video games (Dickey, 2006b) there is a growing recognition that the design of effective educational video games needs to be considerate of gender.

In consideration that the gender of NPCs can have a significant impact on relatedness and para-social relationships (Linek, Schwarz, Hirschberg, Rust, & Albert, 2007), the design of educational games must be considerate of player gender. Whereas it may be possible to design games that are equally appealing to both males and females, a more progressive approach is to consider adapting games based on the player's gender to ensure an optimal gaming experience (Steiner, Kickmeier-Rust, & Albert, 2009).

2.4.2.2 Sociality and Learning

Social interactions can play a significant role in learning through providing challenges, establishing meaningful contexts, and creating stimulating interactions. Not surprisingly social interaction is a constituent part of many learning theories. The inherent impact of social interaction is emphasised by (Papert, 1980) in how children construct their knowledge using the 'models and metaphors suggested by the surrounding culture'. More concrete constructivist theories such as Problem-based Learning clearly establish the importance of sociality. This sentiment is further reinforced in the theory of the Zone of Proximal Development (Vygotsky, 1978). Whereas Experiential Learning does not explicitly require social interaction it can evidently benefit from sociality through creating experiences. Further to this, the manner in which para-social interactions can trigger reflection (Horton & Wohl, 1956) reinforces the benefits of learning through social interaction.

2.4.2.3 Narrative in Game Design

One of the key ways in which sociality is fostered within games is through the use of narrative, either to create social interactions with NPCs or with other players. Although narrative is a common feature of educational video games and video games in general, it is by no means requisite for the creation of an effective game (Frasca, 2003). From a game design perspective, narrative falls under the need for representation in games (Crawford, 1984; Salen & Zimmerman, 2003). The importance of representation in games stems from the need to situate a game's rules, conflicts, and goals within a meaningful context. Whereas simulations create representation through presenting simplified but accurate models of reality, games achieve this through a combination of a stylised reality that often contains a fantasy element. In essence simulations aim for a realistic meaning that is conveyed accurately, whereas in games a virtual meaning is conveyed with clarity.

> *"A simulation bears the same relationship to a game that a technical drawing bears to a painting. A game is not merely a small simulation lacking the degree of detail that a simulation possesses; a game deliberately suppresses detail to accentuate the broader message that the designer wishes to present. Where a simulation is detailed a game is stylized."* (Crawford, 1984)

The distinction between games and simulations is continually debated and there are numerous examples of games that are simulations such as the SimCity[11] and Civilisation[12] franchises, and simulations that have game like features such as the Microsoft Flight Simulator franchise. One distinction that is offered by (Alessi & Trollip, 2001) is that games must possess a winning state and also to been designed to incorporate an element of fun. This allows for game based simulations and yet ensures that pure simulations are not classified as games.

The use of narrative as a form of representation creates a context in which the goals of a game can be understood and attained. As a means to contextualise learning content and experiences, narratives have been extensively used within educational games (Ang & Rao, 2008; Champagnat, Delmas, & Augeraud, 2008; Dickey, 2006a; Jenkins, 2003; Kiili, 2007; Linek, 2007; K. Squire et al., 2003; Van Eck, 2007). Although the benefits of narrative in educational games are well supported there is an ongoing debate between the benefits of designing for narrative, and the benefits of designing for fun. The narrology versus ludology debate has emerged in response to the opinion that video games are extensions of drama and narrative. In support of the ludology movement the work of (Frasca, 2003) emphasised how the playing of a game cannot be understood solely through its outcomes and it is the experience that is significant. Additionally the notion that games are repeatedly played, is considered to be at odds with typically linear narratives that have the same ending.

Although the narrology vs. ludology debate continues, it has prompted research into the effective combination of narrative and ludic techniques as explored by (Ang & Rao, 2008; Jenkins, 2003; Mateas & Stern, 2005; Riedl & Stern, 2008). Despite the divisive potential of this debate it has triggered greater exploration into the factors that create ludic or fun engagement within games. Of particular interest is the distinction that arises between *paidia* and *ludus* rules as described by (Caillois, 2001). *Paidia* rules are considered to impact playfulness, creativity, make-believe, and kinetic play, whereas *ludus* rules are concerned with social interaction, progression, and winning (Frasca, 2003). This more granular distinction between types of rules can aid in the design of educational games that do not include a narrative component.

2.4.3 External and Internal Game Context

The context in which an educational video game is played can be considered from two perspectives. In the first, one can examine the real world external context in which the game is played considering the environment (e.g. a school classroom), and the reason for playing (e.g. task

[11] Developed by Maxis (http://www.maxis.com/), designed by Will Wright.

[12] Developed by MicroProse (www.microprose.com), designed by Sid Meier, Bruce Shelley.

or enjoyment). Secondly, one can examine the internal learning context created within the game world and the resulting impact on learning.

The external game context is of particular importance when looking at game based learning holistically and the factors that influence effective integration into existing tuition practices and curricula. Within a classroom environment the issue of teachers being able to effectively support students playing educational video games has been highlighted by (Cher P. Lim et al., 2006). Of particular significance is how educational games can include learning theories such as reflection and inquiry based learning, where both students and teachers may be unfamiliar with such practices. Additional factors that require consideration are (i) the frequency of gameplay, (ii) the types of exercises involved, (iii) the types of interaction with students and teachers, and (iv) the qualities of the game itself (Gros, 2007).

The benefits of considering the external context of gameplay can aid in the effective integration of games into classroom environments as is observed by (Lee, Luchini, Michael, Norris, & Soloway, 2004). However, as it is the instructor that is charged with managing and ordering a classroom environment, it is unsurprising that they will ultimately dictate the successful uptake of educational video games (Moreno-Ger, Burgos, & Torrente, 2009; Papert, 1980; Prensky, 2001).

Although the ability of the educational game designer to influence external context is limited by economic, social, and political factors, they do have considerable control over the internal game context. The creation of a meaningful internal game context requires that the learning content is presented in a manner harmonious to the game world, in essence one must "find ways to put information inside the worlds the players move through, and make clear the meaning of such information and how it applies to that world" (Gee, 2003). The goal of relevantly incorporating learning content within a game world has evident parallels with situated cognition. The situation of the content and the authentic activities that are associated with it are inherently influenced by the nature of the game. Of particular relevance is the game genre, the type of learning content, and how effectively the integration has been achieved. The issue of integrating learning content into video games is addressed specifically in the following section.

2.5 Integration of Learning Content

The issue of effectively integrating learning content into video games has been a concern for educational game designers since the emergence of the first edutainment titles. The challenge of effective integration can broadly be separated into two challenges, firstly of identifying a game genre suitable for the learning content, and secondly of identifying means of situating the learning content naturally within the game genre. In this section we will begin with an overview of edutainment and its deficiencies, followed by the impact that game genre can have on educational game design, finally this section will conclude with a section discussing the sources of contemporary educational games and the effectiveness of each type in terms of integration.

2.5.1 Edutainment

The emergence of so called edutainment titles was the first attempt to create commercially viable educational game titles. However, the approach taken to develop these games typically involved taking existing learning content and applying game-like features to it (Moreno-Ger et al., 2008). Although the intention was to enhance the existing content with motivating game features, the result was in effect to create a poor gaming experience and ineffective learning content. The term Shavian reversals (Papert, 1998) is often used to describe such games whereby neither the game features nor the learning content are effectively realised. The criticism of these titles largely surrounds the failure to integrate the learning content within the game world in a meaningful way (Kirriemuir & McFarlane, 2004; K. Squire & Jenkins, 2003; Van Eck, 2006). These games have also been identified as adopting behaviourist learning as they often incorporate drill and practice style activities (Alessi & Trollip, 2001). Some of the commonly criticised features of edutainment games include:

- Distinctly separate gaming and learning sections
- Content oriented and curriculum focused
- Typically low level learning objectives such as drill and practice
- The intentional concealment on learning and the associated lack of scrutability

One of the key explanations for the emergence of such titles has been the conflicting objectives of game designers and instructional designers. Whereas game designers prioritise the creation of an experience that is often non-linear and player driven, instructional designers typically emphasise the content in a linear, hierarchical and instructor-oriented manner (Van Eck, 2007). The need to progress educational game design away from edutainment style games has resulted in greater emphasis being placed on game design. Although an entertaining educational game is the ultimate goal, this must be achieved by finding the synergies between pedagogy and game design (Van Eck, 2006). Whereas the more user-centric approaches as proposed by (Prensky, 2008) may play an important role in achieving this, the following sections elaborate on the importance of game genres and the meaningful integration of learning content. Despite the prevalence of criticism for edutainment style titles the term edutainment by no means is a clear classification of games. The term is also used to describe effective and well designed educational games notably in the Edutainment Conference[13] and the LNCS Transactions on Edutainment[14] journal.

2.5.2 Video Game Genres

The selection of an appropriate game genre is influenced by the nature of the learning content, the associated learning objective, and the learning theory employed. Although there is no de facto classification of game genres the following list proposed by (Prensky, 2001) is both comprehensive and has correlations with the work of (Crawford, 1984; Van Eck, 2007).

Video Game Genres (Prensky, 2001)[15]

- Action
- Role-Playing
- Adventure
- Strategy
- Simulations
- Sports
- Puzzles
- Building/Construction
- Reflex Games

The nature of each individual game genre presents affordances and restrictions for their suitability for specific learning content. As each varying genre has separate interaction modalities, control dynamics, visual style, and reward mechanisms it is unsurprising that there is great scope for both synergies and incompatibilities with learning content. The selection of a suitable game genre can be dependent on the learning content, the learning objective, and the learning theory employed.

2.5.3 Game Genres and Learning Content

The key factor in the selection of a video game genre is the nature of the learning content. The importance of matching learning content to an appropriate game genre has been supported by (Amory et al., 1999; Fisch, 2005; Prensky, 2001). The importance of an appropriate genre is also significant as it allows the learning content to be at the heart of the gameplay, feedback, and hint

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[13] http://www.edutainment2012.de

[14] ISSN: 1867-7207, http://www.springer.com/computer/lncs/transactions+edutainment?SGWID=0-159704-0-0-0

[15] Additional game genres such as Fighting Game (Crawford, 1984; Van Eck, 2007) are considered to be part of the listed game genres, in this case Action games.

structures (Fisch, 2005). The following table adapted from (Prensky, 2001) highlights the game genres that are compatible with varying learning content.

Table 3. Learning Content and Video Game Genre Compatability (Prensky, 2001)

Learning Content	Learning Activities	Possible Game Style/Genre
Facts	Questions, memorization, association, drill	Game show competitions, flashcard type games, mnemonics, action & sport games
Skills	Imitation, feedback coaching, continuous practice, increasing challenge	Persistent state games, role-playing games, adventure games, detective games
Judgement	Reviewing cases, asking questions, making choices (practice), feedback, coaching	Role-playing games, detective games, multiplayer interaction, adventure games, strategy games
Behaviours	Imitation, feedback, coaching, practice	Role playing games
Theories	Logic, experimentation, questioning	Open ended simulation games, building games, construction games, reality testing games
Reasoning	Problems, examples	Puzzles
Process	Systems analysis and deconstruction, practice	Strategy games, adventure games, simulation games
Procedures	Imitation, practice	Timed games, reflex games
Creativity	Play, memorization	Puzzles, invention games
Language	Imitation, continuous practice, immersion	Role-playing games, reflex games, flashcard games
Systems	Understanding principles, graduated tasks, playing in microworlds	Simulation games
Observation	Observing, feedback	Concentration games, adventure games
Communication	Imitation practice	Role-playing games, reflex games

The prevalence of both role-playing and adventure games in Table 3 is an indication that these genres are particularly suited for a variety of learning content. Interestingly, both of these genres typically include a large narrative and social component whereby players must interact with NPCs. Evidently the importance of narrative and sociality are significant in facilitating learning in games and resultantly there is support for the usefulness of these genres in education (Amory et al., 1999).

2.5.4 Game Genres and Learning Behaviours

The learning outcomes from playing educational video games are often characterised in terms of skills based, cognitive, and affective, as was illustrated in section 2.3.5. However, within instructional design it is common to refer to the outcomes of learning in terms of learning behaviours. The most commonly used classification for these behaviours is that of the learned capabilities proposed by (Gagné & Briggs, 1974). These capabilities include Motor Skills, Attitude, Verbal Information, Cognitive Strategy, and Intellectual Skills. In regards to educational video games, emphasis is often placed on Intellectual Skills, which are said to include Discrimination, Concrete Concept, Rule Using, and Problem Solving (Figure 4).

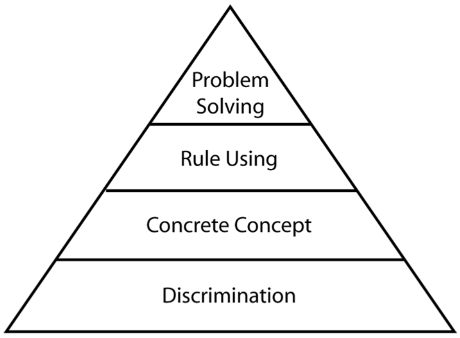

Figure 4. Gagné's Intellectual Skills

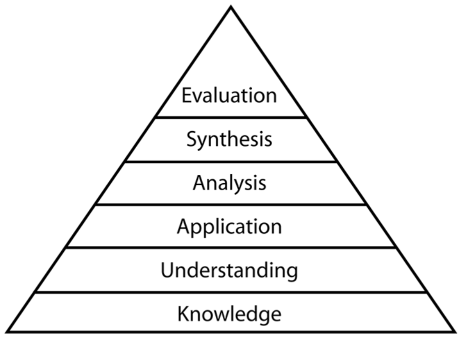

Figure 5. Blooms Taxonomy of Cognitive Skills

The relationship between game genres that are suited to developing learning behaviours is illustrated in Table 4 that has been adapted from (Van Eck, 2007). As well including Gangé's intellectual skills Van Eck also includes the learning objectives from Bloom's taxonomy (Bloom & Masia, 1956). These objectives from the lowest order to highest order are: Knowledge, Comprehension, Application, Analysis, Synthesis, and Evaluation (Figure 5).

Table 4. Matrix of Game and Learning Taxonomies, adapted from (Van Eck, 2007)

Taxonomy of Games	Explanation of Genre	Gangé's Intellectual Skills	Bloom's Taxonomy
Action	Keeps the player moving and involved at all times. Primary skills are eye/hand coordination and quick reflexes. Deep thinking is generally not required	Defined Concepts & Below	Application & Below
Role Playing	Revolves around characters, story and combat and takes place in large, expansive worlds. Usually collaborative, often online.	Problem Solving & Below	Evaluation & Below
Adventure	Story based on exploration and puzzle solving where the player is the protagonist. Player must determine best path through storyline and obstacles on own or with others.	Problem Solving & Below	Evaluation & Below
Strategy	Emphasize strategy and theory, often in recreations of historical or human events.	Problem Solving & Below	Evaluation & Below
Simulations	Simulation of processes, event, or phenomenon. Emphasis on realistic representation.	Problem Solving & Below	Evaluation & Below
Sports	Allows players to play simulated sports activity.	Defined Concepts & Below	Application & Below
Fighting Games	Players engage in combat individually or in teams. Story is present but ancillary to fighting skills.	Defined Concepts & Below	Application & Below
Casual	Games for the "new gamers" easy to learn, not difficult to master.	Defined Concepts & Below	Application & Below

The four game genres of Role-Playing, Adventure, Strategy, and Simulations are best suited for developing higher level intellectual and cognitive skills, and are highlighted accordingly in Table 4 above.

In consideration that the genres of Role-Playing and Adventure are also well suited to catering for a variety of learning content there is much to support the development of educational games in these genres. However, as both genres feature both a large narrative and social component, the design of educational games in this genre must draw considerably on the fields of narrative design and social interaction.

2.5.5 Situating Learning Content

The selection of a game genre that is both suited to the learning content covered, and the desired learning behaviours is an important consideration in game design. However, the manner in which the learning content is manifested can considerably impact its effectiveness. The importance of situating learning content within games in a meaningful and appropriate manner is paramount to the success of an educational game. In essence, a meaningful and appropriate manner is a way in which the rules of the game world do not have to change to accommodate the learning content.

An example of poorly situated learning content is where the presentation of the learning content is achieved through popup windows or other devices that otherwise have no game usage. The consequences of using an approach are highlighted in (Van Eck, 2007) whereby a game based PDA is used to deliver learning content. In this case the PDA is used solely as an educational tool and adds little to the fun or engagement of the game. Often poorly integrated content can be influenced from non-game based eLearning software. The example of using dialogue boxes to present content is an approach often found in eLearning software but is an approach seldom appropriate in a game world (Elliott, Adams, & Bruckman, 2002).

> *"People are quite poor at understanding and remembering information they have received out of context or too long before they can make use of it [...]. Good games never do this to players, but find ways to put information inside the worlds the players move through, and make clear the meaning of such information and how it applies to that world."* (Gee, 2003)

In order to meaningfully situate learning content one must examine the affordances of the game genre that has been selected. Through this approach it can become possible to truly make the learning content an integral part of the gaming experience. In (Frazer, Argles, & Wills, 2008) a survey of 12 entertainment video games across four genres are reviewed to identify their affordances. Evidently the small number of games surveyed does not give a comprehensive view over all games in a particular genre; however, it is indicative of how one would identify the affordances of a chosen genre.

Table 5. Educational affordances of video game genres (Frazer et al., 2008)

	First –Person Shooter			RPG/Adventure			Puzzle			Strategy		
	1	2	3	1	2	3	1	2	3	1	2	3
Conversation	X	X	X									
New Knowledge	X	X	X	X	X	X			X	X	X	X
World Creation	X	X						X				
World Exploration	X	X	X	X	X	X					X	X
Useful feedback		X	X	X		X				X	X	X
Balance Difficulty						X				X		
Clear goals		X	X		X	X	X	X	X			X
Contextualisation	X	X	X			X	X	X	X			X
Provoke curiosity	X			X	X	X						
Immersion	X	X	X	X	X	X	X	X	X			
Offer rewards	X	X	X	X	X	X			X	X	X	X
Unite resources				X	X	X				X	X	X
Blended support									X	X	X	
Full pedagogy												
Standards	X	X						X				
Games	1. Half Life 2 2. Team Fortress 2 3. Battlefield 2			1. Final Fantasy X 2. Grand Theft Auto III 3. Oblivion			1. Tetris 2. Polarium 3. Puzzle Quest			1. SimCity 2. Civilization IV 3. Company of Heroes		

As concrete means of integrating learning content, both pedagogical agents (Conati, 2002; Gómez-Martín, Gómez-Martín, & González-Calero, 2004; Johnson, Vilhjalmsson, & Marsella, 2005; Linek, 2007; Van Eck, 2007) and descriptive narratives (Amory et al., 1999; Dickey, 2006a; Riedl & Stern, 2008; Sharda, 2008; K. Squire et al., 2003) have garnered significant interest. The use of pedagogical agents in particular allows for learning content to be delivered in a natural manner and through a means (i.e. a NPC) that is also relevant to the game.

Despite established research in educational games that can aid in selecting a suitable game genre and a means of situating learning content, any effective realisation ultimately contains a creative component. This creative element is what allows an educational game designer to find the right balance of game genre and gameplay features to seamlessly integrate the learning and gaming experiences. However, in order to achieve this, the designer must possess both game design and instructional design skills, a seldom found and very specialised skill set. The importance of game design in this skill set is often emphasised (Aldrich, 2004; Prensky, 2001; K. Squire et al., 2003) and is clearly illustrated below by Kurt Squire.

> *"There is a well-known saying among makers of serious games: 'If you want to take all of the fun out of it, get a bunch of educators involved'"* (K. D. Squire, 2008)

This evidently presents a problem as to who will create these educational games. The game designers lack pedagogical insight, the educators lack the game design skills, and the expert edu-game designer is a seldom-found resource. However, successful educational games have and are being developed despite this, the sources that are creating these games is the topic of the following section.

2.5.6 Sources of Edu-games

The creation of educational games depends on a variety of skills to blend engagement and education (Kelly et al., 2007). The way to achieve this "is not to privilege one arena over the other but to find the synergy between pedagogy and engagement in DGBL [Digital Game Based Learning]" (Van Eck, 2006). However, the skill set required is typically beyond the means of most instructional designers and game designers. In response to this challenge the following three approaches to educational game design have been popularised (Van Eck, 2006).

- The reuse of existing off-the-shelf entertainment computer games
- Engage the end-user students in the design of the games
- The use of professional educational game developers

The reuse of existing entertainment games can be effective where the entertainment games are already inherently educational. Successful studies have shown the educational benefit of Nintendo 'Brain Training' for mental arithmetic and self-esteem (Miller & Robertson, 2010), and the use of Civilisation III for history education (K. Squire & Jenkins, 2003). Although this approach can show educational benefits and has very low development costs it is reliant on coincidental learning content in commercial games, and often lacks curriculum conformance or covers a very narrow selection of content and activities.

The engagement of end-users and students in the design of games has been promoted by (Cher Ping Lim, 2008; Prensky, 2008; K. D. Squire, 2008). In consideration that the majority of commercial educational games target pre-adolescents (K. Squire & Jenkins, 2003), games that are designed for adolescents by adolescents will address an under resourced market.

As a paradigm this approach supports user-centric design and suggests that the students who will be playing these games are inherently more aware of what will and will not work. Further to this the considerable experience that these students have with video games, and computers in general, certainly provides them with a considerable understanding of the medium.

> *"the next generation of educational games—the games that will truly engage and teach students—is likely to come from the minds of other students, rather than from their teachers."* (Prensky, 2008)

Although students may have an acute understanding of the game market they are developing for they will not have the technical or design skills to author large scale games. Whereas the small scale mini-games that are created by this approach can be combined to form a more coherent curriculum, the issues of scale and quality remain. However, one of the consequences of this approach is that learning can occur through the creation process, which essentially makes this a constructionist activity.

The final approach to the development of educational games is to professionally author the games using experts in both game and instructional design. This approach has been noted to be both resource intensive (Van Eck, 2006) and require a diverse set of skills (Kelly et al., 2007) and rarely used in academic research due to budgetary constraints. Despite the effectiveness of these games they are typically highly focused on a particular curriculum and end user. As result of this, they offer poor value for money as they cannot easily be adapted for new content or different audiences.

However, approaches to improve the adaptability of these games and techniques to aid authoring that allow the roles of instructors and game designers to be separated are promising. Essentially, in order to create the most effective and affordable games, techniques to facilitate adaptability and promote independent authoring by both instructors and game designers must be developed (Van Eck, 2007).

2.6 Digital Natives

Of the many arguments in support of educational video games, the argument that there is a need for these games because the learners have changed is perhaps the most interesting. Depending on the author these new learners are referred to as 'Digital Natives' (Prensky, 2001), 'Generation.com' (Garris et al., 2002), and a variety of other labels such the 'Net Generation', 'Generation Y', and 'Millennials'. Despite the label that is being applied, this group of learners born roughly between 1980 and 1994 (Bennett, Maton, & Kervin, 2008) is characterised by their inherent familiarity with computers and digital media, and the ease at which they interact, communicate and socialise using digital media.

The benefit of classifying an entire generation as being digitally literate is not inherently useful and has attracted criticism (Bennett et al., 2008). Evidently there are economic and socio-political influences that can affect digital literacy and familiarity with technology. However, the digital natives moniker is a useful designation for those learners who have a far more pervasive understanding of digital media than their parents. The significance of this in terms of educational video games is in the acceptance of game based and computer based learning by learners.

Characteristics of Digital Natives

- High familiarity with playing video games. 67% of US households play video games (Entertainment Software Association, 2010), gamers are 53% male, 47% female (Entertainment Software Association, 2012)
- There are increasingly starting to play video games at a younger age. Average US gamer age in 2010 was 34, by 2012 that had dropped to 30 (Entertainment Software Association, 2010, 2012).
- High level of comfort with using computer controlled simulations (Prensky, 2001) (cf. previous generations' difficulty with video games (Leutner, 1993))
- Visually oriented learners who are accustomed to on-demand, accessible information sources (Van Eck, 2006).

Whereas the suggestion that these new learners adopt radically different learning styles (Prensky, 2001) has yet to be empirically justified (Bennett et al., 2008), there is support for how these learners are utilising digital technology in innovative ways. They are also beginning to expect the same innovative interactions from their eLearning experiences (Vassileva, 2009).

The digital natives debate may not provide justification for changing existing educational practices, but it does at least support the idea that the acceptance and applicability of digital game based learning is maturing. As opposed to trying to replace conventional education, video games are another tool that learners and educators can utilise. It is now for the first time that the end users are willing and able to accept them, the remaining barrier is the willingness and ability of the instructors and educators to adopt them.

2.7 Summary

This chapter has examined the underlying educational benefits of video games, techniques and practices to design effective educational games, and the challenges associated with effectively integrating learning content with educational games.

The challenges limiting the uptake of educational video games surround the three areas of appropriate pedagogy, holistic design, and appropriate content integration. The pedagogical approaches used reflect the move towards more learner-controlled, self-directed, and constructivist perspectives, and a move away from behaviourist approaches to learning. The emerging best practice approach to educational game design is a user focused design process aimed at providing the most coherent, meaningful, consistent and enjoyable experience possible. In achieving this, the matching of game genres to the learning content presented is a key consideration.

Further to this the adaptation of games to learners' abilities has been shown to be beneficial as it allows an appropriate and suitable challenge to be presented, a prerequisite of a flow experience, and a key factor in engagement. However, adaptations although beneficial, must be in line with the learner's understanding and expectations of the game world as disruptions can be detrimental to immersion.

The design of games to meet the expectations of learners is also an emerging consideration as they are becoming increasingly accustomed to highly interactive and personalised experiences both within games and in other digital media. A final consideration is the significance of the context in which educational games are to be played, be it in a formal or informal setting and whether an instructor plays a role in the use of the game.

Despite the growing familiarity of students with digital media and video games, the realisation of pervasive game based learning remains limited. Due to limited effectiveness as found in edutainment titles, and due to high development costs, games as learning tools remain on the periphery of mainstream education. However, progressive research in this area is fuelling a sea change that proposes approaches towards cost effective and reusable games. The remaining hurdle is thus no longer technical or economic, but social. A difficult obstacle considering the self perpetuating social phenomenon that is conservatism in the world of education (Papert, 1980).

3 Analysis - Adaptive Instructional Systems

The origins of Adaptive Instructional Systems stems from initial efforts in Computer Aided Instruction (CAI) in the 1960s. At this early stage the potential of computer systems to provide cost effective tuition was identified. The work of Benjamin Bloom (Bloom, 1984) in empirically identifying the educational benefits of one-to-one tuition, spurred on this research to identify means with which CAI could be individualized. The motivation to address the individual learner lies in the acceptance that each learner has unique preferences, abilities, motivations, and learning context, to name but a few of the diverse range of learner attributes. It is accepted that the inherent ability of a tutor to adapt to the traits of a learner is the key benefit of one-to-one tuition (Bloom, 1984; Park & Jung, 2003).

In this chapter the progression of Adaptive Instructional Systems from CAI, through Intelligent Tutoring Systems is examined. The significance of Learner Modelling and Personalisation is also highlighted as well as the progression towards Adaptive Hypermedia and the corresponding shift in learning theories applied to these systems. This chapter will conclude with a discussion on Adaptive Educational Games as a progression in Adaptive Instructional Systems. Through a survey of contemporary Adaptive Educational Games the strengths and challenges of this emerging learning medium are discussed.

3.1 Intelligent Tutoring Systems (ITSs)

The emergence of Intelligent Tutoring Systems (ITSs) in the 1970s and 80s was driven by the desire to tailor tuition to each individual learner. The ability of these systems to adapt to the individual traits of a learner is often referred to as personalisation. The learning theories employed by early ITSs focused on the need for explicit tuition on a prescribed curriculum. Through combining this with an understanding of the student the core components of an ITS (Wenger, 1987) accordingly are:

- Learner or student model
- Domain or expert model
- Teaching or tutor model
- Student interface

The interaction of these four components within an ITS is illustrated in Figure 6 below. Although Figure 6 is representative of many ITSs it is by no means comprehensive. The omission of the interface component in this diagram is indicative of the importance typically placed on the user interface. That is, the interface component in many ITSs is often considered a minority component and often assumed to exist or is under emphasised.

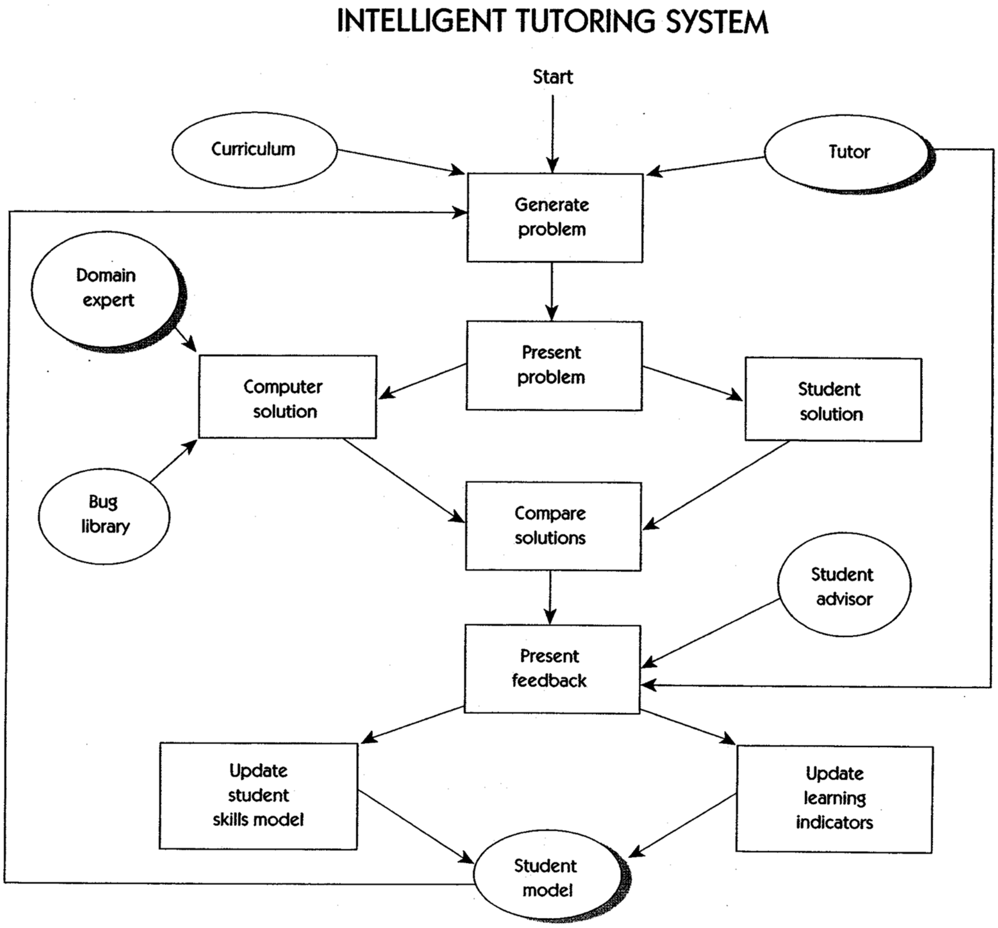

Figure 6. Diagram of an Intelligent Tutoring System (Shute, 1996)

The presence of the explicit tutoring component in ITSs is indicative of the behaviourist, associative, and remedial approach to learning that these systems typically embody. Through the focus on remediation a great deal of ITS research has focused on problem generation, error identification, and learner modelling. However, in the last 30 years of ITS research there has been a steady progression from problem generation, through model tracing, towards learner control (Shute, 1996), as is detailed in Table 6 below.

Table 6. Progression of ITS research

Problem Generation →	Model Tracing →	Learner Control
The creation of problems based around the current curriculum that will remedy any errors the student has created.	The identification of the remedial steps required to take the student from the current state of errors towards the ideal solution (Anderson, Boyle, Corbett, & Lewis, 1990).	The benefits of allowing self-directed learning and the consequences of reducing direct instruction. The mixed benefits of self-control as reported by (Park & Jung, 2003) have continued the debate in this area.

The progression of learning theories through the 1970s, 80s, and 90s is marked by the continuing shift away from behaviourist and cognitivist approaches towards more learner-centric and constructivist approaches (Wasson, 1997). In consideration of this there has been significant debate about the continuing relevance of ITSs in consideration of their inherent tuition oriented approaches, and their failure to consider many valuable learning principles and instructional strategies (Mödritscher, Barrios, & Gütl, 2004; Park & Jung, 2003; Shute, 1996).

One of the noted deficiencies of ITSs is that they do little to address learner disengagement during prolonged use (Arroyo et al., 2007), and that lack of student motivation (identifiable by students 'gaming the system') can be detrimental to learning (Baker, Corbett, & Koedinger, 2004). It has also been observed that the domain focused nature of ITSs has resulted in motivational aspects being overlooked (Soldato & Boulay, 1995). Although approaches to address disengagement such as the use of non-invasive interventions to promote self-reflection are effective (Arroyo et al., 2007), the issue of de-motivation is predominately tackled by remedial actions. In consideration that constructivist learning theory advocates that learning is both instinctive and inherently desirable, the relevance of ITSs in light of contemporary learning theories is debatable.

Despite the criticisms of ITSs, they have shown considerable educational benefits and evidently are effective learning tools in the domain of direct instruction (Anderson et al., 1990; Graesser, Vanlehn, Rosé, Jordan, & Harter, 2001; Shute, 1996). In identifying the benefits of ITSs it is apparent that the adaptation provided and prerequisite learner modelling is of considerable importance. Although the requirements that ITSs place on modelling the learner can often be complex and in some cases intractable (Self, 1990), many of the techniques developed are applicable across all Adaptive Instructional Systems. In consideration of this the following section explores the area of learner modelling and the variety of approaches used in the creation of learner models.

3.2 Learner Modelling

The Learner Model is a key component of any adaptive learning system. The process of Learner Modelling accordingly is the manner in which characteristics about the learner and their learning context are gathered. In essence a learner model is an abstract representation of a learner which contains characteristics of the learner that will be combined with an appropriate pedagogical strategy to personalise a learning experience (Wasson, 1997). The exact content and structure of the learner model is dependent on the adaptations the system is trying to achieve.

With the origins of learning modelling (also known as student or user modelling) in ITSs there was a strong emphasis on modelling learner performance. Through modelling performance it became possible to identify errors that had been made and to enact appropriate tuition to remedy these errors. As research into user modelling progressed throughout the 1970s and 80s both the variety of data collected and the adaptations provided diversified. Some common uses of learner models in ITSs were identified by (Vanlehn, 1988) and are given below.

- Adapting explanations for problematic concepts
- Offering unsolicited advice
- Appropriate problem generation
- Advancement through a curriculum

One of the major criticisms for how learner models are used within ITSs is their use to model solution spaces. In a classical ITS the learner's solution to a problem is compared to the ideal solution (see Figure 6) in order to determine the performance of a learner. Whereas this approach is effective it requires that both the ideal solution (including all requisite steps) are modelled. Further to this when considering model-tracing approaches (Anderson et al., 1990) a model of all envisaged errors additionally needs to be compiled. These challenges have arguably limited the reuse and flexibility of ITSs.

The intractability of generating comprehensive models of ideal solutions and potential errors would at first seem to limit the potential of learner modelling. However, it is in fact not the learner modelling process that is intractable but the pedagogical approach (Self, 1990). It is argued by John Self that solely the observing of a learner's actions is a limited approach to modelling that is error prone and intractable. As opposed to abandoning learner modelling, Self advocates reassessing the necessity of remedial tuition in ITSs, and the use of more integrated methods of learner evaluation. The following four slogans from (Self, 1990) identify many of the criticisms of learner modelling as used in ITSs.

- Avoid guessing - get the student to tell you what you need to know.
- Don't diagnose what you can't treat
- Empathise with the student's beliefs, don't label them as bugs[16]
- Don't feign omniscience - adopt a 'fallible collaborator' role

Whereas learner modelling in traditional ITSs often required the comprehensive modelling of particular traits, the work of (McCalla, Vassileva, Greer, & Bull, 2000) advocates the significance of the activity of modelling, and determining what is necessary to model. The idea of just-in-time learner modelling acknowledges that learner modelling can occur for many differing purposes and

[16] In ITS research is common to refer to a learner's misconception or piece of incorrect knowledge as a 'bug'

a model can be created as needed, for a purpose, and be effective without being comprehensive. Under this approach the three processes of (i) Retrieval, (ii) Integration/aggregation, and (iii) Interpretation, become the basis for learner modelling. In correspondence with the move away from a monolithic model that acts as a global description, the following new purposes for learner modelling are proposed by (McCalla et al., 2000).

- To promote *reflection* through making the learner model accessible.
- To *validate* beliefs about domain knowledge.
- To act as a *matchmaker* to identify peers for collaboration.
- To facilitate *negotiation* and knowledge sharing.

Reflection on one's own learning plays a significant role in constructivist learning theories and is a key feature of the evolving approaches to learner modelling. The work of Judy Kay illustrates how through making the learner model scrutable and accessible to inspection and revision by the learner, a sense of self-control can be fostered (Kay, 2001). Although allowing greater self control can cause a learner to take ownership of the learning experience, the scrutability of learner models can add additional cognitive load and may not be desirable by all learners. To further add to this debate the externalisation and visualisation of learner models is a complex issue (McCalla et al., 2000) that is made all the more difficult with the complex statistical modelling processes that are increasingly in use.

3.2.1 Statistical Modelling

The need for statistical methods of inference is due to the inherent ambiguity surrounding observed learner actions. One of the key problems of learner modelling is the amount and quality of learner information that can be obtained, a property often referred to as bandwidth (Vanlehn, 1988). Although no computer system can access the internal thoughts of a learner, an approximation can be made based on the observable actions of the learner. Within early ITS systems this problem was addressed by limiting the number of possible interactions so assessment would be simplified. However, in providing greater learner control the freedom of choice of the learner must also be increased and so assessment is made more difficult. Through using statistical modelling multiple learner actions (from potentially multiple learners) can be observed allowing a probabilistic model of learner actions to be developed. The following statistical approaches are regularly used in learner modelling (Zukerman & Albrecht, 2001).

- Linear Models
- Term Frequency Inverse Document Frequency (TFIDF) Models
- Markov Models
- Neural Networks

- Classification and rule induction methods
- Bayesian Networks

Of the above statistical approaches it is Bayesian Networks (BN) that have seen a considerable growth in popularity. The flexible nature of BNs and their ability to make predictions about a number of variables has lead to their increasing usage. The uses of BNs typically involve prediction and classification tasks. They have been used to predict the type of assistance needed, and the next actions a learner may perform (Zukerman & Albrecht, 2001), additionally they have been used in plan recognition, performance assessment, and learner emotion assessment (Conati, 2002; Conati, Gertner, & Vanlehn, 2002; Millán & Pérez-De-La-Cruz, 2002). Despite the benefits provided by BNs they are not without their deficiencies, in particular the need to initialise the network with appropriate probabilities remains a challenge. Further to this the computational complexity of large BNs can introduce unacceptable delays in decision making (Zhao, 2002), a considerable factor considering the fast paced nature of many educational video games. Although BNs do present challenges in their adoption, they have been beneficial in highlighting critical areas of learner modelling. Of particular significance is the issue of managing older evidence, identification and consideration of errors and omissions, handling learner guessing, and considering the impact previous adaptations are having on learner performance.

3.2.2 Competence-based Knowledge Space Theory

The growing use of statistical models such as Bayesian Networks has aided in learner modelling tasks where the learner has a great deal of choice and control, and where modelling all possible interactions becomes intractable. In line with the movement towards constructivist learning theories and self-control, the manner in which the learner interacts with their environment is growing under increased scrutiny. One of key factors in these environments is the manner in which learner modelling data is gathered, and how this impacts the learning experience (Self, 1990). One such approach that advocates statistical modelling and implicit assessment is Competence-based Knowledge Space Theory (CbKST) (Heller et al., 2006).

The origins of CbKST lie in the theory of Knowledge Spaces (Albert & Lukas, 1999; Doignon & Falmagne, 1985). The theory of Knowledge Spaces is a behaviourist approach to model the structure of a domain of knowledge. A domain of knowledge is represented by a set of test problems which is structured by a prerequisite relation (or surmise relation; "if a learner does not master problem *a*, we can surmise that they also will not master problem *b*"). The knowledge state of a learner is defined as the subset of test problems that they can solve, and the set of all possible knowledge states which is restricted by the prerequisite relations is called a knowledge space. The primary use of these models was in the adaptive assessment of knowledge.

An example of a prerequisite structure between test problems is given in Figure 7. In this diagram each node (*a* – *e*) represents a test problem (and associated skill) with the connecting edges representing a prerequisite relationship interpreted from bottom to top, e.g. *c* is a prerequisite of *e*. The corresponding knowledge structure and possible skill states derived from Figure 7 are given in Figure 8. In Figure 8 each node represents a skill state consisting of a set of skills or test problems. The edges represent possible transitions between skill states by gaining or losing a particular skill. As a consequence of using the prerequisite structure (Figure 7) to generate the skill space the number of possible skill states is constrained. In this example the there are 10 possible skill states whereas a skill space with no prerequisites would have 2^n skill states, i.e. the cardinality of the superset of *Q*.

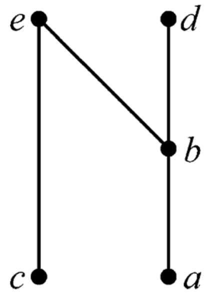

Figure 7. An example surmise relation on the domain *Q = {a, b, c, d, e}* (Heller et al., 2006)

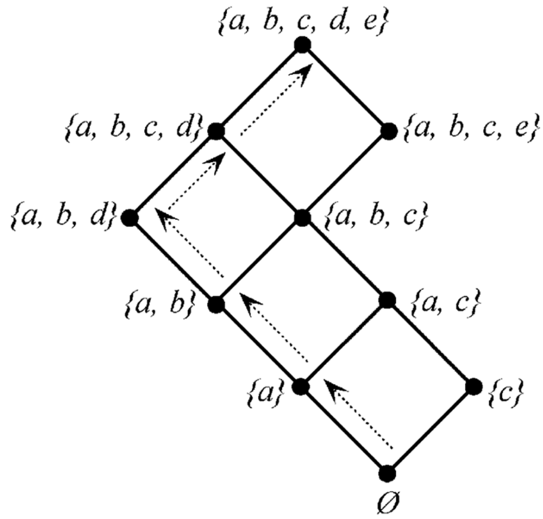

Figure 8. The knowledge structure induced by the surmise relation of Figure 7. The dashed arrows indicate a possible learning path. (Heller et al., 2006)

The development of CbKST was a result of examining the cognitive structures underlying the behaviourist knowledge spaces. According to CbKST, a domain of knowledge is described by a set of (abstract) skills or competences which are structured by prerequisite relationships as described above. Skills are assigned to learning objects or test problems within this domain as required, and as taught or tested competences. Based on the competence structures, suitable skills to be learned can be suggested for the individual learner, and based on the skill assignments, learning objects can be offered which fit best to the learner's current knowledge state.

As a core component of CbKST, a mapping is established between the learning objects and the skills or competencies to be learnt (Albert, Hockemeyer, Kickmeier-Rust, Peirce, & Conlan, 2007). Importantly this mapping is not absolute, in that a successful task being completed with a learning object does not concretely indicate the mastery of a particular skill. Through the use of a generalized Bayesian update rule the successful use of a learning object shows evidence of skill mastery and so increases the probability of a the skill being mastered, these skills are referred to as required skills. As well as the positive evidence of skill use, a user's action may also represent incorrect usage or misconceptions. In this case the probabilities of the associated skills will be reduced, and accordingly these skills are referred to as missing skills. One flexible aspect of CbKST is that it can accommodate partially correct usage whereby a learner's action represents both positive understanding of some skills and negative understanding of others.

The following four steps adapted from (Albert et al., 2007), which is in effect a Bayesian update, indicates the process involved in using CbKST to generate a likelihood distribution over the knowledge space covered:

1. The learner performs an action, i.e. they interact with a learning object.
2. The action is interpreted by the required and missing skills associated with the new state of the learning object.
3. The likelihoods of the skill states are updated according to the new positive (required skills[17]) and negative (missing skills) evidence. The entire skill space is then normalized to create a probability distribution of the skill states.
4. The likelihoods of the individual skills being mastered by the learner are computed through summing the probability of each skill state that contains the given skill.

The skill probabilities calculated using the above four steps can then be used as a basis for adaptation, allowing skill based adaptation that can be based solely on the actions performed by a learner. The key characteristic of CbKST that make it suitable for game based learning are evident in the manner that it enables efficient skill assessment without the need for explicit questions. Further to this, the ability of the theory to cater for imprecise information, such as the observed actions of a learner, allow it to accommodate for learner actions such as errors, guessing, and omissions. As the theory incorporates a consideration of both positive and negative learner evidence there is no presumption of progression and so it offers a means of assessment that is realistic to the way learners can master and also regress skills.

The challenges of using CbKST for skill assessment lie in the difficulty of assigning skills to user actions, and in the computational complexity of the algorithm used. Although the assignment of skills to actions can be achieved by a domain expert, the computational complexity of calculating

[17] Required skills are so called as they are considered to be required in order for the learner to be in a skill state. Conversely missing skills are those skills the learner is showing evidence of not possessing.

skill probabilities can limit the granularity of the skill structure. Although the number of skills in the skill structure does influence the resulting number of possible skills states, it is the prerequisite structure that is the key determining factor. This becomes immediately apparent when one considers the range of skill states obtainable from *n* skills as can be calculated by the equation in Figure 9 below.

$$\left[n+1, \left(\sum_{k=1}^{n} C_k^n\right)+1\right] = [n+1, 2^n]$$

Figure 9. Possible range of CbKST skill states from *n* skills

In the case of there being four skills the possible number of skill states is in the interval of [5, 16], the exact number being determined by the prerequisite skill structure, with contrasting examples being shown in Figure 10 and Figure 11. The minimum number of skill states is obtained where there is a single line of prerequisites (Figure 10) and the maximum is obtained where there are no prerequisite relationships (Figure 11).

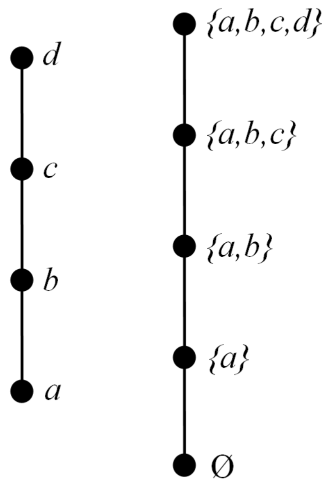

Figure 10. The minimum 5 possible skill states for the skills {a,b,c,d}

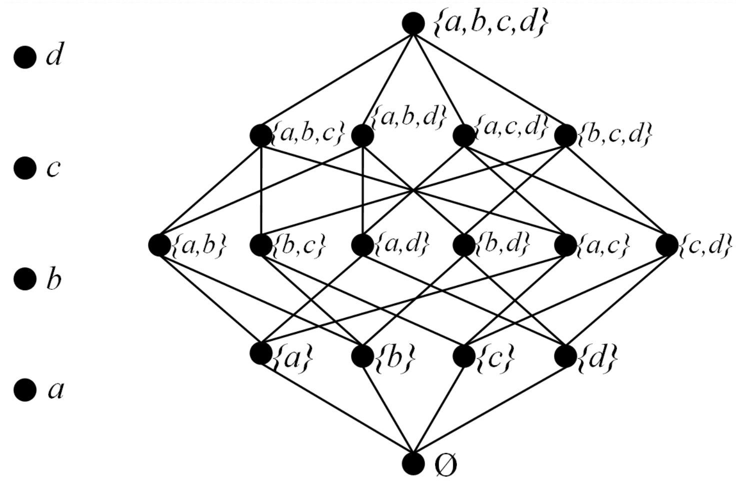

Figure 11. The maximum 16 possible skill states for the skills {a,b,c,d}

The computational complexity of CbKST is also dependent on the Bayesian update used to calculate the individual skill probabilities, this algorithm has a worst case exponential complexity of $O(2^n)$ for the number of skills. A further elaboration of CbKST is available in (Albert et al., 2007).

3.3 Personalisation

Within adaptive instructional systems, personalisation refers to the tailoring of a system to the characteristics of an individual learner for the benefit of their learning experience. Due to the diverse range of factors that can influence the learning process, personalisation can focus an adapting the learning content and activities, its presentation, the instructional techniques employed, and the support and feedback the learner receives. The three general categories of personalisation are commonly identified as Macro-adaptive, Aptitude-Treatment Interaction, and Micro-adaptive (Mödritscher et al., 2004; Park & Jung, 2003). These three categories although often used independently are not mutually exclusive and can be combined in adaptive instructional systems.

3.3.1 Macro-adaptive Personalisation

A Macro-adaptive system is characterised by the adaptive selection and sequencing of learning content based on the learner's abilities and the instructional goals (Mödritscher et al., 2004). A fundamental premise of macro-adaptation is that learning content can by segmented and annotated to identify its instructional impact. Based on the learner's abilities and learning goal as derived from the learner model, the system will generate a personalised course. This course can either be static and generated at the outset of the learning session, or can be dynamically adapted during the course based on the learner's progress.

The segmentation of the learning content and associated assessment can greatly benefit the accuracy of the learner model as a concrete indication of the learner's abilities can be obtained. However, this approach gives little indication as to the progress of the learner within a segment of learning content, and even if indicators were available, adaptations can only be performed between segments. The periodic nature of this form of adaptation limits its usefulness in providing feedback targeted at particular learner actions as and when they occur.

3.3.2 Aptitude-Treatment Interaction (ATI)

The theory of Aptitude-Treatment Interaction (Cronbach & Snow, 1977) proposes that the unique characteristics of a learner (their aptitudes) may require an entirely different form of instruction (the treatment) as compared to a different learner. Within this theory aptitudes are categorised to be either cognitive, or conative and affective (Snow & Swanson, 1992). The cognitive categorisation is further elaborated to include analytical reasoning, visual spatial abilities, verbal abilities, mathematical abilities, memory space, mental speed, cognitive and learning styles, and prior knowledge. Within conative and affective aptitudes the constructs of anxiety, achievement motivation, interest, volition, and self-efficacy are all significant considerations.

Whereas ATI is considered to have practical and self evident benefit in matching appropriate instruction to a given learner's aptitudes, there is a lack of convincing evidence as to which individual variables are useful for differentiating alternative treatments (Park & Jung, 2003). This lack of significant merit may account for the limited usage of ATI based personalisation.

3.3.3 Micro-adaptive Personalisation

As opposed to Macro-adaptive systems, Micro-adaptation is performed within segments of learning content and on a more continual and reactive basis. As a means to adapt a learning experience it focuses on maximising the benefit of the learning content through techniques such as continuous difficulty adjustment, targeted feedback, focused guidance, and motivational support (Park & Jung, 2003). The high frequency and regularity of the adaptations can increase the likelihood of learners experiencing a consistently suitable learning experience. In regards to difficulty adjustment the presence of a continually suitable challenge can be a strong contributing factor to a *flow* experience (Csikszentmihalyi, 1990), an experience that is desirable for its inherent motivation. However, one of the key challenges facing micro-adaptive systems is in the need for a continuous assessment of the learner due to the absence of concrete assessments as in the case of macro-adaptive systems. This continuous assessment of the learner's performance and abilities is based on the learner's interactions with the learning content and as such rarely takes the form of a clear assessment. The presence of such indicative yet imprecise evidence requires the use of inference methods comprising of expert systems and statistical modelling as discussed in section 3.2.

Despite the greater challenges of learner modelling within micro-adaptive systems they offer a greater potential to improve learning as opposed to macro-adaptive and ATI approaches (Park & Jung, 2003). The trend towards the use of adaptation within 3D and immersive learning environments warrants consideration of appropriate strategies for use in these highly interactive environments. Significantly it should be noted that micro-adaptation is the predominant form of personalisation performed within contemporary entertainment video games (Charles, 2003; Charles et al., 2005), arguably the most highly interactive form of digital media.

3.4 Adaptive Hypermedia

The research field of Adaptive Hypermedia (AH) (Brusilovsky, 1996, 2001) has had a strong focus on personalised instruction since its inception. As a combination of research efforts in user modelling, adaptive systems, and hypermedia; educational Adaptive Hypermedia has attempted to alleviate the difficulties of content comprehension and orientation. This is most commonly achieved through the use of adaptive presentation, content sequencing, and content selection to adapt the learning content to the learner's prior knowledge, capabilities, and goals. Despite the numerous instances of effective AH systems such as Interbook (Brusilovsky, 1996) and AHA! (De

Bra et al., 2003; De Bra & Calvi, 1998; De Bra, Smits, & Stash, 2006) the extent of adaptations possible within AH are limited by the nature of the media. The limited periodic interactivity provided by hypermedia as well as its limited leaner model bandwidth has been highlighted by (Murray, 1999). Further to this the increased familiarity of students with static web pages can cause confusion when content structure and availability is altered as is the case within an AH system (De Bra, 2000).

The limitations and interactions possible with hypermedia constrains the range of adaptations possible to be largely macro-adaptive in nature. However, this research area has contributed significantly to adaptive instructional systems research with notable examples being the multi-model metadata driven approach to adaptation (Conlan, Wade, Bruen, & Gargan, 2002) and the feasibility of providing personalisation as a service as is evident in the APeLS system (Conlan, 2004; Conlan, Power, Higel, O'Sullivan, & Barrett, 2003; Conlan & Wade, 2004). The educational theories applied to AH systems vary considerably from earlier behaviourist theories originating from ITS systems, towards more modern constructivist theories incorporating learner control and adaptation based on learning styles. Although more modern socio-constructivist learning theories are being embraced within AH, the medium itself does not inherently promote their uptake. This is in contrast to adaptive educational video games as explored in the following section whereby the nature of the medium actively promotes, if not requires their adoption.

3.5 Adaptive Educational Games

> *"The biggest thing limiting games in education in my view is the lack of good artificial intelligence to generate good and believable conversations and interactions….We need games with expert systems built into characters and the interactions players can engage in with the environment. We need our best artificial tutoring systems built inside games, as well….Then we will get games where the line between education and entertainment is truly erased."* -- (Gee, 2003)

Adaptive Educational Games (AEGs) are educational video games wherein the educational experience is tailored to the unique characteristics of the learner. As a merger of educational games and adaptive instructional systems this research area considers the challenges of game design, learning content integration, pedagogical theories, learner modelling, as well as the challenges that are unique to adaptive educational games. The most significant challenge to this emerging research area is the difficulty of preserving the 'fun' of the game whilst adapting the educational content that is invariably intertwined within the game.

One of the earliest ventures into adaptive educational games was by (Burton & Brown, 1976). Their development of the “How the West Was Won” game (see Figure 12 below) was strongly influenced by the prominence of ITS systems at the time.

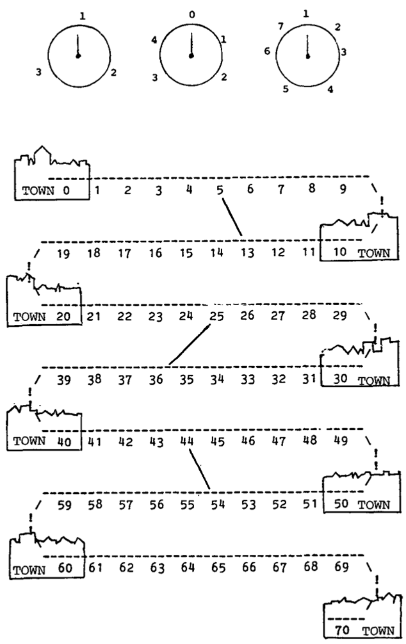

Figure 12. User Screen from 'How the West was Won', (Burton & Brown, 1976)

The arithmetic based drill and practice nature of the game is also indicative of the behaviourist learning theories that were popular at the time in CAI. Despite the early nature of the research a number of key points for the successful design of AEGs were identified including the importance of learner enjoyment, temporal learner modelling, and the importance of maintaining learner control.

The work of Burton and Brown continued to evolve beyond their first game and they explored differing learning theories such as guided discovery learning, and the significance of learner control and the learner’s gaming experience (Burton & Brown, 1979). The ITS approach being used was increasingly scrutinised as the deficiencies of using a single expert model became apparent, most notably where students were using superior play tactics than those anticipated by the experts. Further to this criticism the importance of non-invasive assessment through inference was highlighted as a desirable feature in such games.

> *"Since the student is primarily engaged in a gaming or problem-solving activity, any explicit diagnosing of a student's strengths and weaknesses must be unobtrusive or subservient to his main activity."* (Burton & Brown, 1979)

In addition to highlighting the difficulties of integrating ITSs and educational gaming, Burton and Brown also recommended 12 principles for the development of AEGs. These principles have been adapted below.

1. Advice should only be given for a learner's weak issues.
2. When illustrating an issue, only use an example that is dramatically superior to the learner's attempt.
3. When giving advice allow the learner to immediately employ the new advice.
4. If a student is about to lose, only interrupt them with advice to prevent them from losing.
5. Do not offer advice and tuition too regularly.
6. Allow the learner time to discover the game before tutoring them.
7. Do not only provide criticism from the tutor, also congratulate and explain exceptional actions.
8. Following advice allow the learner the option to retake a move but do not force them.
9. Always have computer experts play an optimal game.
10. If the student asks for help, provide several levels of hints.
11. If the student is losing consistently, adjust the level of play.
12. If the student makes a potentially careless error, be forgiving. But provide explicit commentary in case it was not just careless.

Although the above principles are more relevant to ITSs there are a number of key points surrounding learner control, feedback, immediacy, and challenge that persist into contemporary AEGs.

Despite the growth of educational games as highlighted in the preceding chapter, the instances of AEGs remained limited throughout the 80's and 90's. Whereas commercial video games at this time were experiencing an explosion in popularity the average student was still inexperienced with using computer systems. This inexperience was noted by (Leutner, 1993) in the 'Hunger in the Sahel' game where students had difficulties using the computers keyboard and monitor interface. This simulation game employed guided discovery learning to tutor geography students about the economics of small scale farming (Figure 13).

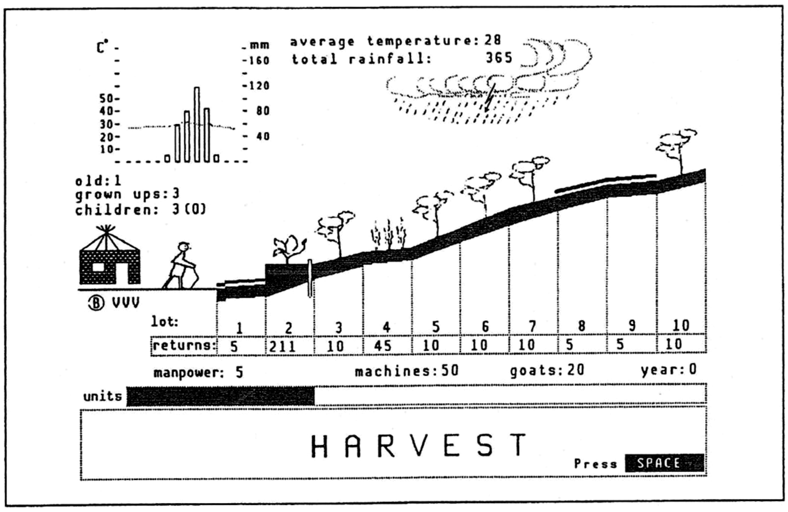

Figure 13. User Screen of 'Hunger in the Sahel' game, (Leutner, 1993)

The work of (Leutner, 1993) was a marked progression in AEGs as it began to consider the significance of learner motivation and self-confidence in conjunction with adaptation. Whereas (Malone & Lepper, 1987) had identified the importance of motivation within educational games, Leutner observed the impact of adaptive advice on learners with varying self-confidence and motivational states. This research highlighted how adaptive advice was more beneficial in acquiring domain knowledge than for functional knowledge. However, the adaptive support was also observed to hinder progress in learning how to play the game. In considering that the game was created by "overlaying a computer simulation game with a tutor module" (Leutner, 1993) it is evident the poor integration of the adaptive advice into the game was disrupting the gaming experience.

Further to the observations regarding motivation and self-confidence, Leutner also remarked on the challenge of evaluating AEGs and adaptive instructional systems in general. Of particular significance was whether it is the information that is presented that causes the learning effect, or is it the adaptive selection of that information. Whereas Leutner found that learners with higher anxiety benefited less from the adaptive selection he also suggested that this may be the result of the less anxious learners treating the experience as solely a game, and without any instructional intention. This leads one to propose that where an AEG can be made to seem more game like than instructional, the learners will be less anxious and consequently the adaptation will have a greater effect. Evidently the importance of tightly integrated gaming and learning in AEGs is an even greater concern than in educational games alone.

Despite this early progress in the development of AEGs the majority of the research in adaptive educational games has emerged since 2000. The interdisciplinary nature of the research drawing equally on adaptive instructional systems and educational game design has resulted in a fragmented publication base. However, this can be seen as a benefit with varying aspects of AEGs being published in areas such as instructional design, game design, human computer interaction, interactive digital storytelling, artificial intelligence, eLearning, and intelligent tutoring systems. This variety of publication targets has highlighted the considerable challenges faced in the development of AEGs as it is still an emerging research area.

3.5.1 Non-Invasive Adaptation

Contemporary video games feature highly crafted feedback loops and immersive experiences designed to maximize engagement. Over many years the art of video game design has evolved to achieve an optimal balance between interactions, challenges, game rules, and user control (Salen & Zimmerman, 2003). The introduction of adaptation into this finely balanced system presents benefits in terms of more suitable challenges and feedback, however this process of adaptation may detrimentally impact the player's understanding of the game world. The process whereby by a player plays a game involves them accepting the explicit rules of the game, and building a mental model of the implicit rules of the game world. Although these game rules can be unrealistic and fantastical, provided they are consistent a player can actively suspend their disbelief and become immersed within the game.

The main challenge with introducing adaptation into a video game lies in not disrupting the player's mental model of how the game world works. Whereas disrupting explicit game rules is unlikely, doing so can be perceived as the game cheating the player. As technical restrictions usually prevent the breaking of explicit game rules, the main concern of adaptation thus lies in preserving implicit game rules.

The expected or implicit rules of a game are determined by a player based on a combination of prior experience with similar games and expectations that are carried through from reality. The actions within an AEG that are likely to break these rules are those associated with explicit assessment for learner modelling, and the changes applied to the game world to realise adaptations. The need for non-invasive learner modelling has been identified by several authors (Burton & Brown, 1979; Conati & Zhao, 2004; Westra, van Hasselt, Dignum, & Dignum, 2009). Although explicitly questioning a learner can lead to a more accurate learner model and hence more appropriate adaptation, there exists a conflict whereby the gaining of direct feedback detrimentally affects the gaming experience and so hinders the learning experience. In doing this the benefits of game based learning are mitigated in a manner akin to the Shavian Reversals detailed in the preceding chapter. The need for non-invasive assessment has spurred the uptake of the inference and probabilistic learner modelling techniques detailed in section 3.2, and examples of these techniques in use are given in the following section

The second focus of non-invasive adaptation examines the impact that educational changes made to the game world can have on the gaming experience. The key to enabling non-invasive adaptations is to achieve all adaptations in a manner befitting the nature of the game. Essentially all adaptation must be considerate of the game context and must also anticipate the gaming impact of the educational adaptation. Achieving this context aware adaptation is typically achieved through a game design that limits adaptations to ensure they are non-invasive by nature. This approach although effective requires greater consideration from the game designer in designing adaptations and requires the game to be altered to add or amend adaptations. Further to this the adaptation becomes tightly bound to the specific game being adapted thus limiting future reuse.

3.6 Survey of Adaptive Educational Games

In this section a number of significant Adaptive Educational Games are surveyed to highlight the variety of approaches being applied in this research area. The following games each highlight methods and techniques that are being employed in game design, learner modelling, authoring, abstraction and reusability. This survey will conclude with a discussion on the current state of Adaptive Educational Games and the topics of concern within this field of research.

3.6.1 <e-adventure> framework

The <e-adventure> framework is a flexible game development framework designed to allow the easy authoring of 2D and 3D adaptive educational games. Although not a game in itself a number of example games have been developed using the framework including “Hall of the Kings”(Moreno-Ger, Martínez-Ortiz, Sierra, & Manjón, 2005), “Paniel and the Chocolate-based Sauce Adventure” (Moreno-Ger et al., 2007), and “HCT Blood Test” (Torrente, Moreno-Ger, Fernández-Manjón, & del Blanco, 2009).

Figure 14. Games developed with the <e-adventure> framework (Moreno-Ger et al., 2007)

The system provides the ability to author games which feature macro-adaptive task ordering and selection based on learner prior knowledge, in game exams, and learner task performance.

As a framework the <e-adventure> system aims to address the high development costs associated with video game production by employing reusable assets and providing authoring tools aimed at educators. The framework also tackles the issue of integrating video games into existing curricula through integration with Learning Management Systems (LMSs). Through focussing on a particular game genre, in this case point and click adventure games, the <e-adventure> framework enables a Domain Specific Language (DSL) to be used to author the games (Moreno-Ger et al., 2005). The advantage of this approach lies in the simplified authoring possible due to constrained options, and advantages in terms of assessment as learner model checking techniques can be used (Moreno-Ger, Fuentes-Fernández, Sierra-Rodríguez, & Fernández-Manjón, 2009). The DSL approach used in the <e-adventure> framework allows for a highly structured game to be developed that has clearly defined tasks and paths between tasks. This task structure is represented in the learner model and consequently allows for a verification model to be created allowing in game assessment.

The assessment of a learner's progress is the first step in providing an adaptive educational experience. Within the <e-adventure> framework assessment is performed based on the differences between the current learner model and a verification model that represents the ideal solution. Using assessment rules the differences between the two models can be analysed and appropriate adaptations performed. Although the use of verification models and model tracing can be considered intractable problems (see section 3.2) within specific domains they can have the added benefit of making the adaptation verifiable. The issue of the software verification of adaptive games is one rarely addressed, however it is an area that is increasingly important with the growing prevalence of adaptive educational games. The use of AEGs that are verifiable will no doubt benefit the uptake of such games in mission critical training. In the case of the <e-adventure> framework this approach no doubt justified the use of adaptive game based learning in the area of medical training (Moreno-Ger, Fuentes-Fernández, et al., 2009).

The adaptation within the <e-adventure> framework uses adaptation rules and finite state machines (FSMs) to tailor the learning experience to each individual learner (Moreno-Ger et al., 2008). Due to the LMS integration it becomes possible to boot-strap each game with the learner's prior knowledge as provided by the LMS (Figure 15). This approach ensures that the learner is going to be faced with a suitably challenging game from the offset. The adaptation performed consists of amending, omitting, or repeating tasks as appropriate for the learner. As each task is associated with a section of the game story this form of adaptation is entirely Macro-adaptive. To ensure the consistency of the game storyline while adapting the system, each individual task is authored in a manner so that its inclusion, omission, or repetition is not detrimental to the gaming experience.

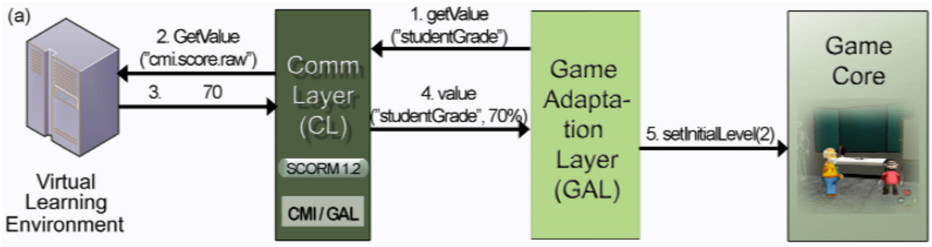

Figure 15. Example of the <e-adventure> framework bootstrapping a game from a VLE (del Blanco, Torrente, Moreno-Ger, & Fernández-Manjón, 2009)

The <e-adventure> framework makes use of a two layer middleware in order to achieve adaptation across multiple VLEs and multiple heterogeneous games. This consists of a Communications Layer (CL) that communicates with the VLE and supports eLearning standards such as SCORM (ADL, 2006), and a Game Adaptation Layer (GAL) that is game specific and is dependent on the nature of the game. The communication between the CL and GAL is based on abstract adaptation and evaluation concepts. The GAL translates these abstract concepts into actions or transformations within the educational game. This abstraction mechanism allows diverse games to integrate with a given VLE (see Figure 16), effectively mitigating the challenge of integrating adaptive educational games into established curricula.

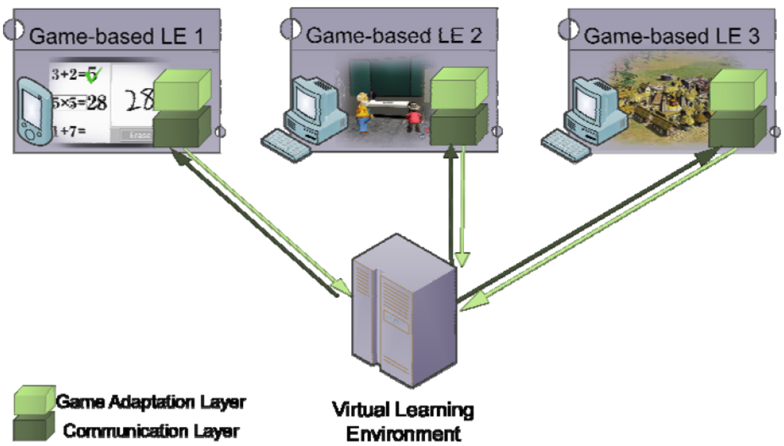

Figure 16. <e-adventure> Architecture Supporting Multiple Games (del Blanco et al., 2009)

The focus of the <e-adventure> framework VLE integration addresses the challenge of integrating educational games into existing eLearning systems and curricula. Further to this, the manner in which it supports reusable assets and instructor authored content aids in reducing the barriers to creating cost-effective educational video games. However, the importance of creating a compelling story within games is also noted by the authors and this is not a skill inherent to the average course instructor (Moreno-Ger et al., 2008). As well as identifying the need for collaboration between game designers, artists, and instructors, the adaptation model is identified as an area for future elaboration and enhancement (del Blanco et al., 2009). In consideration of the diverse possibilities for adaptation within video games, to solely restrict the games to Macro-level adaptation through task selection and ordering is not exploiting the full potential of the medium.

3.6.2 Façade: A One Act Interactive Drama

Although not directly promoted as an educational game, Façade has received considerable media attention[18] and respect for its academic achievements (Mateas & Stern, 2003, 2004, 2005) due to the highly innovative personalised gaming experience it provides. The game focuses on building awareness of the importance of gestures and verbal interaction in social relationships (see Figure 17 below).

Figure 17. Real-time rendered characters Grace and Trip in Façade (Mateas & Stern, 2003)

Centred around the married couple Trip and Grace, the player is immersed in the dramatic events that unfold one evening between the couple. Through an innovative dramatic sequencing system the actions and inactions of the player affect the ultimate outcome of the evening be it mutual happiness, marital breakdown or all possibilities in between. Allowing the player to enter natural language phrases, and gestures (via the mouse) the game micro-adaptively personalises the unfolding drama in a highly plausible and effective manner.

Although significant for the degree of adaptation provided the Façade game highlights many of the issues associated with developing complex adaptive educational games. With the creation of a number of custom technologies and a development time of five years, the Façade game exemplifies

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[18] "Redefining the Power of the Gamer", *The New York Times* Arts Section, June 7, 2005.
"When looks are no longer enough", *The Economist*, June 2006,
"You Must Play *Façade*, Now!", The Designer's Notebook, *Gamasutra*, July 2005
http://www.interactivestory.net/#press

the effort required in implementing adaptive narratives, even on this small scale of a game lasting 20 minutes.

The Façade game uses an innovative Natural Language Processing (NLP) system to allow the player to converse with the characters directly as well as using the mouse to make gestures towards each of the game characters. In order to ascertain the significance of both entered text and gestures a rule-based inference method is employed (Mateas & Stern, 2004). This technique allows the many possible player actions to be mapped to abstract discourse acts that in turn trigger rules that adapt the game's narrative. Examples of seven of the 24 discourse acts used in Façade include: Agree, Disagree, Oppose, Flirt, Pacify, Intimate, and Advice.

The Façade game demonstrates how innovative language and gesture based interactions can allow a player to directly adapt a games narrative in a coherent manner. However, the adaptation is short lived and effective solely in a confined single setting, highlighting the complexity of managing adaptive narratives and the arduous authoring process. As an adaptive educational game it succeeds in allowing the player to freely interact with the characters in a natural way with the storyline intelligently adapting around it. In consideration that linear game narratives are typically used as a motivating factor that provides an incentive to progress the game, the necessity of such a complex adaptive narrative is debatable. As adaptive narratives are still relatively rare in commercial entertainment video games the necessity of an adaptive narrative in an educational game is questionable.

3.6.3 Prime Climb

The Prime Climb game (Zhao, 2002) is a personalised mathematics game that uses an interactive pedagogical agent as the primary means of adaptation. The learning objective of this game is to aid 11-13 year old mathematics students to improve their factorisation skills. The core objective of this game is to complete all of the factorisations correctly in the shortest time possible. This game is notable for the manner in which the pedagogical agent volunteers assistance and guidance without user intervention. The selection of when to present the guidance is based on a real-time assessment of the learner's progress. Whilst the interface to this game is relatively simple its significance lies in the effective combination of an interactive NPC, player independent guidance, and learner modelling based on performance and pace.

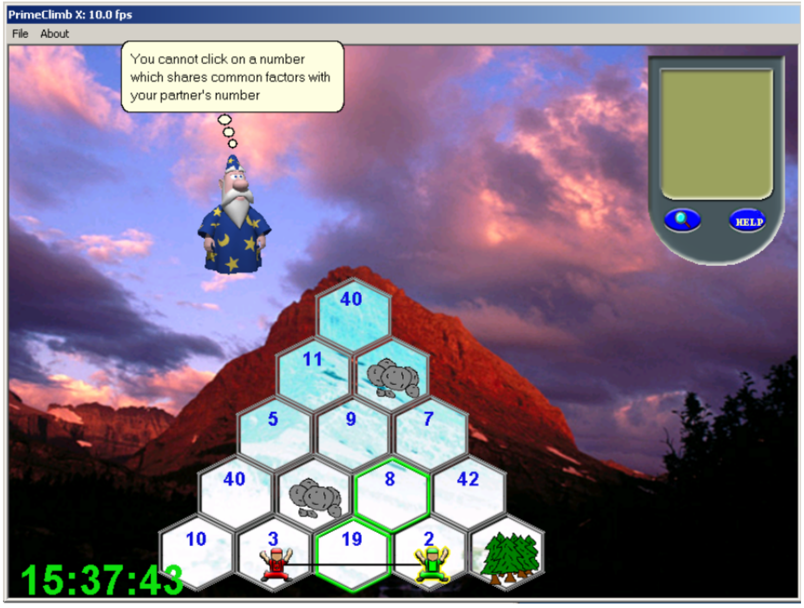

Figure 18. The Prime Climb Game (Conati & Manske, 2009)

A key approach emphasised in the Prime Climb game is the need to avoid explicitly querying the user in order to build a learner model. Whereas explicit questions can present a more accurate learner model the invasive process of questioning can mitigate the motivational and engaging nature of the game. It is for this reason that the Prime Climb game takes the approach of probabilistic user modelling whereby over time observed learner evidence develops a learner model that represents likelihoods as opposed to concrete assessments. Although ideally a learner model could be inferred purely by observing actions, this is rarely feasible and insufficient evidence can result in unreliable assessments. Within the Prime Climb game the necessity of balancing modelling by inference and explicit questions is highlighted. As improved modelling ultimately leads to an improved learning experience the invasiveness versus accuracy challenge becomes a trade-off between a player's learning and their entertainment (Conati, 2002).

The approach to probabilistic modelling used is one of Bayesian Networks to handle the uncertainty of assessment based on learner actions (Conati et al., 2002). The approach further considers the temporal and evolutionary nature of learner characteristics and accordingly uses Dynamic Decision Networks (or Dynamic Bayesian Networks) (Russell & Norvig, 2003) combined with physical sensors to assess the emotional state of learners (Conati, 2002). Whereas this approach considers the value of interactions beyond a mouse and keyboard, e.g. gaze, gesture, heart rate, skin conductance; the trade-off exists between improving the modelling and increasing the invasiveness.

The Prime Climb game highlights the infancy of research into adaptive educational games. Whereas it was envisaged that effectiveness of the learning experience was dependent on complexity and sophistication of the learner modelling, further evaluations of the game have shown this not to be the case (Conati & Manske, 2009). Although improved learner modelling may indeed improve the learning experience through greater personalisation, the invasiveness of interventions in this case was shown to negatively impact the learning experience. Through a further investigation of this phenomenon the authors propose that "some learning can be achieved with an inaccurate model, by favoring unobtrusiveness over intervening when it seems necessary" (Conati & Manske, 2009). The effect of invasiveness as here observed is evidently a challenge to personalised games. In considering addressing this challenge the authors propose the use of learner modelling that considers the expected effects of interventions on both student learning and affect. This approach aims to "achieve a trade-off between maintaining engagement and promoting maximum learning" (Conati & Klawe, 2002). Although the authors do not postulate on where the balance lies as to maintaining engagement and promoting learning, their approach towards improved modelling (and consequent invasiveness) evidently is naïve to the number of factors influencing a game based learning experience. Although a holistic approach to adaptive game based learning may present the greatest benefits, an increased understanding of the interplay between learner modelling, invasiveness, and learner affect will no doubt build upon the initial successes of sophisticated learner modelling (Conati & Zhao, 2004).

3.6.4 Tactical Language and Cultural Training System (TLCTS)

The TLCTS system (Johnson et al., 2004; Johnson & Valente, 2009; Johnson, Wang, & Wu, 2007) is one of the most technically advanced personalised educational games developed to date (see Figure 19 below). The game is targeted at military personnel who need to rapidly acquire a linguistic and cultural awareness in order to operate in foreign locales.

Figure 19. TLCTS Gameplay Screenshots (Johnson, 2007; Johnson et al., 2007)

The learning objective of the TLCTS series of games is to acquire a tactical knowledge of a language and an awareness of cultural sensitivities of the locale where military forces may be deployed. The term tactical language covers the conversational language required to gain the trust of the local inhabitants and determine local knowledge that may assist in military operations. Through an innovative combination of speech recognition, interactive pedagogical agents, and autonomous agent technology the game allows learners to be instructed and to practice speaking the foreign language upon which the game provides realistic feedback based on performance and cultural awareness (Johnson & Beal, 2005).

In addition to other languages the TLCTS has been primarily used to train Iraqi Arabic and Levantine Arabic as well as cultural considerations when conversing in Iraqi or Levantine locales. The game itself immerses the learner in a 3D virtual village where the learner has several goals that can only be achieved by conversing with the village inhabitants and gaining their trust. The TLCTS game is built upon the Unreal Engine and allows for detailed 3D environments with animated pedagogical agents, however the high technical requirements of the game have resulted in challenges in terms of evaluation and deployment (Johnson, 2007).

The approach to learning employed in the TLCTS system has its roots in ITS research. Accordingly the system embodies a largely behaviourist approach to learning whereby the learner engages in progressively harder tasks in which supportive feedback guides the learner to the optimum solution. Through the use of hierarchical problem spaces the best plan to progress the learner towards the end goal can be determined. In consideration of the inherent uncertainty of observed learner evidence a probabilistic approach to skill mastery is used which is then incorporated into a knowledge tracing model (A. T. Corbett & Anderson, 1995), akin to many ITS systems (Johnson, 2007). In a step beyond many model tracing techniques the use of *situated plan attribution* (SPA) is used to match learner behaviour to a library of procedural plans, based on the plans used by the learner the system can identify when a plan is not having the desired effect. Based on the identified plan the system can aid learners in overcoming impasses and can aid in avoiding similar future situations (Johnson, 1995).

The use of pedagogical and autonomous dramatic agents provides a uniquely integrated approach to educational games. The justification for the complexity involved in achieving this lies in the desire by the authors to allow the learners to transfer their new skills to real-world scenarios. Through creating a realistic dramatic environment wherein the learner is immersed in an entirely foreign linguistic and cultural setting, TLCTS strongly emphasises the importance of situated cognition. Although this approach is no doubt effective and beneficial there are aspects of the learning experience that are distinctly removed from the game world, yet of significant educational importance. The accessibility of the learner models is one such example. In this case a scrutable learner model as well as transparent learning objectives are available to the learner, yet in an interface outside of the game world (Figure 20 below). Although presenting a scrutable learner model is a positive advancement, the ability to integrate learner model scrutability and reflection within a game interface remains a desirable feature.

Figure 20. TLCTS Skill Builder interface (Johnson & Beal, 2005)

A key feature of the TLCTS is the extensive use of pedagogical agents throughout the game. The motivations for employing pedagogical agents range from their use as demonstrators and navigational aids to their roles as virtual teammates. The non-intrusive nature of pedagogical agents that are relevant to the game narrative allows them to provide non-verbal feedback through gaze, gesture, and emotional feedback. As well as providing verbal feedback the non-verbal feedback effectively increases the bandwidth of communication between the learner and the pedagogical agents, a feature that increases the ability of the system to engage and motivate learners. It is suggested that through greater engagement and motivation such approaches can contribute to bridging the effectiveness gap between human and computer based tuition (Johnson, Rickel, & Lester, 2000).

In order to imbue the pedagogical agents with a greater sense of realism the game draws on autonomous agent research to enable individual agents to reason over the best course of action based on what they can observe within the game world. Through the use of the THESPIAN system (Si et al., 2005) the pedagogical agents effectively perform an interactive pedagogical drama whereby each agent has independent goals and autonomy. As each agent considers not only the immediate effect of its actions but also the expected responses of other agents, the agents become more believable and appear to make more reasonable decisions. To further enhance the believability of the agents, careful consideration has been given to their interpersonal communication both verbally, and non-verbally through gaze and gesture. Of particular significance is the issue of politeness in these communications and within TLCTS this has been achieved through the application of Politeness Theory (P. Brown & Levinson, 1987). Interestingly the rules that govern polite interactions such as the right to non-distraction, and freedom from imposition can understandably result in non-invasive communications, a considerable factor in non-invasive adaptation.

The approach to personalisation used in the TLCTS system relies on a multi-model approach that employs learner, culture, skill, and language models (Johnson & Valente, 2009). The learner modelling on which the personalisation is based uses a combination of quizzes, dialogue performance, and plan monitoring. Through a combination of direct evidence, inference rules, and Bayesian based knowledge tracing the learner model is continually updated to reflect the learner's current state. Using the learner model the system adapts the difficulty of the game to present an appropriate challenge, intervenes to assist with troublesome tasks, and adapts learner feedback to reflect their learning game progress (Johnson et al., 2005). Although similar levels of adaptation can be found in other adaptive games what makes TLCTS interesting is the effort taken to integrate these adaptations within the game world in a manner that is consistent and appropriate. Although there is no explicit use of a non-invasive component within the TLCTS architecture, the adaptations are effectively non-invasive by design, further to this the dramatic sequencing provided by the THESPIAN system ensures the appropriate interactions of the NPCs with the learner.

The TLCTS series of games represent some of the most advanced adaptive educational games developed to date. The extensive evaluations (Johnson & Beal, 2005; Johnson et al., 2007) of the system as well as the real-world deployment of the system is evidence of the potential benefits of the adaptive educational games. Despite the demonstrated effectiveness of the system there remain challenges surrounding reproducing the results across varying learning content and game styles. The tightly bound nature of the personalization features and the game has been effective but is also a limiting factor in its reuse across varying games.

3.6.5 Virtual Team Collaborator (VTC)

The VTC game (Spring & Ito, 2007) aims to teach basic social skills in group work and project management. Through combining narrative scenarios and problem based learning the VTC game creates a personalised learning path through the game. The approach taken creates an adaptive narrative through the game that also contains learning problems tailored to the skills and preferences of the learner. Through the use of adaptation rules derived from didactical and psychological theories the game personalises the difficulty of the learning content based on the learner's skills and preferences.

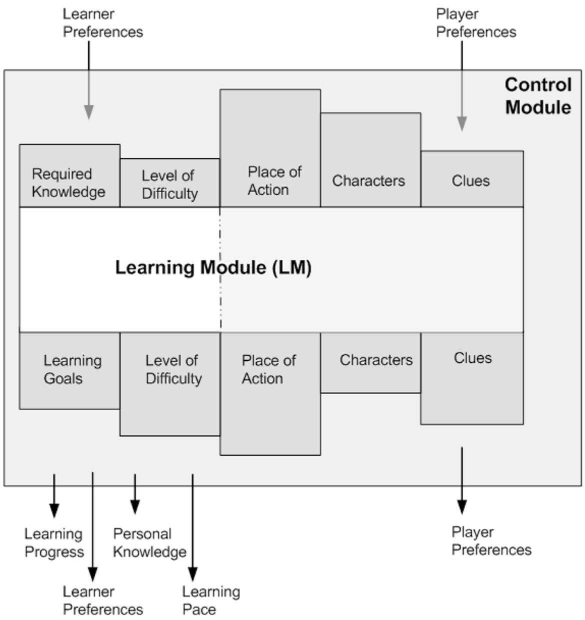

Figure 21. VTC Learning Module showing annotations (Spring & Ito, 2007)

The challenge of maintaining narrative consistency is addressed in VTC using a system of 'lock-and-key' learning modules (LMs) that each consist of a narrative scenario and one or more scenario based learning tasks. The authoring of each LM requires that it be annotated with the accepted incoming and outgoing learning preferences and narrative state (Figure 21). Through building up a repository of LMs it becomes possible to join learning modules together in a manner that ensures both narrative consistency and a learning experience personalised to the learner.

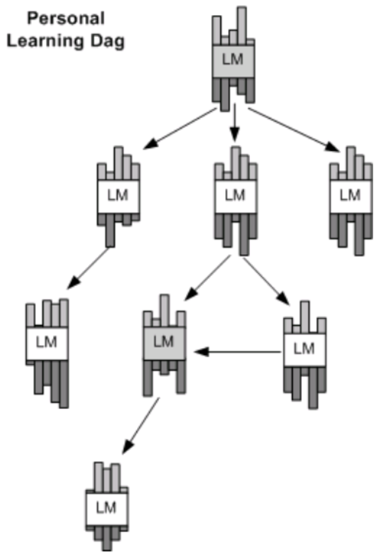

Figure 22. VTC Personalised Learning DAG with grey key plot nodes (Spring & Ito, 2007)

The possible combinations and orderings of learning modules can be represented as a directed acyclic graph (DAG) that consists of all of the paths that can possibly be taken through the game's narrative (Figure 22). The personalisation based on the learner's skills and preferences determine the exact path taken through the DAG.

Although specific details relating to the learner modelling techniques used are not available the authors emphasise the importance of implicit learner modelling. This approach to learner modelling does not interrupt the learner with quizzes and questionnaires that remove them from the gaming context. Further to this the authors' emphasis on maintaining gaming context has evidently influenced the adaptive yet consistent approach to game narrative. A notable feature of the VTC game is that it provides non-invasive adaptation at a macro level. Although this ensures a consistent game narrative it also suffers from the key challenge of other such macro-adaptive games, that being the need to create a large repository of LMs, many of which may never be used by a given learner.

3.6.6 Ecotoons2

The Ecotoons2 game (Carro, Breda, Castillo, & Bajuelos, 2002a, 2002b) aims to address the cost and complexity issues associated with the development of adaptive educational games. The approach taken involves the composition of multiple mini-games into a personalized gaming experience. The Ecotoons2 game shown below in Figure 23 builds upon the existing educational game Ecotoons by expanding the variety of mini-games available and through improving upon their sequential nature. The learning content of the game focuses on mathematical reasoning abilities in the areas of counting, adding, subtracting, and manipulating fractions for learners aged 5-18 years.

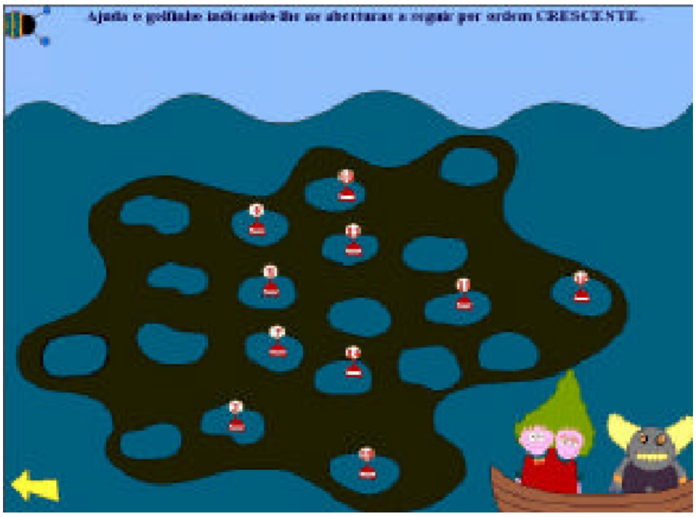

Figure 23. Ecotoons2 Screenshot (Carro et al., 2002a)

The Ecotoons2 game personalises the learning experience based on learner models that consist of the learner's age, preferred language, and preferred media. Through using a collection of up to 90 mini-games a gaming experience can be dynamically generated for the learning goals of each individual. In order to compose an appropriate learning experience each mini-game is annotated with learning goals, difficulty, and the suitability of the game for each learner profile. Through grouping one or more games into an activity group it becomes possible to create a learning activity that spans multiple games as well as imposing a narrative consistency between the games. The significance of this approach lies in the use of decomposition rules that are associated with each activity group. The decomposition rules indicate the ordering of activity groups and the conditions that will activate a given group at runtime. The conditions for activation are dependent upon the learner's profiles and behaviours whilst playing the mini-games. As a dependency can exist between learning activities prerequisite rules are used to impose a conditional ordering between activity groups. At runtime the Ecotoons2 game dynamically selects and sequences activity groups based on the decomposition rules to identify suitable activities, and prerequisite rules to determine the ordering of these activities. However, as the prerequisite rules depend upon the learners' performance within the mini-games the ultimate sequence and selection of mini-games will be unique to each learner but also to each use of the Ecotoons2 game. An example of how activities map to games is given below in Figure 24. In this example there are two main activity groups Objects and Numbers and seven sub-activity groups. The decomposition rules are indicated by the straight solid arrows and the prerequisite rules are indicated by the dashed curved arrows.

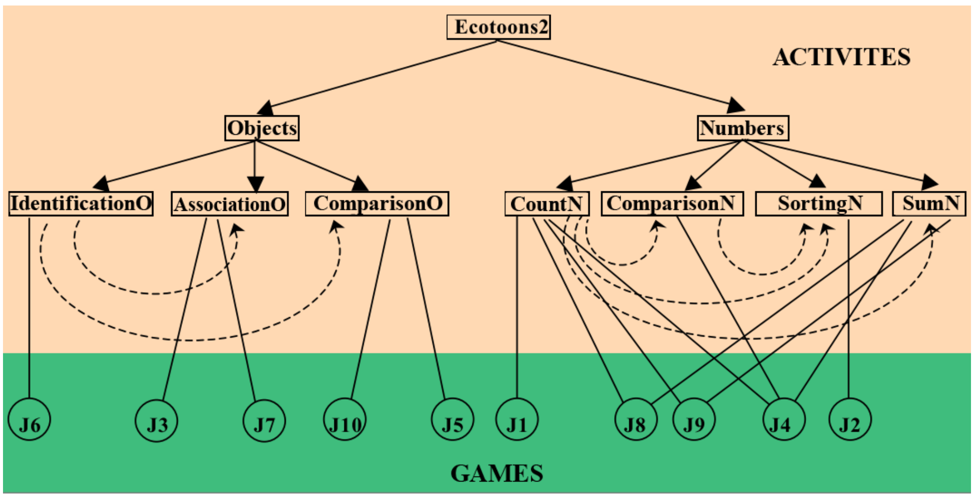

Figure 24. Example Ecotoons2 activities with decomposition arrows and dependencies (dashed arrows). Translated from (Carro et al., 2002a)

The approach taken within the Ecotoons2 game effectively addresses the problem of underused learning resources within adaptive educational games. Although a large collection of mini-games is required by the system, the ability to reuse the same mini-game assets across multiple activity groups and for multiple learning goals maximises their potential reuse. Although this approach maximises the usage of the authored assets in a macro-adaptive game, there remain challenges in providing a consistent feedback mechanism throughout the overall game. Although feedback is provided by each mini-game and activity group there is no holistic approach to feedback whereby progression of feedback is possible. Essentially each mini-games' feedback is entirely self contained and may well be a repetition or even contradiction of previous mini-game feedback. Despite the challenge of consistent feedback the Ecotoons2 game presents a flexible methodology for the design of adaptive educational games that can accommodate varying pedagogical approaches through the authoring or decomposition and prerequisite rules.

3.6.7 VR-ENGAGE / VIRGE

The VR-ENGAGE (Virtual Reality - Educational Negotiation Game on Geography) game is a Virtual Reality adventure game that is based on proven ITS techniques such as overlay user modelling and pedagogical companion characters (Virvou & Katsionis, 2008; Virvou et al., 2005; Virvou, Manos, Katsionis, & Tourtoglou, 2002). The game allows learners to navigate through a 3D virtual reality world in pursuit of the game's goal. To complete the game the learner must find all of the missing pages from the book of wisdom by exploring a medieval castle and where a guard dragon blocks their path and asks questions from the domain of geography (see Figure 25).

Figure 25. VR-ENGAGE Screenshot (Virvou et al., 2005)

The VR-ENGAGE game allows learners to start a negotiation with the game when faced with questions where they are unsure of the correct answer. This approach to knowledge assessment aims to assess partial understanding and to provide a more definitive picture of the learner's knowledge state. The analysis of the learner's negotiations are based on Human Plausibility Theory

(Collins & Michalski, 1989) that "formalizes the plausible inferences based on similarities, dissimilarities, generalisations and specialisations that people often use to make plausible guesses about matters that they know partially."(Virvou et al., 2005). This non-binary assessment of ability requires the extension of overlay modelling to include partial understanding. This approach to modelling further considers that a full or partial understanding of a piece of knowledge will be forgotten over time and that the degree of forgetfulness is a power function of the break duration between exposures. In the case of VR-ENGAGE an approximation of how much may be remembered over time is based on the research of Herman Ebbinghaus (Ebbinghaus, 1998). The equation and graph of the equation shown in Figure 26 illustrates how the percentage equivalent of the amount remembered *b,* is dependent on the time *t* in minutes from when the learning ended, and the constants *k=1.84* and *c=1.25* that are calculated by observation of real world memory results (Ebbinghaus, 1998) (Chapter 7, section 29). The logarithmic nature of this equation results in a quick drop-off of retention shortly after learning, followed by a more stabilized gradual decline.

$$b = \frac{100k}{(\log t)^c + k}$$

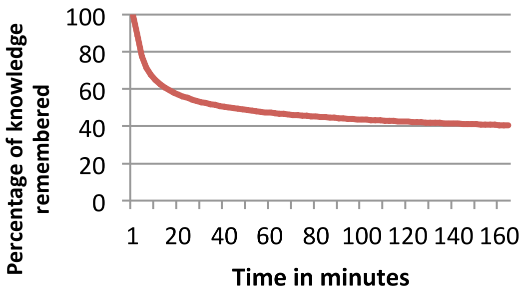

Figure 26. Ebbinghaus equation for knowledge remembered over time (Ebbinghaus, 1998)

The progressively changing knowledge levels coupled with the partial knowledge assessed through negotiation provides an assessment of the learner's knowledge at any given instant. This approach to learner modelling not only acknowledges that knowledge levels can vary over time but also that through the use of non-binary assessment, in this case via negotiation, a finer grained learner model can be derived. This fine grained learner model is then used to generate individualised instruction and advice for students.

The delivery of instruction and advice within VR-ENGAGE is achieved through pedagogical agents that act either as opposition (in the case of the dragon character) or as a companion (as in the case with angel character) as shown in Figure 27 below.

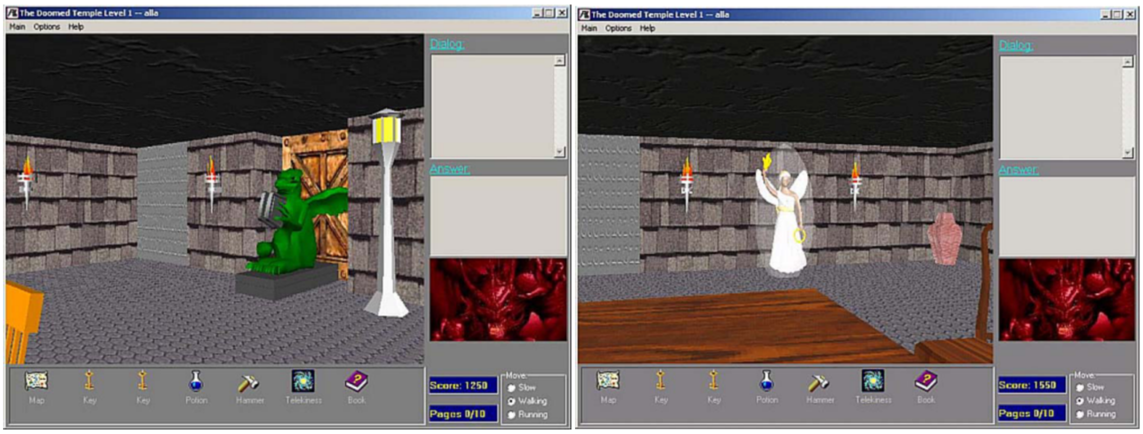

Figure 27. The dragon and angel characters from the VIRGE game (Katsionis & Virvou, 2007)

The use of pedagogical agents within the game is an attempt to create a social context for learning. The importance of the social dimension of learning in this research is further explored in the VIRGE (Virtual Reality Game for English) game through the use of affective learner modelling techniques (Katsionis & Virvou, 2004). The VIRGE game builds upon VR-ENGAGE with the addition of affective user modelling allowing the game's pedagogical agents to express empathy and react to the changing emotional state of the learner.

In order to determine the emotional state of the learner the VIRGE game classifies the user's interaction patterns based on expertly determined criteria. Through the use of log file analysis, five experts were able to associate interaction patterns with emotional states. The approach taken to gathering learner evidence is in this game entirely observational and is effectively non-invasive as there are no explicit prompts or physical sensors employed. The metrics that were shown to be useful in determining emotional states were answering time, pause time after a system response, the number of textual corrections, and mouse movements. These metrics were found to correspond to measures of the degree of speed, degree of surprise, degree of certainty, and the degree of concentration, frustration or intimidation. Further to these measures, the following specific inference rules were used to measure anxiety and determination.

> *"If a student repeatedly answers questions with a high degree of speed and s/he produces a high degree of incorrectness then this may show* anxiety*."*
>
> *"If a student repeatedly shows a high degree of confidence irrespective of correctness of his/her answers then this may show* determination *(the student does not give up)."*
> (Katsionis & Virvou, 2007)

The use of declarative inference rules is further elaborated in (Katsionis & Virvou, 2007) whereby rules are authored based on threshold values determined from log file analysis.

A further novel aspect of the VIRGE architecture is the use of web services to separate the client interface from the long term student model. This approach allows the system to centralise the learner models facilitating subsequent log file analysis whilst allowing individual clients to perform the inference for learner modelling. Although this approach is effective on desktop based PCs the system's architecture would be hindered on resource constrained devices such as smart phones and tablet based computers.

Despite the demonstrated effectiveness of the VR-ENGAGE/VIRGE systems the authors highlight that the effectiveness of their game based learning is predominately of benefit to weaker and underperforming students. The authors further suggests that this unbalanced benefit is likely due to the lack of motivation and interest common among weaker students, and how the gaming environment provides the motivation they are deficient in. This outcome further indicates the importance of motivation in learning and consequently the importance of maintaining an engaging gaming experience, as it is a predominant source of intrinsic motivation.

3.6.8 ELG, S.M.I.L.E, NUCLEO, SCRUB

The current state of the art in Adaptive Educational Games is largely covered by the above games. However, there exist a number of further games that have been developed to a lesser extent or have limited details published. These games none the less each highlight the diverse approaches taken towards developing adaptive educational games and each identify significant aspects in the design of such games.

3.6.8.1 ELG

The ELG game (Retalis, 2008) allows teachers to create adaptive games based around a snakes and ladders style board game (see Figure 28). The ELG game features an authoring environment that allows teachers to generate games on various topics, with examples including mathematics, nutrition and archaeology.

The learner modelling component of the game captures the learner's knowledge level (novice, intermediate or advanced), their interests, and activity data about the questions tried and hints used. The core adaptation performed is to guide the gameplay in order to make the learner repeat certain questions or follow a particular path through the content. This macro-adaptation is achieved through the novel approach of modifying the game mechanics, in this case the assumed random dice rolls are in fact governed by instructor authored rules.

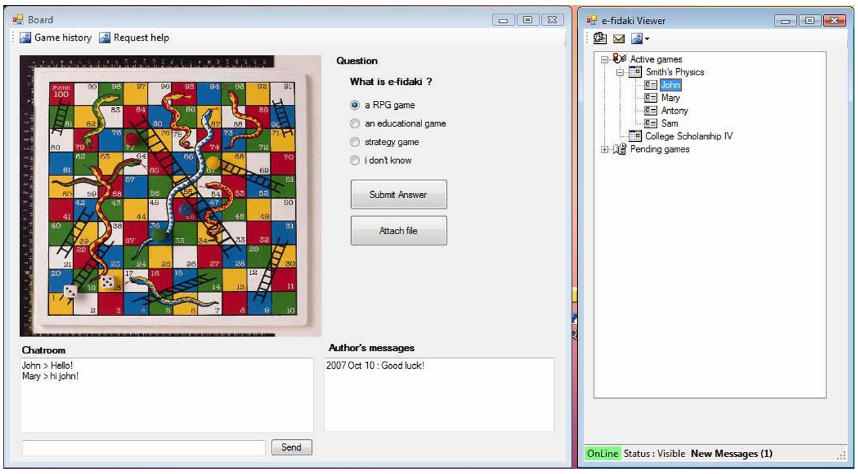

Figure 28. ELG game screenshot (Retalis, 2008)

Through this approach the adaptation is in effect non-invasive as it uses an existing unpredictable game component, the die roll, to modify the game experience. Whereas this approach can effectively adapt the learning experience, should the learner become aware of the biased die their understanding of the implicit rules of the game will change. In consideration that an unbiased die is a realistic norm to expect, the adaptation would seem to break the expected rules of the game, and in the process risk reduced engagement and immersion.

3.6.8.2 S.M.I.L.E.

The S.M.I.L.E. (Smart Multipurpose Interactive Learning Environment) system (Bieliková, Divéky, Jurnečka, Kajan, & Omelina, 2008; Divéky, Jurnečka, Kajan, Omelina, & Bieliková, 2007) further takes the approach of facilitating teachers in the authoring of adaptive games. As the S.M.I.L.E. system allows the game author to target varying subject areas such as mathematics, biology or chemistry, the make up of the game world and non-playing characters needs to vary accordingly. To achieve this, the system composes each game based on the learning content, the available game assets, the user's preferences, and the user's accessibility needs. Further to this, each game is generated at three difficulty levels to allow the game to adapt to the learner's changing skill level during gameplay.

The adaptation of the learning tasks within the game is based upon a learner's estimated skill level. This skill level is determined based on the learner's performance in each task and the difficulty of the task undertaken. The S.M.I.L.E. system reacts to a learner's changing skill levels by guiding the learner towards NPCs and game interactions that will present a suitable challenge for the learner.

One of the key focuses of the adaptability and adaptation of the S.M.I.L.E. system is the emphasis placed on accessibility and universal access. Through this approach the game becomes accessible and useful to a broader audience than is the case for many conventional educational games. In particular the system incorporate an adaptable user interface to cater for visual impairments (see Figure 29 & Figure 30) as well as providing interaction through Braille keyboards, voice recognition, and speech synthesis.

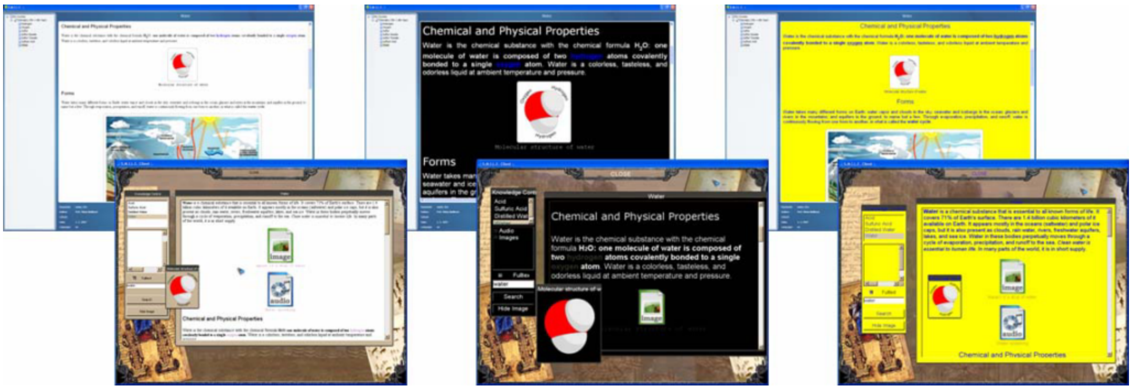

Figure 29. Adaptable User Interfaces from the S.M.I.L.E. system (Divéky et al., 2007)

Figure 30. Adaptable avatars in the S.M.I.L.E. system (Divéky et al., 2007)

3.6.8.3 NUCLEO

The NUCLEO system (Sancho, Fuentes-Fernández, & Fernández-Manjón, 2008; Sancho, Moreno-Ger, Fuentes-Fernández, & Fernández-Manjón, 2009; Sancho-Thomas, Fuentes-Fernández, & Fernández-Manjón, 2009) provides a collaborative eLearning environment based around a role playing virtual world as is shown below in Figure 31. As a learning environment NUCLEO is strongly rooted in socio-constructive pedagogical theory and effectively combines Problem Based Learning (PBL) and Computer Supported Collaborative Learning (CSCL). Within the virtual world the learners work in teams to collaboratively tackle game tasks in areas such as computer programming. As an adaptive educational game the NUCLEO environment is unusual in the target of the adaptations. Due to the multiplayer nature of NUCLEO games any world adaptations performed for the benefit on an individual learner will impact upon all learners. In consideration of this the game takes the novel approach of not adapting game world features but adapting the teams within which the learners play the game.

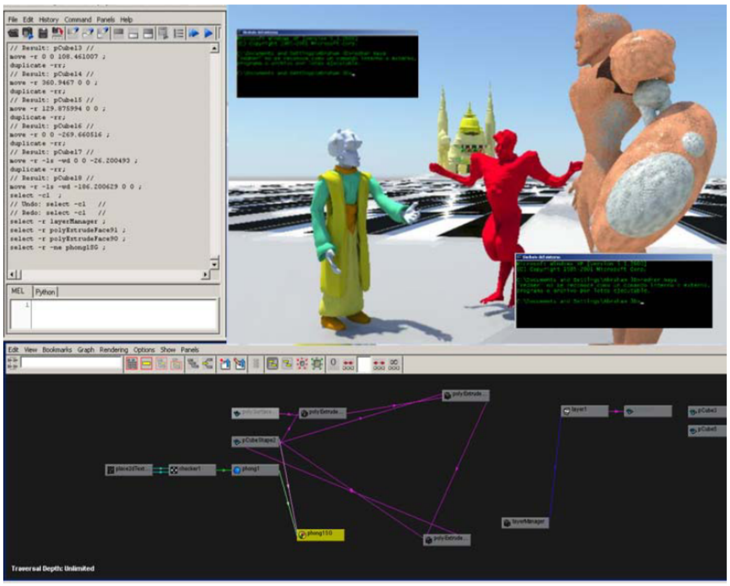

Figure 31. NUCLEO Virtual World Screenshot (Sancho et al., 2008)

Through the use of questionnaire input prior to playing the game, each learner model records a predominant learning style based on Vermunt's learning styles (Vermunt, 1992). The four learning styles classified by Vermunt are meaning-directed (MD), application-directed (AD), reproduction-directed (RD), and undirected (U). In order to create teams based around the learning styles learners are assigned to one of three 'tribes' corresponding to their learning style, due to the similarities between MD and AD these styles are combined into a single profile. Within each team different tasks are assigned to members depending on their tribe, the MD/AD tribe members are in charge of project planning and progress monitoring, the RD members must control and supervise all team members, and the U members must manage the communication between the team and the tutor.

The formation of the initial teams is based on the questionnaire assessed learning styles, however, following each completed mission based on a team's performance, each learner's peer-reviewed score, and the usage made of tribe specific tools learners can be reassigned to different tribes and the teams adaptively recomposed. The re-composition of teams is governed by role assignment rules that can reduce intra-team conflicts and allow learners the possibility of experiencing a variety of social game contexts.

The use of NUCLEO as a tool to foster teamwork skills through collaborative problem based learning is both innovative and considerate of existing pedagogical approaches. As is acknowledged in (Sancho-Thomas et al., 2009) the use of virtual worlds is at odds with many existing pedagogical strategies being used in universities. Through providing a tight integration with Learning Management Systems (LMSs) the NUCLEO game can be integrated with existing eLearning strategies (Figure 32) and presents a realistic approach to promoting the acceptance of game based learning in mainstream formal education.

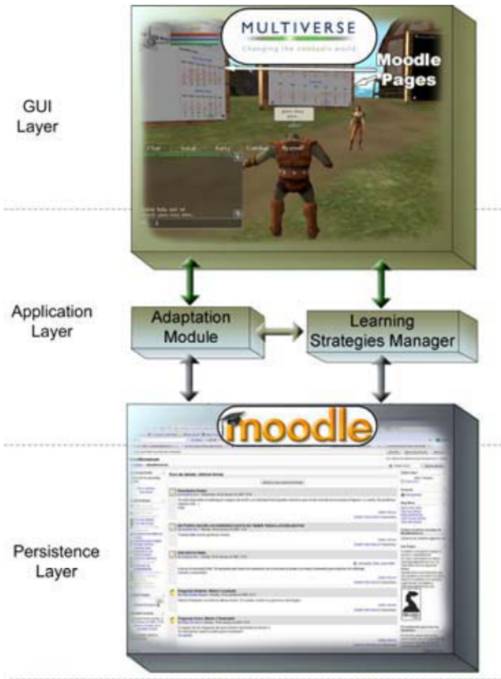

Figure 32. NUCLEO integration with the Moodle LMS (Sancho et al., 2009)

3.6.8.4 SCRUB

The SCRUB (Super Covert Removal of Unwanted Bacteria) game is an adaptive mini-game that aims to teach microbiology concepts (Magerko, Heeter, Fitzgerald, & Medler, 2008). The game in particular aims to demonstrate how rubbing, rinsing, and the use of cleaning agents can affect MRSA (methicillin-resistant staphylococcus aureus) microbes on the surface of the hand.

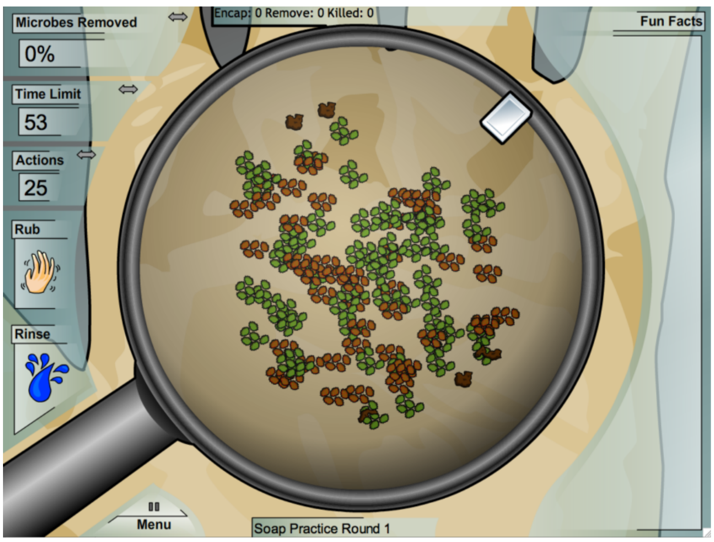

Figure 33. The SCRUB Game (Magerko et al., 2008)

The user modelling component of the SCRUB game aims to classify learners based on the motivations they are likely to have for engaging with the game. In particular the authors identify three types of gameplay motivations: intrinsically motivated *Explorers*, extrinsically motivated performance-approach *Achievers*, and extrinsically motivated performance-avoidance *Winners* (players who are motivated to win to avoid losing). The classification of each learner into these categories is based on either the learner's explicit preferences before playing the game or on a pre-game questionnaire. The appropriate game mechanics features to match with motivation categories are given below in (Figure 34).

	Intrinsic	Extrinsic	
	EXPLORER	ACHIEVER	WINNER
		Performance-Approach	Performance-Avoidance
Explore Mode	Yes	No	No
Bonus (extra) Trivia	Yes	No	No
Timer (speed bonus points)	No	Yes	No
Leader Board	No	Yes	Yes
Trivia Qs (show me option)	No	No	Yes
Tutorial	No	No	Yes

Figure 34. Matching game mechanics and motivation categories for the SCRUB game (Magerko et al., 2008)

The novel approach taken within SCRUB to accommodate the varying motivations is to adapt the game mechanics to better suit each category of learner. This approach in effect maintains the educational content of the game yet lets learners play in their preferred game style. This approach is significant as it places pertinent emphasis on the diversity of game style preferences amongst learners as well the impact apt game styles can have on motivation. Although this approach may suit within the context of a relatively short mini-game, there may exist challenges within this approach in consideration of certain game styles being appropriate for particular leaning content as is popularised by (Prensky, 2001).

3.6.9 Comparison of Key Features across Adaptive Educational Games

The representative adaptive educational games surveyed in the above sections demonstrate the variety of determinants (the learner evidence), constituents (what is being adapted), and the adaptation logic being employed in contemporary adaptive educational games. Despite the breath of research directions being undertaken a number of thematic considerations emerge as significant design goals in adaptive educational games.

3.6.9.1 Evolving Pedagogical Strategies

The nature of educational and adaptive educational games has progressively changed with advances in computer graphics, user interface devices, and increased processor performance. This technological progression has radically altered the realism and immersive potential of AEGs, however the fundamental constituents of games notably their rules, goals and interaction mechanics have not changed. The changes in educational games that are radically altering the learning experiences are the contemporary pedagogies being employed within these systems. Whereas the initial instances of AEGs were grounded in behaviourist, instructionist theories (Burton & Brown, 1976), contemporary systems have largely adopted constructivist theories such as experiential and problem-based learning (Johnson & Wu, 2008; Mateas & Stern, 2003; Sancho et al., 2008). In line with this move towards constructivist learning theories there has been a notable shift towards a more user-centred learning process that emphasises self-directed learning. As a consequence of this there is a growing trend towards catering for the motivational and affective impact of game based learning, an effect previously orchestrated by a human instructor.

The increasing emphasis being placed on the experiential nature of game based learning is reflected in the increasingly holistic approach to adaptive game design being employed. Of the areas drawing focus in particular are that of game narrative, non-invasive assessment, and situated cognition. The significance of game narrative forms a lynchpin of the Façade, TLCTS, and VTC games. In these games the learner is continually engaged in a narrative that adapts to them yet maintains consistency and plausibility. The growing prominence of non-invasive assessment is evident throughout many of the adaptive games surveyed and is unsurprisingly an increasingly popular approach. As part of a user-centred design approach the use of invasive popups and explicit assessment questions can be seen as at odds with maintaining an enjoyable and immersive gaming experience. The alternative approaches taken to accommodate for this rely on inferring learner evidence based solely on user actions and inactions within the game world. This approach is most evident within the Façade and TLCTS games wherein the learner's interactions with NPCs form the basis for learner modelling. The key challenge of this approach lies in inferring the significance of the learner's actions from a learning perspective. This problem is largely being tackled using a combination of finite state machines (<e-adventure>), rule based logic (Ecotoons2), and statistical modelling techniques (TLCTS, Prime Climb). In the case of the Prime Climb game the use of Dynamic Bayesian Networks presents a powerful technique to assess learner intent and performance based on a diverse and continuous set of inputs. In consideration of the growing complexity of video games and the corresponding abundance of learner and context evidence, statistical modelling is likely to have an increasingly significant role in non-invasive learner modelling.

3.6.9.2 Learning Context Integration

As part of considering the overall integration of educational games and AEGs into mainstream education the role of the instructor is highlighted as a significant consideration. As a key approach to gaining the support and uptake of instructors the use of instructor authored games can create a sense of ownership amongst instructors as well as allowing them to tailor a game for a particular group of learners. In the cases of <e-adventure>, ELG, and S.M.I.L.E. the instructor is given constrained control to add learning content and adjust gameplay mechanics without the need to author an entire game engine.

Despite the benefits of instructor authored games there is an acceptance that game design, educational game design, and adaptive educational game design, are progressively challenging design problems. The challenge of game design alone stems from it being a second-order design problem. In this case the game designer is attempting to design a system to solve the entertainment need as opposed to just creating the entertainment (Salen & Zimmerman, 2003). The challenge is further increased with the addition of educational content and the associated integration challenges, as is highlighted in the preceding chapter. The final challenge of managing adaptation technologies such as finite state machines, rule based logic, and statistical inference, is an unrealistic expectation from a typical instructor's skill set (Moreno-Ger et al., 2008). The ever increasing complexity of educational video games and AEGs does not bode well for the future of instructor designed games without significant advances in authoring tools.

3.6.9.3 Evolving Design Considerations

The increased flexibility offered by contemporary video games in terms of both interfaces and visualisations is altering the design considerations for adaptive educational games. Through the increased use of 3D worlds and highly interactive interfaces the bandwidth of learner interaction is steadily increasing. In line with the growing complexity of the games, the variety and frequency of learner evidence is altering the learner modelling approaches. Whereas Burton and Brown (Burton & Brown, 1976, 1979) dealt with very limited but concise learner evidence, games such as TLCTS and Façade must use complex inference techniques to assess the learner. This added complexity not only removes the authoring of such games from the realm of instructors, it additionally adds to the developmental costs of such games.

One approach that aims to address this cost burden is the use of personalisation services in a manner akin to SaaS (Software as a Service). Through decoupling educational personalisation from game design you facilitate both independent authoring and the reuse of complex adaptation components. Although in its infancy this approach is already being explored by the VR-ENGAGE/VIRGE, NUCLEO, and <e-adventure> systems.

A further burden to the success of such games is the cost of developing collections of game assets and learning content, even though a personalised experience may only reveal a fraction of this content to the learner. One such design change that can alleviate this burden is the more efficient reuse of gaming and learning components. This approach was successfully used in the Ecotoons2 game whereby mini-games could be used in multiple game compositions, aiding in their reuse. Moving beyond the challenge of reuse there is growing interest in the semi-automatic generation of learning and gaming content for use in adaptive educational games. The work of the SIREN project aims to ambitiously tackle these such challenges (Siren Project, n.d.; Yannakakis et al., 2010).

3.6.9.4 Game Comparison Table

The diverse nature of contemporary adaptive educational games is evident from the 11 games reviewed in this chapter. The variation amongst these games in terms of pedagogical approach, game genre, game origin, personalisation technology, and learning content is summarised below in Table 7.

Table 7. Feature Comparison for Reviewed Adaptive Educational Games

	Pedagogical Approach	**Game Genre**	**Game Origin**	**Personalisation Technology**	**Learning Content Topics**
<e-adventure>	Game dependent, constructivist	2D point and click adventure	Academic research/ instructor authored	Macro-adaptive, learner model checking, loosely coupled	Various
Façade	Experiential learning	Role playing	Academic research	Micro-adaptive, interactive narrative, rule based	Interaction in social relationships
Prime Climb	Problem based learning	Puzzle	Academic research	Micro-adaptive, probabilistic modelling	Mathematics factorization
TLCTS	Problem based learning	Role playing	Academic research	Micro-adaptive, autonomous agent, implicit statistical modelling	Language learning, cultural awareness
VTC	Problem based learning	Unspecified story driven genre	Academic research	Macro-adaptive, graph based narratives	Social skills, project management
Ecotoons2	Unspecified constructivist learning	Puzzle, varying mini-games	Academic research	Macro-adaptive, rule-based	Mathematical reasoning
VR-ENGAGE/ VIRGE	Behaviourist conditioning, problem based learning	3D adventure	Academic research	Micro-adaptive, overlay modelling, inference rules, loosely coupled	Geography/ English
ELG	Dependent on authored game	2D Puzzle	Teacher authored	Macro-adaptive, rule based	Mathematics, nutrition,

					archaeology
S.M.I.L.E.	Problem based/ discovery learning	Role playing/ virtual world adventure	Teacher authored	Macro and micro-adaptive, statistical modelling	Mathematics, biology, chemistry
NUCLEO	Problem based learning, CSCL	Role playing	Academic research	Macro-adaptive, rule based	Computer programming
SCRUB	Experiential learning	Varies depending on the learner	Academic research	Macro-adaptive	Microbiology

3.6.9.5 Feature Summary

The following are the key features of adaptive educational games emerging from the survey conducted in this chapter.

- There is typically a tight integration between the games and their personalisation, however, approaches to separation of the game and personalisation systems presents the potential for reuse of the personalisation systems.
- These is a variety of learning content topics addressed by AEGs including both hard and soft skills, with the game genres used being appropriate to the learning content.
- The variety of pedagogical approaches employed are predominantly focused on constructivist theories which advocate self-control and learner directed games.
- The origin of these games is predominantly from academic research due to the unique skill sets required that bridge game design and educational personalisation.
- Both macro and micro adaptive approaches to personalisation are being used and leverage a variety of expert systems and AI techniques. However, the issue of limited content usage with macro-adaptive systems remains a challenge.
- A diverse variety of personalisations axes are being used including but not limited to skill based, affective feedback, motivational support, interface accessibility, and game player type.
- Where a game narrative is used, significant effort is applied in maintaining its consistency as this directly impacts on the engaging nature of the game.

3.7 Summary

In this chapter the current state of the art in Adaptive Instructional Systems was reviewed and analysed. In particular the contributions of ITSs, learner modelling, and personalisation research to the emerging area of Adaptive Educational Games was discussed.

The current approaches to personalisation within adaptive educational games was examined including Macro-adaptation, Aptitude-Treatment Interaction, and Micro-adaptation. The historical progression of Adaptive Educational Games was presented with consideration for the importance of non-invasive personalisation. This chapter then continued with a survey of 11 adaptive educational games and their significant contributions to the state of the art. This chapter concluded with an analysis of the emerging trends in adaptive educational game design and comparison of the diverse approaches being taken in this research field.

4 Planning - ALIGN and the ELEKTRA Game

4.1 Introduction

Within educational video games the most significant design issues and their corresponding requirements relate to the integration of learning content, the appropriateness of the game genre used, the selection of an appropriate pedagogical approach, and the real-world environment in which the game is to be used. Further to this, the issues influencing personalisation within educational video games are the appropriateness of the adaptations to the gameplay, the invasiveness of the learner modelling, the type of personalisation used, the tight integration of adaptation technologies, and the variety of game styles and platforms in use.

This chapter introduces the Adaptive Learning In Games through Non-invasion (ALIGN) system, the steps taken in designing the system, its integration with the ELEKTRA educational game, and its technical implementation in the context of the ELEKTRA game. These three steps of design, integration with an educational game, and the technical implementation are focused on fulfilling the objectives and goals of this thesis.

This chapter begins with an introduction to the Action Research methodology that was applied in this research and accordingly influences the structure of this thesis. In line with this methodology this chapter represents the planning stage of an action research cycle. The design of the ALIGN system is presented based on the influences from the state of the art reviews given in chapters 2 and 3. This is followed by a discussion on the rationale of separating game and personalisation logic along with details of the approach taken to learner modelling within the ALIGN system. These two sections form the prerequisites for the Four Stage Approach to Non-invasive adaptation that is presented as the final section in the design of ALIGN.

Following the design of ALIGN, the ELEKTRA game is introduced as the first game that will be personalised by the ALIGN system. The design of the ELEKTRA game is presented as well as the considerations necessary for learner modelling, and personalisation within this game. The final section of this chapter presents the technical implementation of ALIGN including the technical architecture, the component descriptions, and implementation details specific to the ELEKTRA game.

4.2 Methodology

The methodology employed in the design, implementation, and evaluation of the ALIGN system is influenced by both the objectives of this thesis and the requirement of a need to assess if these objectives are being satisfied. Consequently the methodology used within this thesis is based on

Action Research. This methodology is a progressive approach to research that takes place in real world situations and aims to solve real problems (Lewin, 1946; Susman & Evered, 1978). As a progressive process, action research prescribes a continuous cyclical process of Analysis, Planning, Action, Observation, and Reflection (Dickens & Watkins, 1999) as illustrated in Figure 35.

Figure 35. Spiral Process of Action Research

The close ties of Action Research with a real world context dictates that the action researcher is not looking for something to experiment on, but responds to the provocations of the research field to determine their focus. Whereas this can limit the applicability of action research to large focused research projects it does however ensure there is a clear benefit to the participants as it is their problems that are being addressed. In essence action research is a collaborative research methodology where "the researcher must be of value to those being researched, and both parties must successfully negotiate their goals" (Baskerville, 1999).

One of the key challenges in the uptake of action research methodologies is the qualitative evaluation metrics it supports. As with any holistic user-oriented approach to research the outputs are interpretative and dependent on so called soft metrics such as user satisfaction.

4.2.1 Application of Action Research

Within the research conducted for this thesis, Action Research was applied as a series of two progressive cycles. The analysis and planning from the first cycle are reflected in chapters 2, 3, and 4 whereby taking the influences from the state of the art, an initial design, and the implementation of ALIGN is presented. Further to this the integration with the ELEKTRA game poises the ALIGN system for a real world experiment that reflects the action phase.

In the following chapter the evaluation of the ELEKTRA experiment completes the initial action research cycle as the experiment is observed and the outcomes reflected upon. The second cycle of action research is represented in a similar manner in chapters 6 and 7 with the outcome of the first cycle being a direct influence. The mapping of thesis chapters to this methodology is shown below in Figure 36.

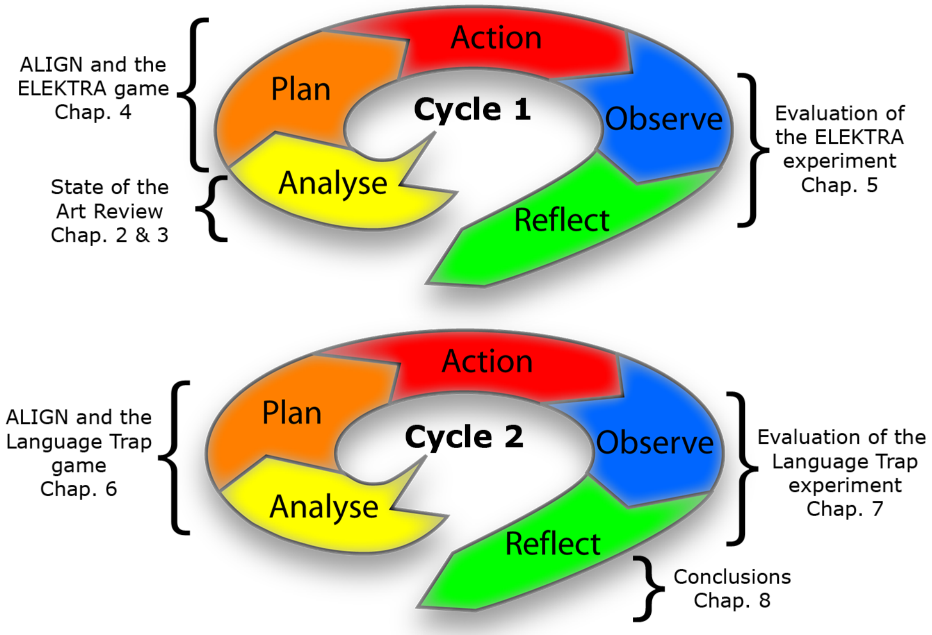

Figure 36. Mapping of thesis chapters to Action Research cycles

In consideration of the Action Research methodology and specifics of the research undertaken in this thesis, the following approaches have been adopted as part of the experimental methodology.

- Due to the number of novel factor that will comprise the ALIGN system a progressive series of experiments will be used with each experiment focussing on particular objectives of this thesis.

This incremental approach to evaluating the system allows subsequent experiments to build upon established features of the system's design. Following this approach the first experiment aims to evaluate the feasibility of separating the personalisation from the game that it adapts, and to realise a variety of personalisations within that game. The second experiment aims to build upon this and examine the non-invasive nature of the personalisation and the further variety of personalisations possible. Further to this the flexibility and reusability of the ALIGN system will be considered following its integration with two contrasting educational games. The nature of these experiments is reflected in the above aims and the focus of the methodology to evaluate real problems in real-world contexts.

- In consideration of the subjective nature of gaming and learning experiences each experiment will consist of a user study where both qualitative data regarding the gaming experience and quantitative data regarding the learning outcome will be considered.

The tightly woven nature of gaming and learning in educational games implies that the quality of the gaming experience inherently impacts the quality of the learning experience. For this reason an overall qualitative evaluation becomes appropriate. However, the correlation between positive gaming experience and learning effectiveness must also be investigated. Through the use of a quantitative learning evaluation this becomes possible as learning outcomes can be directly compared with the learner's qualitative experience.

- The experiments will be conducted within real-world environments wherein the system would typically be used.
- The natural variance amongst the test subjects will be recorded and will inform the subsequent analysis to reduce the effect of confounding variables.

Through the use of learners of similar ages with similar educational backgrounds the impact of confounding variables will be reduced. Those remaining variables such as gender and ability will be considered as part of the data analysis.

4.3 The Design of ALIGN

The design of the ALIGN system draws on the state of the art reviews in Educational Games and Adaptive Instructional Systems presented in chapters 2 and 3 respectively. This section begins with an examination of these influences and results in the design requirements for the ALIGN system being derived. The arguments for separating educational games from the personalisation that adapts them is then presented with reference made to the abstraction of adaptation, and the modelling of adaptations that becomes necessary.

This section then continues with a discussion on learner modelling within ALIGN and how this is influenced by the separation of game and personalisation logic. The final section of the ALIGN design is then presented with the introduction of the Four Stage Approach to Non-invasive personalisation that allows the ALIGN system to achieve the non-invasive personalisation of educational video games.

4.3.1 Influences from the State of the Art

The most significant criteria for the design of the ALIGN system is evident from the structure of the state of the art review wherein there exists two distinct research areas namely Educational Games, and Adaptive Instructional Systems. It is this hurdle of integrating gameplay with educational adaptation that presents a considerable design challenge. The following are the key constituents of this challenge.

- There exists potentially conflicting objectives between the desire to personalise the learning experience and the need to preserve a meaningful and immersive game.
- Existing approaches to adaptive educational games are typically tightly integrated with limited reusability requiring bespoke and resultantly costly solutions for each game.

The requirements that emerge from these challenges are addressed below under the influences from the state of the art in Educational Game design and Adaptive Instructional Systems.

4.3.1.1 Educational Games

Through the analysis of the current state of the art in educational games in chapters 2 and 3 it is apparent that several of the factors that influence effective educational games are also relevant to any system wishing to adapt them. In particular the emphasis placed on the prioritisation of fun within educational games (Papert, 1998; Prensky, 2001; Salen & Zimmerman, 2003), the importance of a storyline for motivation (Caillois, 2001; Dickey, 2006a), the necessity to tightly integrate gameplay and learning content (Kirriemuir & McFarlane, 2004; K. Squire & Jenkins, 2003; Van Eck, 2006), and the acute awareness of players to the implicit and explicit rules of the game environment, are all relevant to any system wishing to adapt a game. Respectively these four factors contribute to the design requirements given below. Within this thesis all design requirements for the ALIGN are codified as R*n*, with game design requirements codified as G*n.* A complete list of all codified requirements is given in Appendix E.

R1. The prioritisation of the gaming experience over educational personalisation is necessary where these objectives conflict as this ensures the intrinsically motivating immersive gameplay is maintained.

R2. It is necessary to ensure that any adaptations are performed in a manner consistent with the player's understanding of the game world including the game's rules, storyline, and character consistency.

Although the above requirements apply to a system attempting to adapt an educational game, the analysis of the state of the art also indicates how such a system should be evaluated. In particular any game that is to be adapted must itself conform to best practices in educational game design. Consequently the following requirements are derived for the design of any educational game that is to be adaptive.

The attainment and maintenance of a *flow* experience can be highly beneficial to the learner's experience.

G1. Adaptation to the learner's abilities enables the presentation of a personalised challenge.

Social interaction and narrative can be beneficial to immersion and motivation.

G2. Adaptive game characters can be used to promote social interactions yet must act in accordance with, and considerate of the game narrative.

The tight integration of learning content can present a seamless gaming and learning experience.

G3. Learning content must be matched with appropriate game genres; further to this the game genres must be appropriate for the intended audience.

Educational game design should be considerate of evolving pedagogical theories and their application.

G4. The game design should reflect the move towards more learner controlled, self-directed, learner-centric, constructivist approaches, and a move away from behaviourist approaches.

A game's design should consider the real world context in which the game is to be played.

G5. The context[19] where the gaming and learning occurs is significant and approaches should cater for both formal and informal learning contexts.

The increasingly pervasive levels of digital literacy and the expectations of Digital Natives should be catered for.

G6. There is a need to provide highly interactive experiences to learners who are increasingly accustomed to personalised experiences.

4.3.1.2 Adaptive Instructional Systems

The pervading adoption of constructivist pedagogical theories within technology enhanced learning is increasingly noticeable in the field of adaptive instructional systems. The shift away from behaviourist theories is unsurprisingly evident in this area due to the emphasis placed on the experience of the user and user-centric design, as is the case with adaptive educational games. The following requirements have been identified for the design of a modern user-centric adaptive instructional system.

R3. Inference techniques should be employed to deal with learner evidence that is application specific or too granular for the purposes of personalisation.

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[19] The physical setting where the game is played, be it a formal classroom or an informal home location.

R4. The learner should be able to influence and dictate their learning direction to enable self-directed learning and to increase their sense of ownership of the experience.

R5. Learner skills and motivation should not be modelled as continually progressive processes and the non-linear progression of skills should be considered.

Effective personalisation requires that all processes that inform and enable the personalisation should be considered holistically and not independently.

R6. There is a need for both non-invasive user modelling and non-invasive adaptations in order to achieve non-invasive personalisation.

R7. The responsiveness of any personalisation performed must be sufficiently fast so as not to impact the highly interactive nature of the game-based learning and detrimentally affect the immersive and engaging nature of the gaming environment.

The development of large content repositories is costly and inefficient as adaptive systems may use only a small portion of the developed content for each learner.

R8. There is a need for greater content reuse through techniques such as micro-adaptation wherein content can be used more extensively and tweaked for each individual learner.

R9. The independent authoring and reuse of adaptation logic across multiple games should be enabled through the separation of game logic from educational adaptation.

4.3.2 Separation of Game Logic and Personalisation Logic

In the context of adaptive educational games the tight coupling of adaptive logic and game logic within an adaptive game has benefits due to its innate understanding of the game. However, this approach greatly reduces the reusability of the adaptive logic across varying educational games as it will invariably contain specifics relating only to the game in question, and may not consider the requirements of games in varying genres and subject domains. In consideration of the complexity of developing adaptive logics with their associated inference, reasoning, classification, and prediction algorithms, it is desirable to reuse such costly components across multiple games. Moreover, unlike game design and its requisite novelty, educational adaptation has significant similarities across games such as the desire to personalise the challenge presented or the motivational support given.

For these reasons the separation of the adaptive logic from the game engine presents opportunities for the reuse of adaptation and can facilitate the independent authoring of both the game engine and the educational personalisation, which arguably require disjoint skill sets. The design of ALIGN as a system separate to the educational game it personalises fulfils the design requirement R9 through separating the game logic from the personalisation logic.

In separating the adaptation from the game engine there is an immediate loss of context on which the adaptation must operate. In this case the context consists of both the precise actions of the learner and their significance within the current game world. Whereas with integrated adaptation the co-authoring of the game and the adaptation can ensure an awareness of the game state, there exists a deficiency when these two components are separated. In order to overcome this context deficiency an adaptation service must infer this game context through observing evidence from the game engine.

Through this observation it becomes possible to identify game contexts that have significance for educational personalisation. Importantly, only the game evidence pertinent to the adaptation needs to be inferred with the majority of game context being ignored. It is neither desirable nor necessary to replicate the entire context of the game world; all that is required is an abstract representation of the game evidence that is relevant to personalising the learning experience within the game.

4.3.2.1 Design of Personalisation Logic

The user-centric nature of games allows the user to dictate the paths they take through the game and consequently the paths through the learning content. This absence of a predictably ordered task sequence as well as the potential lack of explicit learner assessments limits the use of overlay user modelling techniques. For this reason it is desirable to use a personalisation technology that can accommodate for game actions with variable orderings, and in doing so support the design requirement R4 of supporting self directed learning. Further to this there is a desire that the personalisation be achieved promptly as is stipulated in design requirement R7.

For these reasons a rule engine was chosen as the core personalisation technology within the ALIGN system. An introduction to rule engines and the Drools (JBoss, n.d.) rule engine used within ALIGN is given in Appendix F.

4.3.2.2 Abstraction of Adaptation

Although it is feasible to perform educational personalisation based on game evidence specific to the game in question, this requires that the personalisation logic employed be tailored for each individual game. This approach however limits the reuse of the personalisation logic as it becomes game specific. In light of this the ALIGN system abstracts the game evidence away from game specifics towards a set of facts that are common across educational games, and in doing so addresses design requirement R3. This concept of abstraction is best illustrated through an example based on two hypothetical games that have two differing pieces of game evidence yet that can both be abstracted to the same abstract concept and fact. The following two games are simplified examples used to illustrate the approach taken to abstraction and do not form part of the evaluation of the ALIGN system.

Geography Game

This game aims to aid learners in understanding physical geography concepts such as plate tectonics through challenging the learners to build a virtual world that is stable enough to allow a civilisation to grow. As the learner is playing this game they mistakenly position a city near to a fault line and it is destroyed by a volcano, see Figure 37. The game evidence in this case would be *"city destroyed due to poor placement"*.

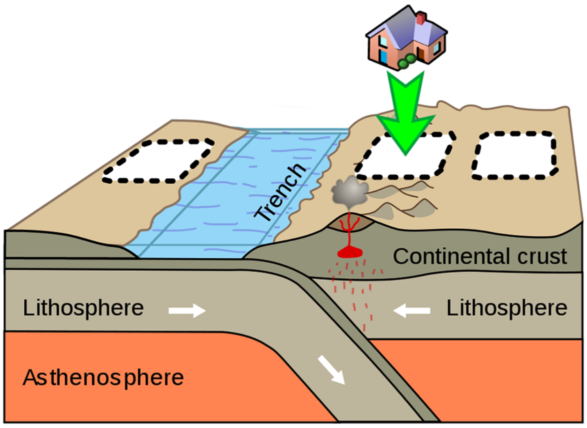

Figure 37. Illustrative Example of Geography Game[20]

Math Game

This game aims to aid learners in understanding the concept of balancing equations through the use of an illustrative levered bridge the learner must cross. As the learner tries to cross the bridge they place weights on the bridge to act as counterbalances, however they have underestimated their own weight and the bridge does not balance as is required to cross, see Figure 38. The game evidence in this case would be *"bridge crossing failed due to insufficient weights"*.

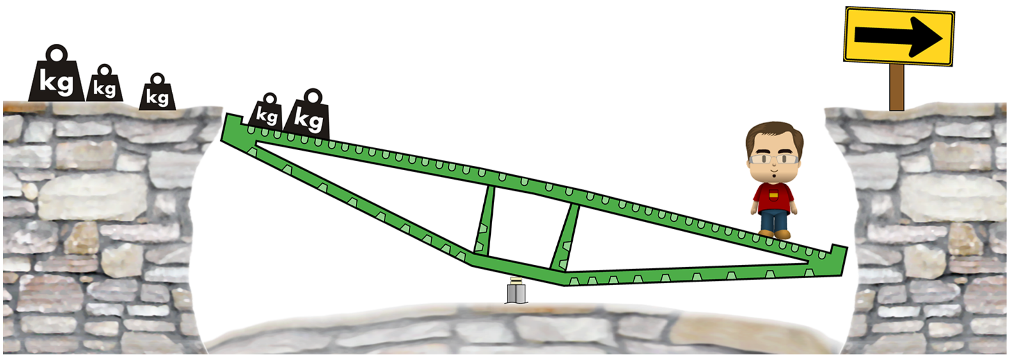

Figure 38. Illustrative Example of Math Game[21]

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[20] Creative Commons attribution for House graphic: http://en.wikipedia.org/wiki/User:Ixnayonthetimmay

In the above two example games the varying forms of game evidence can both be abstracted to the same single concept of a *"failure at a task"*. These abstract concepts are referred to as Abstract Facts as they are facts relating to events within the game that are abstracted away from the specifics of any game in particular.

The process of abstraction can be conveniently achieved using a rule engine whereby rules matching game specific evidence can map this evidence to Abstract Facts. These abstract facts of a task failures can then be used as a basis for personalisation, in this case a rule can execute to react to a task failure as is illustrated in Figure 39 below.

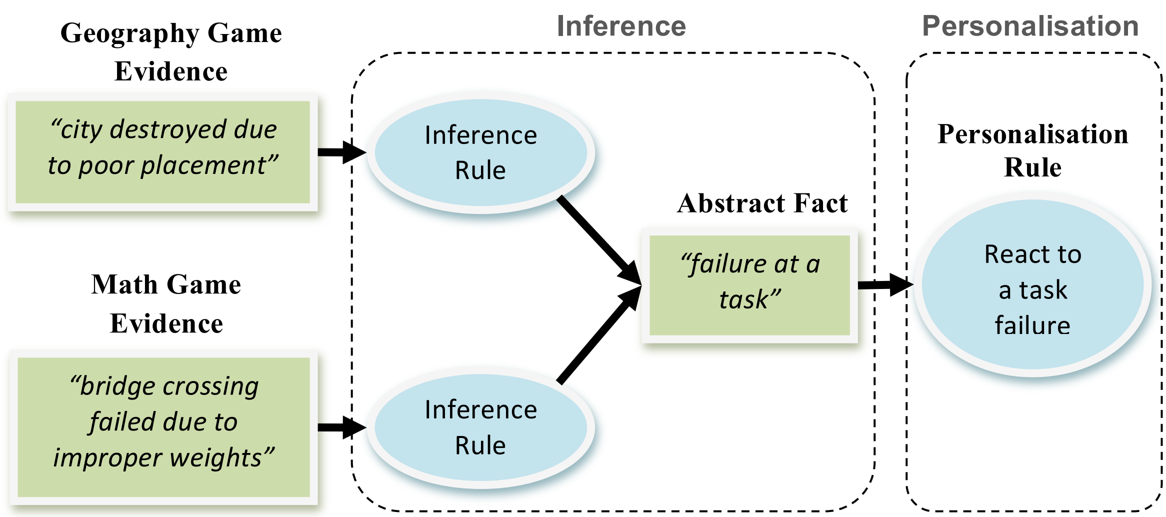

Figure 39. Abstraction of Game Evidence

Through performing personalisation on evidence abstracted from the game specifics; the same adaptation logic can be reused across multiple games simply by modifying the inference rules. Moreover the personalisation rules can be authored without reference to game specifics, but with direct relevance to the learning experience.

The final challenge in achieving personalisation in this way is how the outcome of the abstract personalisation rules can be mapped to specific changes in a given game. The challenge in achieving this lies in the personalisation having an understanding of what can be changed within a game and the envisaged impact this change will have. All of the possible changes that can be made within a game are referred to as Adaptive Elements and are detailed in the following section.

[21] Creative Commons attributions: http://es.wikipedia.org/wiki/Usuario:Ajgonzalez, http://commons.wikimedia.org/wiki/User:Roulex_45, http://commons.wikimedia.org/wiki/User:MDBR

4.3.2.3 Adaptive Elements

An Adaptive Element (AE) comprises of a reference to a change that can be made within a game and also one or more envisaged outcomes that will result from enacting this change. The inclusion of the envisaged outcomes within an Adaptive Element allows the personalisation rules to select desirable changes to make to the game without the need to understand the specific nature of the game. An example of Adaptive Elements that would be selected given the hypothetical games illustrated in Figure 37 and Figure 38 is shown below in Figure 40. This example illustrates how two separate games can be adapted based on the same personalisation rule.

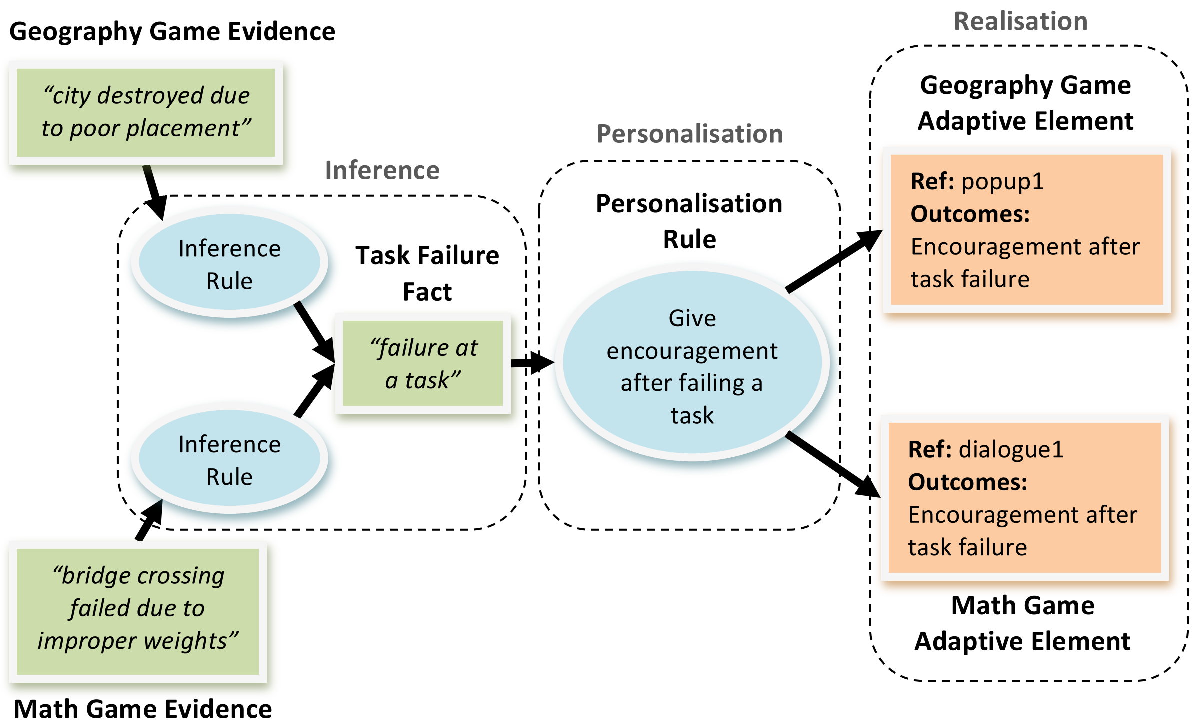

Figure 40. Mapping from game evidence to abstract adaptation to game adaptations

In this scenario both the Geography game evidence and the Math Game evidence are inferred to the same abstract fact, in this case a fact representing a task failure. The personalisation rule then acts upon this fact. The adaptation strategy in this case is to provide encouragement when a learner fails a task, and achieves this by using an Adaptive Element that provides the outcome of "Encouragement after task failure". Due to the varying nature of the two games how this encouragement is realised varies greatly. In the case of the Geography Game the encouragement could be presented through the use of a popup window with encouraging text (Adaptive Element: popup1), whereas in the Math Game the encouragement could be provided through a dialogue with a NPC (Adaptive Element: dialogue1).

As this example illustrates, the specific nature of what an AE does is game specific and enables the game designer to realise the adaptation in a manner best fitting a particular game. Whereas a popup window may be appropriate within the Geography Game, a NPC dialogue is more appropriate to the Math Game. The choice of when it is possible to use an AE is also decided by the game designer and the mechanism to achieve this is detailed in the following section.

Despite the varying nature of the above AEs they both ultimately provide the same outcome of giving encouragement to the learner after they have failed a task. Although this example uses two feedback mechanisms, namely popups and dialogues, AEs are generic and can represent anything that can change within the game world, be it a character dialogue, a change in game difficulty, a start of a new task, or any other adaptation that can be associated with a learning outcome.

Design of Adaptive Elements

The design of AEs is predominantly a task for the game designer. Through determining what adaptations are possible within the game world the game designer dictates to what extent the game can be adapted. Through associating the educational outcome of each possible adaptation with an AE the game designer exposes these adaptations to the personalisation rules. As the personalisation rules can only work with the AEs available to it, how adaptive a game is relies on the game designer implementing more adaptations. When considering the case of modifying existing non-adaptive games for this purpose there is an evident hurdle in providing large numbers of AEs.

The separation of AE authoring from the personalisation rules allows for the game designer to modify how adaptations are realised (provided they result in the same outcome), and to add in new AEs that can automatically be used. This separation allows for a common language between game designers and the authors of the personalisation rules so that the former can specify what can be adapted and the latter when to perform the adaptations.

Game State Restrictions

So far Adaptive Elements have been described as referencing a specific game change and providing an outcome. Whereas this allows an AE to be chosen for a desired educational outcome it does not dictate whether this change is appropriate to make at this point within the game. For this reason each AE is annotated to indicate when in a game it can be used. These annotations indicate within which game tasks an AE can be used and also what specific events within the task must have occurred. The following two figures, Figure 41 and Figure 42, are examples of AEs encoded in XML that have an id, an outcome and a task requirement. These two Adaptive Elements are used in the Geography and Math games respectively and their selection was illustrated previously in Figure 40.

```
<element id="popup1">
        <outcome id="Encouragement after task failure" value="0"/>
        <task-req>creating_cities</task-req>
</element>
```

Figure 41. Example Adaptive Element for the Geography Game

```
<element id="dialogue1">
        <outcome id="Encouragement after task failure " value="0"/>
        <task-req>crossing_the_bridge</task-req>
</element>
```

Figure 42. Example Adaptive Element for the Math Game

The use of a common outcome id in the above two AEs allows for the same abstract rule shown in Figure 55 to select them even though they both make changes in different games and these changes are manifested differently. The 'value' attribute of an outcome can optionally be used to indicate a particular level for an outcome such as the degree of encouragement given.

Realisation

The abstraction of adaptation allows for abstracted personalisation to be performed on game evidence from multiple games. This approach facilitates both the reuse of adaptation logic and the independent authoring of adaptation logic and game logic, as per design requirement R9. Under this approach it becomes possible to add new game tasks and content that will automatically be available to the personalisation rules. Similarly it becomes possible to amend the personalisation rules without the need to change the game as the personalisation is based solely on abstract facts and not on game specifics.

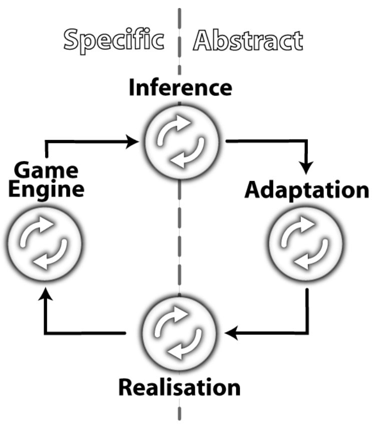

Figure 43. The transitions between specific and generic evidence though Inference, Adaptation, and Realisation

The inherent challenge in providing abstract adaptation lies in the ability of the system to make game adaptations that are still appropriate to the game in question. This challenge is referred to as Realisation. Whereas inference is the process of taking raw game evidence to abstract facts, the converse process of realising abstract adaptations is referred to as Realisation as illustrated above in Figure 43. The process of Realisation involves mapping adaptations, as determined by the personalisation rules, back to specific changes within the game being played and this is achieved in ALIGN through the use of Adaptive Elements.

4.3.3 Learner Modelling

The approach taken to user modelling within the ALIGN system is indicative of its usage within a gaming environment and how this poses specific requirements only present in game based adaptive systems. The overriding consideration in this approach is the need to maintain an enjoyable and meaningful gaming experience. In consideration of this the learner modelling achieved through a gaming environment must not be detrimental to the gaming experience and so must only be explicit where it is game relevant, and implicit at all other times. As a result of this approach the user modelling employed will deal with a small amount of explicit and precise user evidence as well as a large amount of implicit, potentially vague learner evidence. This emphasis on implicit learner modelling that is not invasive to the gaming experience in part fulfils design requirement R6.

In light of the limited amount of explicit user evidence available for modelling, the use of a fixed user model schema has limited benefits as it will be sparsely populated and unable to capture the wealth of implicit learner evidence. For this reason the user model within the ALIGN system is represented as a set of facts, and rules that operate over these facts to determine significant facets of the learner. In effect, the rules provide a view over the learner model that represents an implicit schema. The manner in which the rules interpret the facts determines their significance in this implied schema. The intentional use of an implied schema is a result of the desire for ALIGN to be able to cater for diverse personalisation rules. Within these diverse rules it may be desirable to access the learner model data typologically, chronologically, by frequency, by event patterns, or by any other means. Whereas rules to accommodate these approaches can feasibly be written, these forms of interpretation would be far more challenging when dealing with a fixed schema encoded in a hierarchical encoding such as XML.

The use of an implied schema evidently limits the exchange of user models as would be possible with standards such as IMS LIP (IMS Global Learning Consortium, n.d.) or PAPI (IEEE/LTSC, n.d.). However, it should be noted that these standards are designed for the interchange of information as opposed to run-time user modelling. Additionally these standards do not capture the wealth of user evidence that is either imprecise or ambiguous but is however useful for statistical and probabilistic modelling. In the realm of user modelling exchange, this approach of using a set of user facts can be viewed as a short term user model in a manner akin to (Conati & Zhao, 2004). A long term exchangeable model can then be derived from the short term user model as needed.

4.3.3.1 Inference Techniques

In the presence of a large amount of implicit learner evidence the use of appropriate inference techniques becomes a key part of effectively understanding the learner's actions. The choice of an inference technique within a gaming context is bound by the necessity to provide prompt calculations so as to ultimately create game adaptations that appear reactive to the leaner's actions.

Within the ALIGN system inference is predominantly achieved through the use of inference rules. These rules can capture declaratively the meaning of individual, multiple, or patterns of facts. Further to this, rule-based systems such as Drools can scale almost linearly as the number of facts and/or rules increase ensuring a responsive method of inference.

Statistical Modelling

One of the limitations of rule based systems is that when dealing with subtle and varying evidence the number and complexity of rules can rapidly grow as individual rules are required for each possible combination of evidence. To accommodate for this limitation it is possible to make use of statistical and probabilistic inference techniques to feed the inference rules. Through this approach specific learner characteristics can be inferred statistically and their significance can then be determined by inference rules.

Due to the diverse nature of video games any inference technique needs to be flexible enough to best interpret the evidence coming from a game engine. Whereas rule based inference can accommodate this there will be certain games wherein statistical or probabilistic inference techniques will also be beneficial. In such cases as these, statistical or probabilistic methods create abstract facts that can then further feed the inference rules. This concept is illustrated in Figure 44 below.

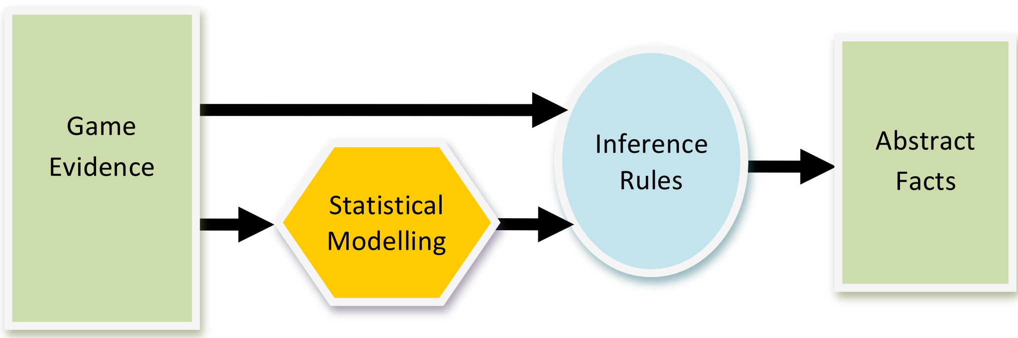

Figure 44. The role of Statistical Modelling within ALIGN Learner Modelling

Within the ALIGN system two statistical modelling techniques are used. These techniques are linear modelling (Zukerman & Albrecht, 2001), and Competence-based Knowledge Space Theory (CbKST) (Albert et al., 2007; Conlan, Hampson, Peirce, & Kickmeier-Rust, 2009). In the case of linear modelling the weighted sum of input values are used to produce a value for an unknown quantity. An example usage of this technique is in the prediction of a learner's current ability. In this case all of a learner's previous task successes and failures are considered in order to predict a value for their current ability. This form of modelling can be easily extended and generalised and enables the prediction of unknown values such as learner ability that are not explicitly available.

A more sophisticated method of predicting learning ability is CbKST as was detailed in chapter 3. This statistical modelling technique relies on building a prerequisite knowledge structure of the concepts in a learning domain, and associating evidence of these concepts being mastered to a learner's actions. Although this is an effective and robust method of predicting a learner's competences, it is dependent on there being a prerequisite knowledge structure for the learning content of the game. As not all games will have such a clearly defined prerequisite knowledge structure CbKST is an optional inference technique and its usage is dependent on the nature of the game being adapted.

Despite the benefits of statistical modelling as an inference technique its usage is game dependent and is not applicable across all educational games. As such statistical modelling is an optional add-on to inferring game evidence.

4.3.4 The Four Stage Approach to Non-invasive Personalisation

The second objective of this thesis is to "*To develop a flexible game agnostic software system that can non-invasively personalise the educational experience within an educational video game.*" In line with fulfilling this objective the following design requirements are addressed by the four-stage approach to non-invasive personalisation.

- R1. The prioritisation of the gaming experience over educational personalisation is necessary where these objectives conflict as this ensures the intrinsically motivating immersive gameplay is maintained.
- R2. It is necessary to ensure that any adaptations are performed in a manner consistent with the player's understanding of the game world including the game's rules, storyline, and character consistency.
- R6. There is a need for both non-invasive user modelling and non-invasive adaptation in order to achieve non-invasive personalisation.

The design of this approach has been influenced by both the state-of-the-art in Educational Video Games (Chapter 2) and in Adaptive Instructional Systems (Chapter 3). Through a joint consideration of both the design requirements of educational games and the facilities provided by contemporary adaptive instructional systems, this system has been designed to address the shift towards learner centric pedagogies and to aid in the cost effective reuse of adaptive technologies.

The progression of learner centric pedagogies has placed an increasing significance on the learner and their individual learning experience. Through considering the tight integration between learning and gaming within educational games it becomes apparent that in order to maintain a coherent learning experience one must maintain a coherent gaming experience. As any educational adaptation will affect the gaming experience the entire process of personalisation from user modelling through to adaptation selection must be considerate of this. It is this requirement of non-invasiveness that dictates the need for non-invasive user modelling and adaptation constraint that is aware of the game context.

Expanding these concepts we elicit the first three stages of the four stage approach, namely 1) *Inference*, as required for non-invasive user modelling, 2) *Context Accumulation*, as required to inform adaptation selection and to build up the learner model, and 3) *Adaptation Constraint*, as is needed to ensure that the adaptations selected are appropriate for the game context. The final stage in the process is 4) *Adaptation Selection* where the learner model is reconciled with the personalisation strategy to select adaptations from the constrained adaptations. The design influences for each of the four stages are illustrated below in Table 8.

Table 8. Design influences for the Four Stage Approach to Non-invasive Personalisation

Stage	Influences
1. Inference	As explicit user modelling can be disruptive to a gaming experience the greater use of implicit learner modelling is appropriate, consequently inference must be performed to understand the significance of implicit learner actions performed within the game.
2. Context Accumulation	In order to make reasonable and sensible adaptations to a game we must understand what has changed with the learner, the game, and also the adaptations we have previously performed. The accumulation of the pertinent context information is thus necessary.
3. Adaptation Constraint	In order to maintain a convincing and meaningful gaming experience it is necessary to make adaptations to the game that are appropriate at the given time. To achieve this, the range of possible adaptations must be constrained to be only those adaptations that are feasible and appropriate.
4. Adaptation Selection	In order to cater for the individual characteristics of a learner the gaming experience must be personalised based on the learner and the instructional strategy designed to benefit their learning.

4.3.4.1 High Level Architecture of ALIGN

The four stages of this approach as outlined above are designed to act sequentially in order to provide the non-invasive personalisation of a video game. However, in considering the design requirement of reusing learning content to benefit cost effectiveness, the use of intermittent Macro-adaptation is not appropriate. Whereas the use of Micro-adaptation addresses this issue it consequently requires a process of more regular adaptations that can occur within learning tasks. In consideration of this the high-level architecture of ALIGN represents a cyclical and continuous process as is illustrated in Figure 45.

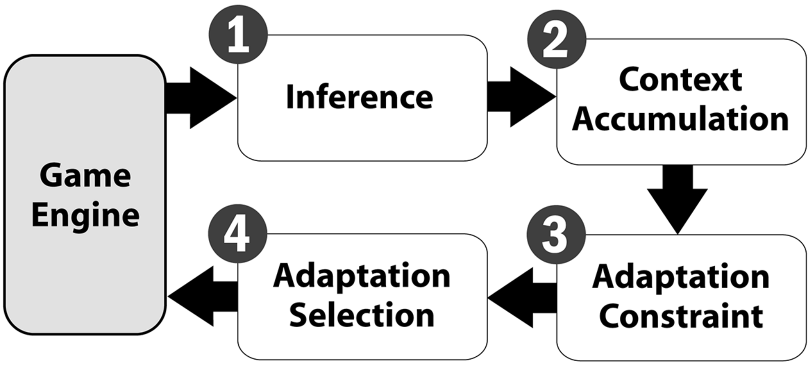

Figure 45. High level Architecture of ALIGN

As well as providing for more regular adaptations the cyclical nature of the process benefits the ALIGN system as both the adaptation constraint becomes aware of previous adaptations that were performed, enabling it to limit the reuse of adaptations that would detrimentally affect the gaming experience.

In order to ensure that the design of the ALIGN system meets all of the design requirements it is necessary to design features that address each requirement. The mapping between design requirements and design features is given below in Table 9.

Table 9. Mapping of Design Requirements of ALIGN to Design Features

Design Requirement	Design Features
R1 The prioritisation of the gaming experience over educational personalisation is necessary where these objectives conflict as this ensures the intrinsically motivating immersive gameplay is maintained.	**Adaptation Constraint**
R2 It is necessary to ensure that any adaptations are performed in a manner consistent with the player's understanding of the game world including the game's rules, storyline, and character consistency.	**Adaptation Constraint**

R3 Inference techniques should be employed to deal with learner evidence that is application specific or too granular for the purposes of personalisation.	**Game Evidence Inference**
R4 The learner should be able to influence and dictate their learning direction to enable self-directed learning and to increase their sense of ownership of the experience.	**Context Accumulation** (Flexible user modelling is employed to enable varying learner actions)
R5 Learner skills and motivation should not be modelled as continually progressive processes and the non-linear progression of skills should be considered.	**Game Evidence Inference** (The use of statistical modelling such as CbKST) **Context Accumulation** (Fact pruning to disregard old evidence)
R6 There is a need for both non-invasive user modelling and non-invasive adaptation in order to achieve non-invasive personalisation.	**Game Evidence Inference** **Context Accumulation** **Adaptation Constraint**
R7 The responsiveness of any personalisation performed must be sufficiently fast so as not to impact the highly interactive nature of the game and detrimentally affect the immersive and engaging nature of the gaming environment.	**Game Evidence Inference** (The use of an efficient rule based approach) **Context Accumulation** (The use of fact pruning)
R8 There is a need for greater content reuse through techniques such as micro-adaptation wherein content can be used more extensively and tweaked for each individual learner.	The continuous cyclical nature of the system enables greater awareness of actions within tasks and consequently how they can be adapted.
R9 The independent authoring and reuse of adaptation logic across multiple games should be enabled through the functional and logical separation of game logic from educational adaptation.	The nature of ALIGN as a system separate from a game engine and also the authoring of personalisation rules that are abstracted away from game specifics enables this.

In the following sections the design of the four independent stages of the approach are detailed.

4.3.4.2 Game Evidence Inference

The process of game evidence inference takes evidence from a game engine and interprets it into abstract facts that form part of the learner model or facts that update the current game context. The process of inference is in effect a normalisation of the game evidence towards a common set of facts over which personalisation rules can be applied. The principal method of inference employed is the use of a rule engine to translate groups, patterns, and individual game evidence facts into a canonical set of facts. The advantages of using a rule-based approach for this inference are:

- Clear method of capturing declarative mappings from raw evidence to canonical facts.
- Fast and scalable inference method.

- Inference rules can be incrementally improved independently of the other three stages of the ALIGN system.

The Inference stage of the ALIGN system is the first of the four stage process. The constituent parts of this stage namely the Inference Rules and the Statistical Modelling are illustrated in Figure 46. The statistical modelling component is represented with a dashed line as it is an optional component of the Inference stage and is only applicable for certain games.

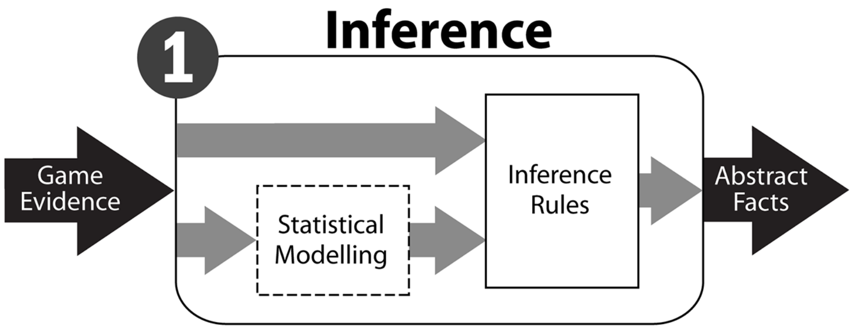

Figure 46. ALIGN Stage 1 - Inference

Game Engine Evidence

In order to simplify the possible inference rules that are needed a vocabulary of the types of evidence accepted by ALIGN is defined. Based on the state of the art review of adaptive educational games the following types of evidence were determined to be common across games and sufficiently detailed to capture all learning related game evidence. As each piece of evidence is inserted into the Drools rule engine it is converted into a Java object and is referred to as a fact. The fact names for each piece of evidence and their properties are given below in Table 10. As there are common attributes across all facts used within the ALIGN system all of the facts extend the same abstract Java class *AbstractFact*. This class is extended by all of the other facts shown in Table 10 below.

Table 10. Fact names and game evidence descriptions

Fact Name	Fact Properties	Evidence Description
AbstractFact	**id**: String **timestamp:** long **self**: AbstractFact	This fact is extended by all other facts giving them all an identifier, a time of creation/update, and a self reference to ease rule authoring.
UserLogin		The login and identification of the learner.

TaskEvent	**eventType**:int {UNDEFINED, TASK_START, TASK_END, TASK_SUCCESS, TASK_FAILURE} **cause**: AbstractFact	Learning task related evidence including task starts, end, successes, and failures.
SubTaskElementEvent	**parameters**:HashMap	Evidence relating to an ongoing task that is relevant to the learner completing the task including game specific parameters.
Option	**parameter**: String	Explicit options chosen within the game by the learner.
ConfidenceDegreeEvent	**value**:int	Confidence degrees expressed by the learner about a task they are about to undertake.
Recommendation	**value**: int **desiredOutcome**: String	A record of an Adaptive Element that was sent to the game engine to adapt it. The value of the used AE and the desired outcome of the AE are also included.

The definition of a task used within the above vocabulary is of an event related to learning within the game that has a start, an end and optionally an indicator of success or failure. No restriction is imposed or assumed about the ordering of tasks and they may overlap and run concurrently. The focus of this vocabulary on tasks that have a duration, and the changes that occur within these tasks is testament to the inherent support for micro-adaptation provided. Once a game provides evidence within learning tasks as opposed to solely at their conclusion it becomes possible to personalise the task to the learner as they complete the task. In doing this the learning tasks become applicable to a greater number of learners, effectively benefiting content reuse as is stipulated in design requirement R8.

Although the vocabulary consists of six types of evidence it is designed to provide maximal coverage of evidence and does not imply that the game must deliver all of these evidence types. It is quite conceivable that a game may not have explicit options or confidence degrees and so would omit these when using ALIGN.

Whereas ideally a game engine would convey all of the above fact types to the inference rules it is unrealistic to assume every game will convey the same types of facts. For this reason one of the key roles of the inference rules is to identify latent events within the game evidence that are significant to the learning experience. The following example illustrates how a latent fact could be identified from game evidence.

Example Game Evidence Inference

In this example of game evidence inference the same Maths game as detailed in section 4.3.2.2 is the source of the game evidence. In this case the game only conveys evidence of the bridge being in balance or out of balance through the use of a Sub-task Element Event. Each time the user attempts to balance the bridge the game generates a *SubTaskElementEvent* with the identifier "bridge" and a parameter "weight" which has a value range of -100 to 100.

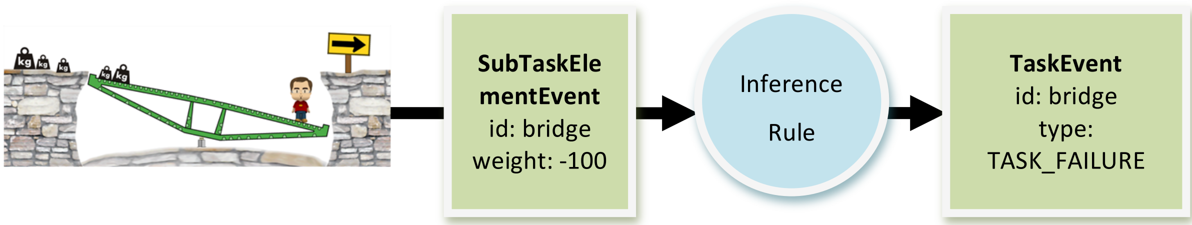

Figure 47. Example of fact inference in the Math Game

In this example specific knowledge of the game is necessary to translate the *SubTaskElementEvent* into a *TaskEvent* indicating a success or a failure. Within the game negative values for weight indicate the weights are too light, zero indicates a balance, and positive weights indicate too heavy. The following inference rules (Figure 48) demonstrates how this specific game knowledge is captured in order to achieve the inference shown in Figure 47.

```
rule "infer bridge task success"
      when
            $s:SubTaskElementEvent(id == "bridge", weight == "0")
      then
            insert new TaskEvent("bridge", Task.TASK_SUCCESS, $s);
end
```

```
rule "infer bridge task failure"
      when
            $s:SubTaskElementEvent(id == "bridge", weight != "0")
      then
            insert new TaskEvent("bridge", Task.TASK_FAILURE, $s);
end
```

Figure 48. Example Inference Rules

Once the inferred *TaskEvent* has been inserted it forms part of the learner model and additionally further inference rules can act upon it as necessary.

4.3.4.3 Context Accumulation

The process of context accumulation within the ALIGN system involves the construction of a historical model of the events that have taken place within the game engine. The notion of context within the ALIGN system is defined as:

> *"The historically significant events that have taken place within the game engine that are relevant to the objective of personalising the current learning experience within the game."*

This definition of context includes all actions made by the learner in relation to their learning experience, all previous adaptations made within the game, and the current state of the game as defined by the tasks currently being undertaken by the learner.

The necessity of context accumulation lies in the desires to 1) better understand the learner to achieve the best possible personalisation, 2) to choose the most appropriate adaptations in consideration of what has been chosen before, and 3) to ensure that the adaptations chosen are appropriate to be made given the current learning tasks. These three desires are respectively addressed in the Learner Model, the Adaptation History, and the Game State as is shown below in Figure 49.

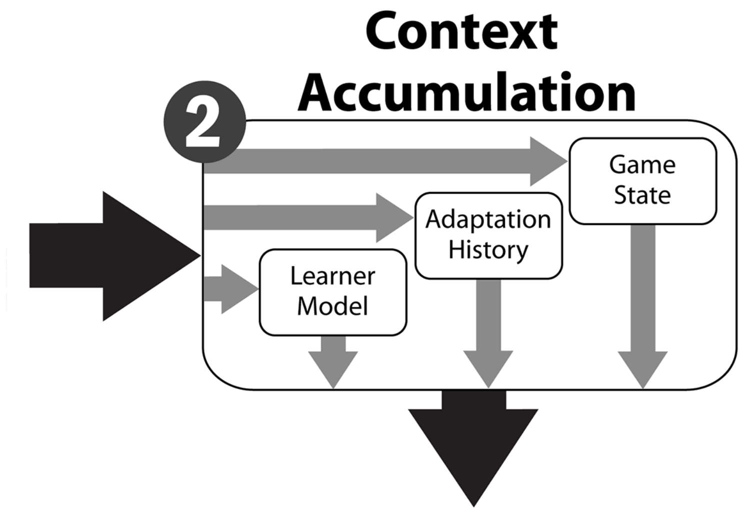

Figure 49. ALIGN Stage 2 - Context Accumulation

The constituents of these three components are defined as follows:

- The Learner Model
    - A historical record of learning relevant facts about the learner, based on their interactions within the game and through inferences made. This learner model

consists of *UserLogin, TaskEvent, SubTaskElementEvent, Option,* and *ConfidenceDegree* facts.

- The Adaptation History
  - A historical record of the adaptations the ALIGN system has previously sent to the game engine. Within this component all of the *Recommendation* facts are stored.
- The Game State
  - The significant state of the game world in terms of the game tasks that have been completed and are on-going. This component consists of *TaskEvent* facts and *SubTaskElementEvents*.

Fact Pruning

The highly interactive nature of video games is one of reasons why they are so highly engaging. In consideration of this, any approach to adapt a video game must be able to maintain this interactivity and execute in near real-time. As a consequence the learner modelling of an adaptive game needs to execute quickly. Within the ALIGN system this is catered for by using a fast and efficient rule engine and also by maintaining the entire user-model in memory. However, due to memory constraints this approach requires the learner model to be pruned in line with evidence aging approaches used by (Virvou & Manos, 2003). The use of evidence aging removes old evidence from the learner model as is not considered to be as relevant as recently received evidence. The pruning of facts is performed in order to maintain both (i) the freshness of the Learner Model and (ii) the responsiveness of the rule engine.

In the case of freshness of evidence, through performing the personalisation on only the most recently accumulated context the personalisation is more reactive to actions the learner has recently performed. From a pedagogical perspective the personalisation is more reactive to changes in a learner's performance over a short period of time, be this an improvement or a disimprovement. This approach fulfils design requirement R5 and caters for changes in abilities in either direction and does not assume learners always improve. The pruning rule shown in Figure 50 demonstrates how only the four most recent task failures are maintained in the Learner Model.

```
rule "keep only the newest four task failures"
       when
              $oldestTask:TaskEvent(eventType == Task.TASK_FAILURE,
                          $oldest:timestamp)
              TaskEvent(eventType == Task.TASK_FAILURE,
                          timestamp > $oldest)
              TaskEvent(eventType == Task.TASK_FAILURE,
                          timestamp > $oldest)
              TaskEvent(eventType == Task.TASK_FAILURE,
                          timestamp > $oldest)
              TaskEvent(eventType == Task.TASK_FAILURE,
```

```
                                        timestamp > $oldest)
        then
                retract($oldestTask);
end
```

Figure 50. Example Old Fact Pruning Rule

As the Drools rule engine scales almost linearly with the number of facts and/or rules, by retracting old facts the performance of the rule engine remains consistent over time.

4.3.4.4 Adaptation Constraint

The process of adaptation constraint ensures that from all of the adaptations that are technically feasible within the game engine, only those adaptations that can be realised in the game engine, and are appropriate, are put forward for selection by the Adaptation Selection stage. As is detailed in section 4.3.2.3 all possible adaptations are represented by Adaptive Elements. This process effectively enables only those AEs that can be used at this time within the game engine and are also appropriate to be used given the adaptations that have been performed previously. The process of Adaptation Constraint operates on Adaptive Elements and contains the processes of Game Constraint and Appropriateness Constraint as illustrated in Figure 51 below.

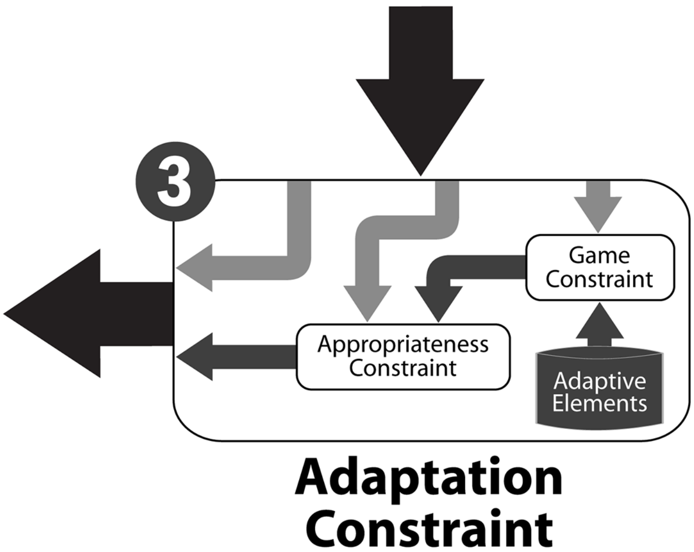

Figure 51. ALIGN Stage 3 - Adaptation Constraint

Game Constraint

The two stage process of constraint begins with disabling all AEs that cannot be used given the current task that are being undertaken within the game. This constraint reconciles the Game State from the Context Accumulation stage with the restrictions associated with each AE as described in

4.3.2.3. Following this constraint only AEs that can be realised in the game engine remain enabled. In effect AEs are disabled if they cannot be used with the tasks the learner is currently undertaking.

In order to constrain and reason over Adaptive Elements that are initially encoded in XML as is shown in section 4.3.2.3, it is necessary to translate each AE into an *AdaptiveElement* fact that can then trigger game constraint rules. Similarly all of the possible outcomes of an Adaptive Element are represented as *AdaptiveElementOutcomes*. The properties of both of these facts which also extend the *AbstractFact* class are given below in Table 11.

Table 11. Details of the AdaptiveElement and AdaptiveElementOutcome facts

Fact Name	Fact Properties	Fact Description
AdaptiveElement	**taskRequirements**: List<String> **taskExclusions**: List<String> **subTaskRequirements**: List<String> **outcomes**: Vector<AdaptiveElementOutcomes> **environmentEnabled**: boolean **strategyEnabled**: boolean	An Adaptive Element including the tasks, and sub task elements it requires to be used in and the tasks it is excluded from being used in. Also the outcomes provided and the environment and strategy enabled states are provided.
AdaptiveElementOutcome	**value:** String **adaptiveElement:** AdaptiveElement	The outcome of an AE including the value it provides and the AE it is associated with.

For the purpose of constraint each *AdaptiveElement* fact has a property *environmentEnabled* that indicates if it can be used in the current game environment, i.e. whether or not its usage is constrained by the current tasks taking place within the game. As the game state is made up of *TaskEvent* and *SubTaskElementEvent* facts the game constraint rules must operate on *TaskEvent, SubTaskElementEvent,* and *AdaptiveElement* facts.

The game constraint rule to disable all AEs that do not require the current task is given below in Figure 52. As this rule will only disable AEs, additional rules are required to re-enable the AEs when the appropriate tasks start or end. Further examples of game constraint rules are given in Appendix A.

```
rule "Disable Task Dependent Adaptive Elements"
   when
      Task($id:identifier, eventType == Task.TASK_START)
      $s:SubTaskElement($subId:identifier, $time:timeStamp)
      not SubTaskElement(timeStamp > $time)
```

```
      (or element: AdaptiveElement($elemId:identifier,
                   environmentEnabled == true,
                   taskRequirements excludes $id)
          element: AdaptiveElement($elemId:identifier,
                   environmentEnabled == true,
                   numSubTaskRequirements > 0,
                   subTaskRequirements excludes $subId))
    then
       element.setEnvironmentEnabled(false);
       update(element);
end
```

Figure 52. Example Game Constraint Rule

Appropriateness Constraint

Whereas the logic used in the above game state constraint remains unchanged across all games, the game appropriateness constraints must be determined on a per game basis. However, a number of core constraints can effectively be used across multiple games. One of the most useful constraints being the variable selection of AEs that provide the same outcome. In a scenario where there are several AEs that all provide the same outcome it is desirable to vary which AEs are used. The rationale behind this constraint is immediately evident in a game where an AE represents a NPC speaking a dialogue. In this scenario the NPC will vary the dialogues they use as opposed to repeating the same dialogue. A simple method of ensuring a variety of AEs are used can be to employ a round-robin approach to enabling AEs. This approach relies on the Adaptation History from the accumulated context in order to enable the least recently used AEs. As the Adaptation History consists of *Recommendation* facts, the appropriateness constraints accordingly operate over these facts as well as *AdaptiveElement* facts. In order to indicate which AEs have been enabled or disabled by appropriateness constraints the AEs have a property called *strategyEnabled.*

The following two rules in Figure 53 demonstrate how a round-robin appropriateness constraint can be used. This constraint is implemented by disabling the most recently used AE and enabling the least recently used AE for a specific outcome. As these rules also consider the outcomes of each AE, they make reference to *AdaptiveElementOutcome* facts that represent the outcomes associated with each AE. The complete set of rules required to implement the round-robin appropriateness constraint are given in Appendix A to this thesis.

```
rule "Update Adaptive Elements after use"
no-loop
    when
        Recommendation($recId:id, $recTime:timeStamp)
        $element:AdaptiveElement(id == $recId, timeStamp < $recTime)
        $outcome:AdaptiveElementOutcome($outcomeId:id,
                                        adaptiveElement == $element)
    then
```

```
        $element.updateTimeStamp();
        update($element);
        update($outcome);
end
```

```
rule "Round robin disable"
no-loop
  when
    $newerAE:AdaptiveElement(strategyEnabled == true,
                             environmentEnabled == true,
                             $newerTime:timeStamp)
    $outcome:AdaptiveElementOutcome($outcomeId:id,
                                    adaptiveElement == $newerAE)
    $olderAE:AdaptiveElement(strategyEnabled == true,
                             environmentEnabled == true,
                             timeStamp < $newerTime)
    $outcome2:AdaptiveElementOutcome(id == $outcomeId,
                                     adaptiveElement == $olderAE)
  then
    $newerAE.setStrategyEnabled(false);
    update($newerAE);
    update($outcome);
end
```

Figure 53. Round-robin Game Appropriateness Rules

4.3.4.5 Adaptation Selection

The final stage in the ALIGN architecture executes the selection of the Adaptive Elements based on the current Learner Model and the personalisation rules. The Adaptation Selection process consists of personalisation rules that consider the current state of the Learner Model and then select one or more appropriate Adaptive Elements to adapt the game engine as is illustrated in Figure 54.

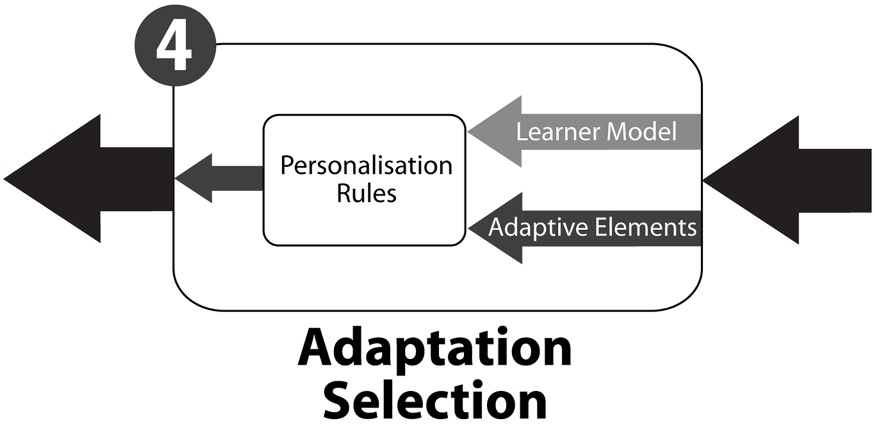

Figure 54. ALIGN Stage 4 - Adaptation Selection

The personalisation rules encode the pedagogical strategy being employed within ALIGN. Due to the preceding Adaptation Constraint stage the Adaptive Elements that are available for selection are guaranteed to be both feasible and appropriate to execute in the current game. This prior constraint allows the adaption rules to be simplified and to be only concerned with selecting desirable adaptations and ignoring how feasible or appropriate they may be. To avoid rules that explicitly reference AEs the personalisation rules select AEs by searching for an AE that provides the desired outcome. This allows for new AEs to be added that provide the same outcome without the need to change the personalisation rules. The simplicity of these rules as a result of the multi-stage approach is evident in the example rule given below in Figure 55. This example rule would be used to select an AE in the example scenario given previously in Figure 40 (p. 90)

```
rule "provide encouragement after task failure"
 when
   TaskEvent(eventType == Task.TASK_FAILURE)
 then
   ruleInterface.sendRecommendationFor("Encouragement for task X", 0);
end
```

Figure 55. Example Abstract Personalisation Rule

In the above rule the method the *ruleInterface* object is used to send a recommendation to the game engine using the *sendRecommendationFor()* method. This method performs a Drools query to select the available AEs based on their *environmentEnabled* and *strategyEnabled* state as is shown in Figure 56 below. The *ruleInterface* object is further detailed in the implementation of ALIGN in section 4.5.2.7.

```
query "get adaptive elements" (String desiredOutcome,
                               String desiredValue)
        element:AdaptiveElement(environmentEnabled == true,
                                strategyEnabled == true)
        outcome:AdaptiveElementOutcome(id == desiredOutcome,
                                       value == desiredValue,
                                       adaptiveElement == element)
end
```

Figure 56. Adaptive Element Selection Query

It should be noted that due to the Adaptation Constraint stage there may be no Adaptive Elements available for the personalisation rules to select. In effect there may be a desire to adapt the game engine for educational benefit however this adaptation is inhibited by either the state of the game (game constraints) or the desire to maintain a coherent gaming experience (appropriateness constraints). This prioritisation of the gaming experience over the educational adaptation is a key design feature of the ALIGN system and ensures that the engaging nature of the game is not mitigated through educational adaptations.

4.3.4.6 Detailed ALIGN Architecture

Through combining the components of each of the four stages detailed above, the detailed architecture of the ALIGN system emerges. This detailed architecture illustrated the cyclical flow of data and Adaptive Elements through ALIGN and is shown below in Figure 57.

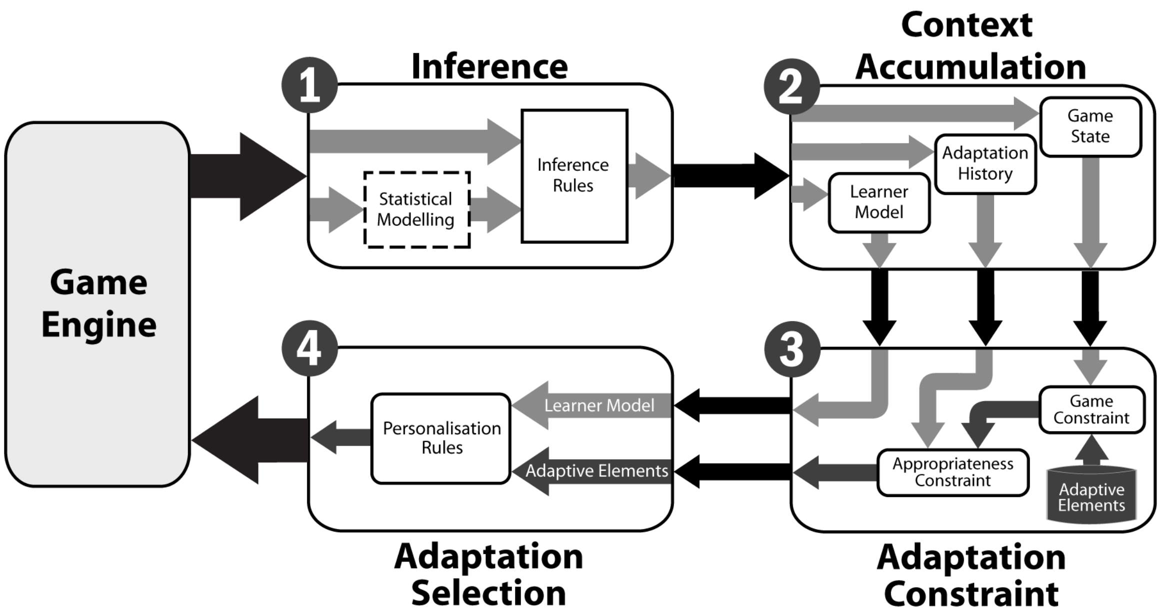

Figure 57. ALIGN Detailed Architecture

4.3.5 Design Summary

In this section the design of the ALIGN system has been presented. The design requirements for the ALIGN system are threefold technical, educational and ludic[22] in nature and are based upon influences emerging from the state of the art analysis conducted in chapters two and three.

As core concepts in the design of the ALIGN system, the approach taken to separating game logic and adaptation logic, as well as the approach to user modelling, were detailed in sections 4.3.2 and 4.3.3 respectively.

In section 4.3.4 the high level architecture of the ALIGN system was introduced with its basis in the four stage approach to non-invasive adaptation. Through elaborating on each of these four stages the cyclical architecture of the ALIGN system was illustrated with reference made to how the design fulfils the requirements derived from the state of the art analysis.

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[22] ludic, *adj.* Of or pertaining to undirected and spontaneously playful behaviour.

4.4 The ELEKTRA Game

In consideration of the diversity of video game implementations and platforms, the ALIGN system was designed to be able to technically accommodate as wide a variety of games as possible. The system provides for this flexibility through being platform agnostic due to its Java implementation, and through providing a communication channel over TCP/IP sockets, one of the most broadly supported network communication protocols. This section illustrates how the ALIGN system was effectively integrated with the ELEKTRA educational video game.

In line with the Action Research methodology the ALIGN system should both address a real world problem and be evaluated in a realistic scenario where that problem exists. For this reason ALIGN was integrated with the ELEKTRA game in order to evaluate the real world benefits of the system. The technical subject of physics was chosen as the focus of the ELEKTRA game as this subject is often considered challenging and contains novel concepts that are difficult to explain, but can be illustrated through experimentation. In having this focus the ELEKTRA game aims to address the real-world problem facing the students, with the ALIGN system aiming to make the ELEKTRA game as beneficial a learning tool as possible.

The following section details the design of the ELEKTRA game including the personalisation made possible by the game. This section in then followed by the technical implementation of ALIGN with the ELEKTRA game.

4.4.1 The ELEKTRA Evaluation Game

The ELEKTRA game was developed as part of the EU commission FP6 funded "Enhanced Learning Experience and Knowledge TRAnsfer" (ELEKTRA) project (ELEKTRA Project, n.d.). The project consisted of nine interdisciplinary partners and aimed to merge their expertise in cognitive science, pedagogical theory, computer science and neuroscience with the innovations of computer gaming, design and development. The final demonstrator system from the project was the ELEKTRA game.

The ELEKTRA game is a single player 3D adventure game that aims to aid students in learning about the physics of optics as studied by 13-15 year old secondary school students. The game is playable on a Windows based PC with a suitable 3D graphics card. Within the ELEKTRA project the ALIGN system was used to personalise the learning experience within the ELEKTRA game.

4.4.2 Game Design

The design of the ELEKTRA game was heavily influenced by both best practices in educational game design and the desire to make an educational game that was as visually attractive as commercial off the shelf games. In line with best practices in game design, the game features an engaging and motivating storyline, an appropriate learning content/game genre match, as well as having learning content tightly integrated into the game.

The design of the game was a collaborative activity involving the ELEKTRA partners. The storyline, visual style, and pedagogy were designed by Testaluna S.r.l[23], LMR[24], University of Graz, and the University of Liege. The influence of the author and Trinity College Dublin was in ensuring the game outputted game evidence, and also that the game could be adapted by the ALIGN system. The technical development of the game was undertaken by Testaluna S.r.l. an Italian serious games developer and LMR. The game was developed using the open-source Nebula Device 2[25] game engine. The contribution of the author lied in the development the personalised learning component of the game in the form of ALIGN system. This component was referred to as the Learning Engine within the ELEKTRA project.

The game's storyline places the learner in the role of George an inquisitive 13 year old boy. At the beginning of the game George realises that his uncle Leo has been kidnapped and seeks to solve the mystery of his disappearance. In trying to find his uncle, George encounters the ghost of Galileo Galilei who reluctantly aids George in solving optics based puzzles in order to uncover the mystery of his uncle's disappearance. As an added help to George his friend Lisa is also available to help and guide him on his quest. Some of the concept art and final level designs for the game are shown below in Figure 58, Figure 59, and Figure 60.

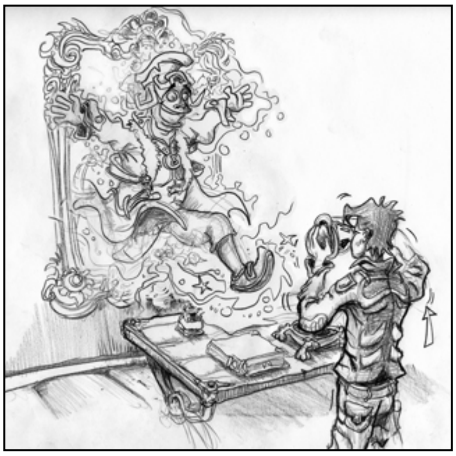

Figure 58. ELEKTRA Concept Art and Background Story

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[23] http://www.testaluna.it

[24] Laboratory for Mixed Realities, Cologne (http://www.elektra-project.org/en/1075/)

[25] The Nebula Device game engine has been discontinued due to the bankruptcy of the developer Radon Labs in 2010. http://en.wikipedia.org/wiki/Radon_Labs

Figure 59. Uncle Leo's Lab showing Lisa in the top left corner

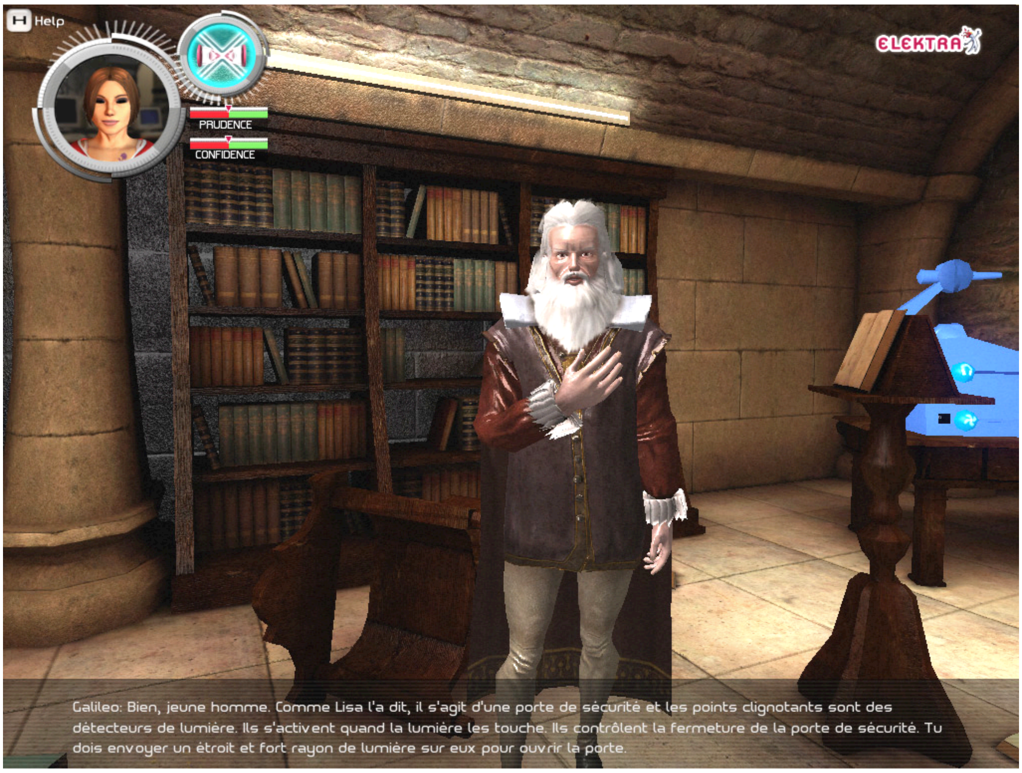

Figure 60. The ghost of Galileo Galilei in the ELEKTRA game

The learning content addressed by the ELEKTRA game is the physics of optics as studied by 13-15 year olds under the French school curriculum. The link to the French curriculum was necessary as the user trials were conducted in schools in France by the project partner ORT France[26]. The game's core mechanic involved the learner progressing through the game story and engaging with physics based puzzles and experiments. The game's pedagogical approach is to employ problem-based and experiential learning through the use of experiments that are both relevant to the game's storyline and also convey concepts relating to optics. Two of the experiments encountered are shown below. In Figure 61 the learner is able to interact with a device that demonstrates the effect of wind and magnetism on materials of different composition (plastic, wood, iron). In Figure 62 the learner must arrange a set of blinds to correctly focus a beam of light and in doing so demonstrate the linear propagation of light and the occluding effects of the blinds.

Figure 61. The ELEKTRA Slope Device

[26] http://www.ort.asso.fr/accueil.html

Figure 62. The ELEKTRA Blinds Experiment

4.4.3 Personalisation within ELEKTRA

The personalisation strategy adopted within ELEKTRA covers many aspects of the learning experience. The following seven points reflect the high-level strategy employed within the game that are realised by ALIGN personalisation rules.

1) Aid learners in clearly understanding their successes and failures at tasks through providing cognitive feedback
2) Foster awareness of approaches learners use in solving problems through the use of meta-cognitive feedback
3) Encourage the students to act prudently and show confidence where appropriate through making them aware of their historical confidence and prudence
4) Continually motivate learners where they are struggling through the use of affective feedback relevant to problematic skills
5) Encourage participation with experiments where excessive pauses are observed
6) Provide appropriate task guidance when a learner is struggling with an experiment
7) Present a suitable challenge to encourage mastery through the use of task repetition

The selection of the above personalisation strategies was influenced both by the state-of-the-art in adaptive educational games, and the research interests of the ELEKTRA partners. In particular the research undertaken in the University of Graz influenced the emphasis on skill modelling and affective feedback, whereas the University of Liege influenced the use of cognitive feedback, meta-cognitive feedback, and task repetition. Although a further variety of personalisations could have been implemented the limitations of the ELEKTRA project in terms of resources and time restricted the project to the above listed strategies. The implementation of these rules and the game evidence on which the personalisations are based is further discussed in *4.5.2.6 Personalisation Rules*.

4.4.4 Game Evidence

The ELEKTRA game provides both implicit and explicit learner evidence to ALIGN. In particular the actions performed by the learner in each of the experiments are sent to ALIGN as well as explicit confidence degree ratings. Each experiment is considered to be a learning task and thus the start of an experiment is considered to be the start of a task. Examples of some of the game evidence received during these tasks include the configuration of the slope device shown in Figure 61, and the positions of the blinds shown in Figure 62.

As part of the game's story the learner must gain the trust of Galileo by acting both confidently and prudently in the experiments they undertake. In order to calculate how prudent and confident a learner is being, they are asked to explicitly give their confidence rating before they perform an experiment, as is shown in Figure 63 below. By comparing the learner's confidence degree with the outcomes of the experiments it becomes possible to infer the learner's confidence and prudence as is detailed in the ALIGN implementation in section *4.5.2.3 Inference Rules*.

Figure 63. ELEKTRA Confidence Slider (Translation: "Determine your degree of certitude")

The learning content within the ELEKTRA game was disaggregated into 26 unique skills relating to the physics of optics by subject matter experts in ORT France and experts in Competence based Knowledge Space Theory in the University of Graz. These skills were then arranged into the prerequisite skill structure shown in Figure 64 below.

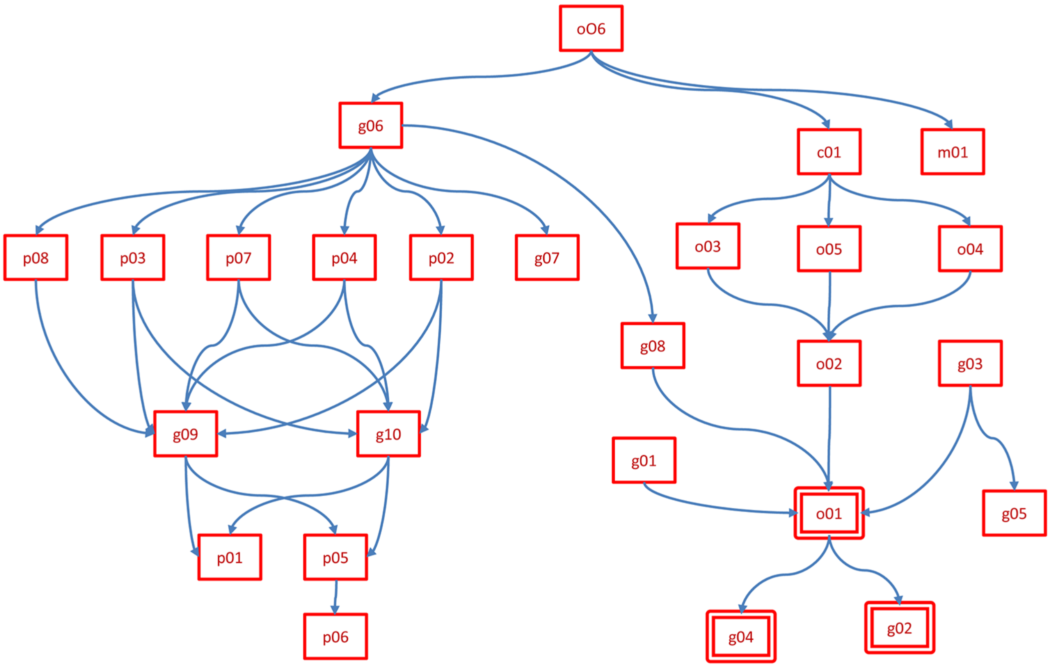

Figure 64. ELEKTRA skill prerequisite structure

Within this structure the prerequisite skills are shown below each skill, that is the arrows point to the prerequisite skills, e.g. skill *o01* (knowledge that light propagates in the form of a light cone) has prerequisites *g04* (knowledge that a spotlight emits light) and *g02* (knowledge that a torch emits light) as is highlighted in Figure 64. The complete description of each skill is given in Appendix A. Although all of these skills are addressed within the ELEKTRA game the game engine itself has no explicit knowledge of the skills. The task of matching game evidence to evidence of skills is an inference task within ALIGN and the implementation of the inference rules is detailed in *4.5.2.3 Inference Rules*. Further details of the skill structure are given in (Albert et al., 2007).

4.4.5 Adaptive Elements

The ELEKTRA game provides 197 adaptive elements that cover all of the seven adaptation strategies listed in section 4.4.3 above. These adaptive elements are associated with 112 unique outcomes, which indicates that certain outcomes are provided by multiple AEs. This multiplicity of outcomes enables the constraint rules to vary the AEs that are used to provide a given outcome. Although the ALIGN system by design does not consider how adaptations are realised within the game engine, the following examples illustrate the variety of ways adaptations are realised in the ELEKTRA game.

As the majority of personalisations constitute feedback of one form or another they are predominantly delivered through dialogues spoken by the Galileo NPC. The speech shown in

Figure 65 below is taken from the French version of the ELEKTRA game used in the evaluation user trials. The text in this case is some cognitive feedback given to the learner that is delivered through the Galileo NPC after a learner has given a partially correct description of an experiment. The translation of the text is *"Galileo: What you wrote is correct, but this is not the essential principle of physics that I expected."*.

Figure 65. Cognitive feedback from Galileo in the ELEKTRA Game

In contrast to how the above adaptation is realised the confidence and prudence feedback as shown in Figure 66 is realised through the use of two sliders within the game's user interface. In addition to these visual adaptations further non-visual adaptations are also used within the ELEKTRA game such as the repetition of parts of the slope device experiment where learners are having difficulty.

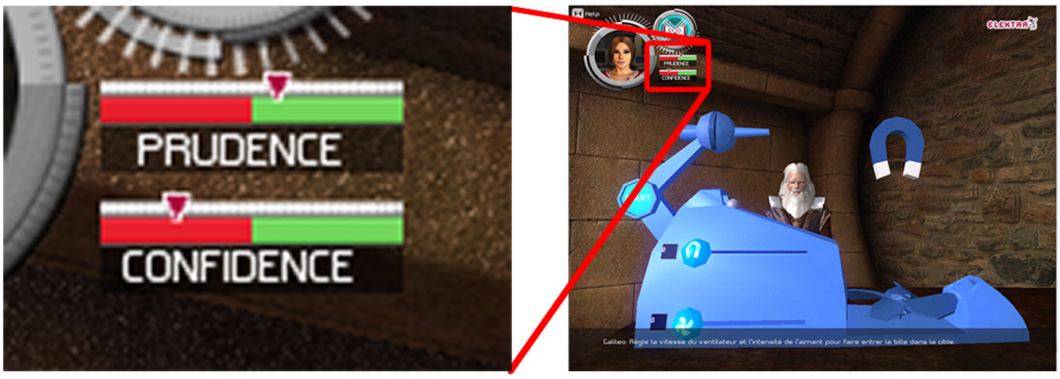

Figure 66. Confidence and Prudence sliders in the ELEKTRA Game

The following example AEs from ELEKTRA are of interest as they show the varying properties of AEs such as providing multiple outcomes (Figure 67), having multiple task requirements (Figure 68), and multiple AEs providing the same outcome (Figure 68).

```
<element id="LeS121_ai_34">
      <outcome id="p01_i_anal" value="0"/>
      <outcome id="p01_d_anal" value="0"/>
      <task-req value="">LeS1.2.1</task-req>
</element>
```

Figure 67. Adaptive Element with Multiple Outcomes

```
<element id="LeS11_GA_102_1">
      <outcome id="metacog_hint_a" value="0"/>
      <task-req value="">LeS1.2.1</task-req>
      <task-req value="">LeS1.2.3</task-req>
</element>

<element id="LeS11_GA_102_2">
      <outcome id="metacog_hint_a" value="0"/>
      <task-req value="">LeS1.2.1</task-req>
      <task-req value="">LeS1.2.3</task-req>
</element>
```

Figure 68. Adaptive Elements with Multiple Task Requirements and a Common Outcome

4.5 Implementation of ALIGN

This section discusses the implementation of the ALIGN system based on the design described in section 4.3 above. This section is broken into four subsections detailing different aspects of the ALIGN implementation. These subsections detail the technologies supporting the ALIGN system, the technical architecture of ALIGN and its components, the steps required to initialize the ALIGN system, and the technical integration with the ELEKTRA game. As this initial technical implementation of ALIGN is realised with the ELEKTRA game the following components are specific to the use of ALIGN with the ELEKTRA game: *4.5.2.2 Rule Flow and Ordering Rule Execution*, *4.5.2.3 Inference Rules*, *4.5.2.6 Personalisation Rules*, and *4.5.2.8 Adaptive Elements.*

4.5.1 Technologies supporting the ALIGN system

The ALIGN system is developed entirely in Java due to its high performance, platform independence and wide variety of open source libraries. At the core of the ALIGN system is the Drools rule engine. This rule engine was selected for its high performance, rich feature set, IDE integration, and open source licence. The object oriented nature of Drools as well as its clear declarative rule language makes it a quick and efficient system in which to create and maintain rules. In order to provide the logging of user evidence and the recommendations made, the Log4J[27] library was used.

[27] http://logging.apache.org/log4j/1.2/

4.5.2 Technical Architecture of ALIGN

The logical architecture that was presented in the preceding design section represented each functional component of ALIGN and the clear ordering in which they operate. Although the technical architecture presented below maintains the logical functionality of the architecture, the individual components are realised in a manner to make them operate efficiently and to best leverage the Drools rule engine.

The most evidently significant difference between the logical and technical architectures is the use of a single Drools working memory that contains all of the facts in the system and all of the rules. Although these rules and facts are technically operating within the same working memory they remain logically separated as they operate over different facts and an execution order for the rules is imposed as is detailed in *4.5.2.2 Rule Flow and Ordering Rule Execution.*

The technical architecture of ALIGN is based around the Drools rule engine coupled with custom rules and a networking and message parsing component as is shown below in Figure 69.

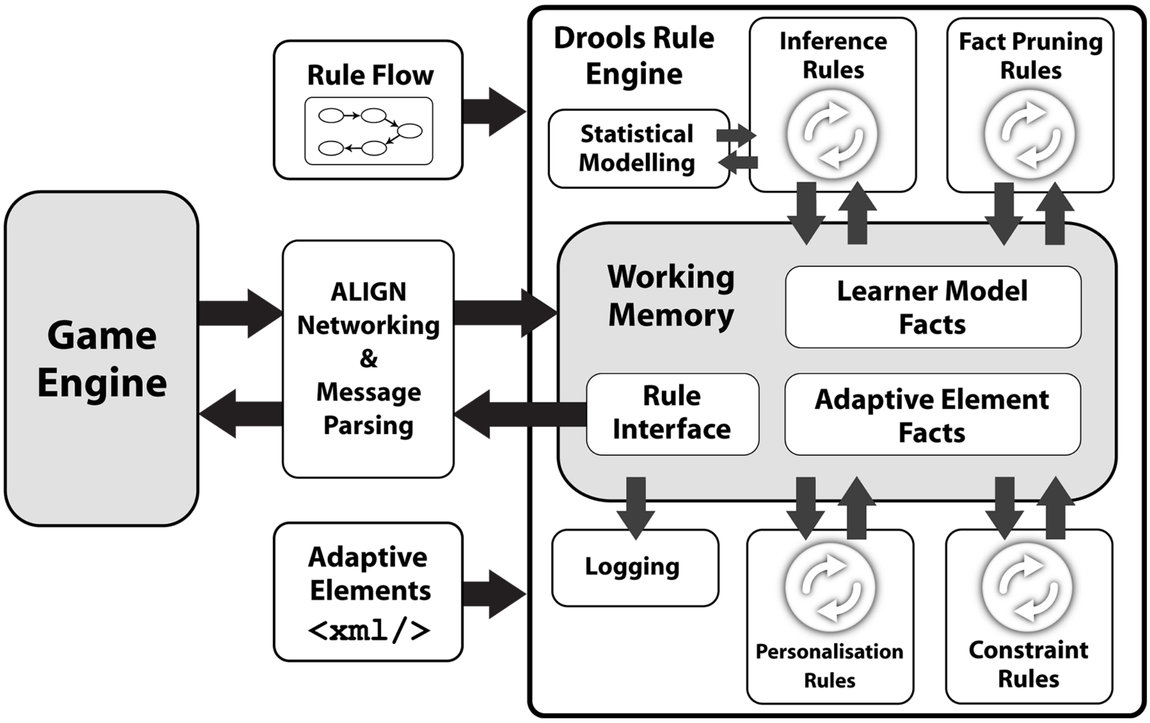

Figure 69. ALIGN Technical Architecture

The technical architecture shown above consists of the following components.

- **ALIGN Networking & Message Parsing** – The component that manages TCP/IP communication and message passing between the Drools rule engine and the game engine.

- **Rule Flow** – The Drools rule flow that imposes an ordering over the execution of all the rules in the working memory.
- **Inference Rules** – The rules applied to game evidence coming from the game engine and detailed in sections *4.3.2.2 Abstraction of Adaptation* and *4.3.4.2 Game Evidence Inference.*
- **Fact Pruning Rules** – The rules applied to accumulated facts to ensure the freshness of the evidence and reasonable memory usage as detailed in section *4.3.4.3 Context Accumulation*.
- **Constraint Rules** – The rules restricting the use of Adaptive Elements based on the tasks being undertaken with the game engine as detailed in *4.3.2.3 Adaptive Elements* and *4.3.4.4 Adaptation Constraint.*
- **Personalisation Rules** – The rules that represent the personalisation strategy to be applied as detailed in *4.3.4.5 Adaptation Selection.*
- **Rule Interface** – A utility class that is a fact within the working memory that provides facilities to search for Adaptive Elements and to send recommendation to the game engine.
- **Adaptive Elements** – The Adaptive Elements that are to be used to adapt the game engine as described in *4.3.2.3 Adaptive Elements.*
- **Logging** – The logging infrastructure to log the facts within the working memory and recommendations made to the game engine.

The technical implementation of these components is detailed in the following sections.

4.5.2.1 Networking and Message Parsing

The design requirements for the ALIGN system require that it be able to communicate with a variety of game engines. Due to the diverse nature of game engines and the platforms on which they are developed the decision was made to use a TCP/IP socket based communication system. This decision ensures the maximum number of platforms will be able to communicate with the ALIGN system as the vast majority of programming languages have libraries that support TCP/IP communication.

The ALIGN communication system uses persistent full duplex TCP/IP sockets. In consideration of the design requirement to minimize latency the ALIGN messaging format was developed as a compact and quickly parsable way of communicating over the TCP/IP socket. By default the ALIGN system listens on port 6600 for new connections but this is configurable as start up.

ALIGN Messaging Format

The messaging format consists of variable length messages that consist of both the game evidence being sent from the game engine and the recommendations for Adaptive Elements that are sent to the game engine. The definite clause grammar for the messaging format is given below in Table 12. An example of a message encoded in the format is given in Table 13. The two message types of USER_EVENT and LS_INITIAL_STATE (Learning Situation Initial State) given below were originally defined as part of the messaging format but were never used by either ALIGN or the ELEKTRA game.

Table 12. ALIGN Messaging Format

Messages Received by ALIGN

```
<message> = <message-type><message-length><message-body>
<message-type> = <integer>
<message-length> = <integer>

Basic Types:
<short> = 2 byte big endian signed integer

<integer> = 4 byte big endian signed integer

<string> = <num-bytes><utf-8-bytes>
<num-bytes> = <short>

<utf-8-bytes> = A variable number of bytes of UTF-8 encoded text

<identifier> = <string>

<parameter-list> = <num-parameters>(<key><value>, ...)
<num-parameters> = <integer>
<key> = <string>
<value> = <string>
```

Message Type	**Message Body**
1: USER_EVENT	Not used
2: TASK_START	<identifier>
3: TASK_END	<identifier>
4: TASK_FAILURE	<identifier>
5: TASK_SUCCESS	<identifier>
6: LS_INITIAL_STATE	Not used
7: RECOMMENDATION_USED	<identifier><integer> (This message contains the identifier and value of an Adaptive Element that was sent to the game engine)
8: SUB_TASK_EVENT	<identifier><parameter-list>

9: USER_LOGIN	<identifier>
10: CONFIDENCE_DEGREE	<identifier><integer>
131: OPTION	<identifier><parameter> <parameter> = <string>
Utility Messages	
128: SHUTDOWN	(This message has no body and indicates that the game engine is shutting down and ALIGN is no longer needed.)
129: DEBUG	<string> (This message is used for debugging purposes and causes a debug message to be logged by ALIGN)
130: DEBUG_MODE	<integer> (Enable verbose logging if <integer> != 0)
Messages Sent by ALIGN	
<recommendation-message> = <adaptive-element> <adaptive-element> = <identifier><outcome-value> <outcome-value> = <integer>	

Table 13. Example ALIGN Message

Message: The learner has succeeded at the task "task1"

<message-type>	<message-length>	<message-body>
5: TASK_SUCCESS		"task1"
0x00000005	0x00000007	0x0005 0x7461736b31

Complete message in hexadecimal (15 bytes):

`00000005 00000007 0005 7461736b31`

Game Engine Connection and Message Parsing

The process of a game engine connecting to the ALIGN system consists of the following steps:

1. The ALIGN system listens for an incoming connection on port 6600.
2. The game engine opens a full duplex TCP/IP connection to ALIGN on port 6600.
3. The game engine begins to send messages to ALIGN using the ALIGN messaging format.
4. The game receives recommendation messages from ALIGN.

The ALIGN system uses a dedicated thread to process all messages that are received and sent. All received messages are processed by the *MessageParser* as is illustrated below in Figure 70.

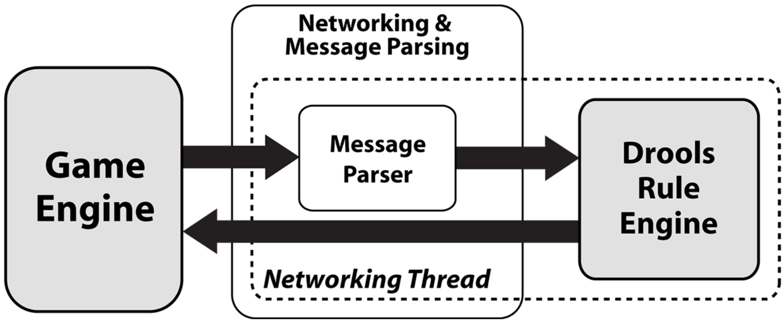

Figure 70. ALIGN message parsing and threading

The message types defined in the ALIGN messaging format in Table 12 have a one-to-one mapping to the facts types (see Table 10, p99) inserted into the working memory. This mapping is detailed below in Table 14. Once a message is received from the game engine it is parsed by the *MessageParser* and the corresponding facts are inserted into the working memory where any inference rules and/or personalisation rules matching the fact will execute.

Table 14. Mapping of ALIGN messages to Java Objects

ALIGN Message Type	Java Object inserted into the working memory
TASK_START	→ TaskEvent(identifier, eventType = TASK_START)
TASK_END	→ TaskEvent(identifier, eventType = TASK_END)
TASK_FAILURE	→ TaskEvent(identifier, eventType = TASK_FAILURE)
TASK_SUCCESS	→ TaskEvent(identifier, eventType = TASK_SUCCESS)
RECOMMENDATION_USED	→ Recommendation(identifier, value)
SUB_TASK_EVENT	→ SubTaskElementEvent(identifier, parameters)
USER_LOGIN	→ UserLogin(identifier)
CONFIDENCE_DEGREE	→ CondfidenceDegreeEvent(identifier, value)
OPTION	→ Option(identifier, parameter)
DEBUG	→ GenericFact(debug_text)

When the game engine is shutting down it can send a SHUTDOWN message to ALIGN which will cause it to cleanly exit.

4.5.2.2 Rule Flow and Ordering Rule Execution

Within a rule engine it can be possible that one or more rules may want to execute based on facts that have been inserted into the working memory. Whereas the rule engine guarantees that all of the rules that can execute do execute it does not stipulate the exact ordering of rule execution. This arbitrary execution order can be problematic when trying to deliver a sequential process such as the four stage process used within ALIGN.

The Drools rule engine however, provides a number of mechanisms to order the execution of rules. The two mechanisms used within the ALIGN system are that of *salience* and *ruleflow-groups*. The salience attribute can be used to assign an execution weight to a rule. By default all rules have a salience value of zero, by settings a salience value higher or lower than zero the order of rule execution can be changed. Rules with higher salience values always execute before rules with lower salience values.

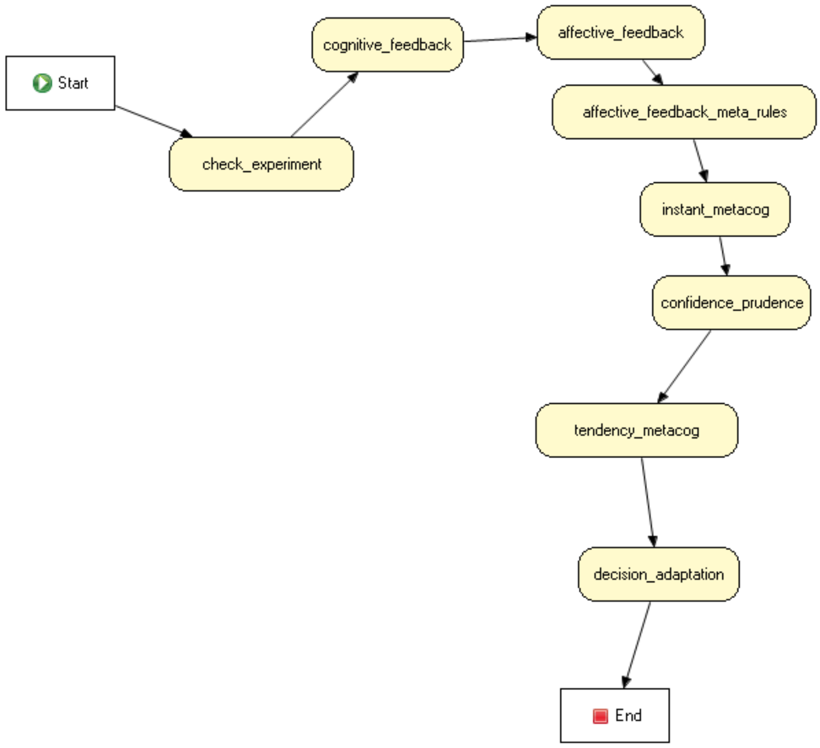

Figure 71. Rule flow diagram for the ELEKTRA game

The second ordering mechanism used is that of *ruleflow-groups*. A rule flow is a specified ordering of *ruleflow-groups* that is loaded at start up. Once a rule flow is started each rule flow group becomes active in a defined sequence. Only rules in the currently active rule flow group are allowed to execute. Once all of the rules in a group have executed the next rule flow group is activated. Each rule can be optionally assigned to a rule flow group when rules are being authored. Within a rule flow group individual rules can be ordered by salience if desired. The rule flow for the ELEKTRA game imposes an ordering for the personalisation rules and is shown above in Figure 71.

Within ALIGN the inference rules are given the highest salience, followed by the constraint rules, the personalisation rules, and the fact pruning rules. The low priority of the fact pruning rules is to ensure the no facts are pruned before they may be used by the constraint or personalisation rules.

4.5.2.3 Inference Rules

Immediately following new game evidence being inserted into the working memory the first set of rules to execute are the inference rules. As these rules are game specific this section will focus on the inference problems unique to the ELEKTRA game.

The three key inference challenges within ELEKTRA are the calculation of confidence and prudence values from task outcomes and confidence degrees, the checking of experiment correctness, and the mapping of game evidence to required and missing skills for use in CbKST. Examples of the rules used to perform this inference are available in Appendix A, however it is necessary to introduce the following utility facts to represent the outcomes of these inferences. The need for these utility facts is as result of neither confidence nor prudence values, or lists of required or missing skills being effectively represented by the game evidence facts we have defined.

Utility Facts

The various fact types that are used in ALIGN to represent game evidence were detailed in *4.3.4.2 Game Evidence Inference*. Although these fact types represent the game evidence and inferred evidence within ALIGN it is both convenient and efficient to define additional fact types that are used to maintain state within ALIGN and simplify the authoring of personalisation rules.

One of the challenges of writing rules where large numbers of similar facts are present in the working memory is that the rule author must be very specific as to the exact fact pattern they are looking for. In particular where facts are often repeated such as when a game task is repeated, rules have to be written defensively and explicitly to only be concerned with the most recent game evidence. In order to simplify the personalisation rules utility facts are used to represent the most recent state of a piece of game evidence. That is a *Task* fact for a given identifier represents the most recent *TaskEvent*, and similarly for a *SubTaskElement* and a *SubTaskElementEvent*. A further utility fact to simplify the rules and maintain state such as counters is the *GenericFact.* This fact type is used to store an individual value. The details of these three utility fact types are given in Table 15 below.

Table 15. Internal Fact Details

Fact Name	Fact Properties	Fact Description
GenericFact	**intValue**: int **doubleValue**: double **stringValue**: String **objectValue**: Object	This fact type is a utility fact that is used to store a single integer, double, String, or Object. It is used to store miscellaneous state values within the working memory such as counters or calculated values e.g. the number of task successes.
Task	**eventType**:int {UNDEFINED, TASK_START, TASK_END, TASK_SUCCESS, TASK_FAILURE}	The Task fact is identical to the TaskEvent fact except it is a singleton object for each individual task identifier.
SubTaskElement	**parameters**:HashMap	The *SubTaskElement* fact acts in a manner akin to a *Task* fact and represents the most current *SubTaskElementEvent* for a given identifier.

In order to ensure that *Task* and *SubTaskElement* facts always reflect the most recent game evidence inference rules are used to update the facts. One of these rules for *Task* facts is given below in Figure 72.

```
rule "update existing task"
no-loop true
   when
        TaskEvent($theId:identifier, $theEventType:eventType)
        $task:Task(identifier == theId)
   then
        $task.setEventType($theEventType.intValue());
        update(task);
end
```

Figure 72. Inference rule to update utility facts

The use of the *no-loop* directive in the above rule ensures that the rule does not activate itself and cause an infinite loop when it updates the Task fact.

Statistical Modelling using Competence-based Knowledge Space Theory (CbKST)

The output of the inference rules mapping game evidence to lists of skills for use in CbKST is represented as a *PosCatSkills* fact. This fact is essentially a list of skills associated with the position category of the experimental setup within the game. As a further facet of the CbKST modelling the output of the calculation is a number of *SkillEvent* facts that represent the most recently updated skill probabilities. In a manner akin to *Task* facts the *Skill* fact represents the most recent probability of a given skill. These three fact types are detailed in Table 16 below.

Table 16. Details of the PosCatSkills, SkillEvent and Skill fact types

Fact Name	Fact Properties	Fact Description
PosCatSkills	**requiredSkills:** String[] **missingSkills**: String[]	This fact represents the required and missing skills for the setup of an experiment in ELEKTRA.
SkillEvent	**probability**: double	This fact represents a change in the probability of a particular skill as computed by the CbKST algorithm.
Skill	**probability**: double	This fact is a singleton fact that represents a particular skill in a manner akin to a *Task* fact.

As was explained in chapter 3 of this thesis, it is possible to use evidence of a user's actions in a learning task to build a probabilistic model of a learner's skills and competencies. This can greatly enrich the learner model allowing problematic skills to be identified and addressed using adaptations. However, the implementation of CbKST within ALIGN presents challenges in maintaining a responsive system whilst not compromising the theoretical underpinnings of CbKST.

The challenges encountered with the use of CbKST in a real-time adaptive system are detailed in the paper (Conlan et al., 2009). In consideration that the number of skill states can be up to $|2^n|$ for n skills the number of calculations required for a modest number of skills is considerable. As was detailed in chapter 3 the calculations required to determine the probabilities of skills using CbKST has a worst case exponential complexity of $O(2^n)$ for n skills. Additionally the dependent nature of the calculations means that the calculations must be performed serially and so cannot easily benefit from the parallelization possible on multi-core CPUs.

In order to realise a real-time calculation of skill probabilities the code used to calculate the probabilities was optimised as much as possible to mitigate the computational complexity of the algorithm. The optimization was achieved through the use bit vectors to perform quick set operations, loop unrolling, reducing method calls, and through minimizing costly calculations where possible.

The following is the process required to update the skill probabilities when a piece of learner evidence is received that indicates a learner has showed evidence of possessing certain skills *S* and is missing other skills *S'*.

1. For each possessed skill *S,* positively update the skill states that contain that skill
    a. Iterate through every skill state and update it if it contains skill *S*.
    b. Sum all of the skill state probabilities to form a normalising value

c. Divide every skill state probability by the normaliser to ensure all of the skill state probabilities sum to 1.0

2. For each missing skill *S'*, negatively update the skill states that contain that skill. Repeat steps *a*, *b*, and *c* above.
3. Calculate the new probability for each skill by summing the probabilities of every skill state that the skill is a member of.

Although CbKST has a worst case complexity of $O(2^n)$, in practice the complexity is considerably less and is highly dependent on the prerequisite structure of the skill space. The number of skill states generated from a prerequisite structure is inversely proportional to the depth of the prerequisite structure, i.e. the less prerequisites a skill has the more skill states that exist. In the case of the ELEKTRA skill structure the 26 skills resulted in 12,414 possible skill states. Despite the number of skill states and the complexity of the calculations required to update the skill probabilities, each CbKST update was consistently achieved in less than 50ms with a typical update taking approx. 20ms when running on an Intel Core 2 Duo 2.5GHz processor.

One final challenge of using CbKST is the determination of all the possible skill states from a prerequisite structure. As the prerequisite structure is encoded in an OWL ontology it can take several minutes to infer all of the possible skill states using the SPARQL (W3C, n.d.) language to query the ontology. For this reason all of the skill states are pre-calculated at design time to prevent ALIGN having to perform this calculation repeatedly at start up.

4.5.2.4 Fact Pruning Rules

The necessity for fact pruning rules is in order to allow evidence aging, constrained memory usage, and provide responsive adaptations to the game engine. In consideration that the Drools rule engine scales linearly with the number of rules and the number of facts in the working memory, the fewer facts in the working memory the faster the rules will execute.

```
rule "consume task event end"
salience -1001
  when
     $start:TaskEvent($id:id, eventType == Task.TASK_START, $t:time)
     $end:TaskEvent(id == $id, eventType == Task.TASK_END, time >= $t)
  then
     retract($start);
     retract($end);
end
```

Figure 73. Example fact pruning rule

In order to maintain a reasonable number of facts in the working memory fact pruning rules can remove facts that are no longer needed. The rule shown above in Figure 73 demonstrates how

TaskEvent facts that are no longer needed can be retracted from the working memory. Importantly this rule has a very low salience value indicating that it will execute after all other rules that have a higher salience value.

4.5.2.5 Constraint Rules

The rules used to constrain the adaptation are broken into two parts. Firstly, the game constraint rules ensure that only adaptive elements that can be realised in the game state are enabled. This constraint operates by considering the current *Task* facts and the required tasks for each Adaptive Element. Where an Adaptive Element cannot be used due to the current task or tasks it is disabled by setting its *environmentEnabled* property to *false.* The two rules used to achieve game constraint are given in Appendix A and perform the following functions:

- Disable Adaptive Elements that have an unfulfilled task dependency.
- Re-enable Adaptive Elements that have task dependencies that can now be fulfilled.

The second form of constraint rules ensures that the Adaptive Elements that are used are not used repeatedly which could create unacceptable changes with the game. This constraint operates by considering every previous *Recommendation* fact that has been sent to the game engine to ensure Adaptive Elements aren't used repeatedly. When an inappropriate Adaptive Element is found it has its *strategyEnabled* property set to *false.*

The three appropriateness constraint rules perform the following functions and their full implementation is given in Appendix A to this thesis.

- Update the timestamp of an Adaptive Element to indicate it was used when the corresponding Recommendation is sent to the game engine.
- Disable Adaptive Elements that provide the same outcome in a round-robin manner so that the most recently used Adaptive Element is disabled.
- Enable the Adaptive Element that is the least recently used for a given outcome.

In the case where only a single Adaptive Element provides an outcome as it is never disabled as it is not possible to provide a variety of Adaptive Elements for that outcome.

4.5.2.6 Personalisation Rules

The personalisation rules encode the personalisation strategies within the ALIGN system. The variety of personalisation that can be provided is dependent on the facts available in the Learner Model, the adaptations possible within the game, and the enabled Adaptive Elements. In the context of the ELEKTRA game the seven types of personalisation detailed in *4.4.3 Personalisation within ELEKTRA* are catered for. In Table 17 below the mapping between personalisation strategies and game evidence is given. Through the different interpretations of the same game evidence it becomes possible to realise a variety of personalisations.

Table 17. Game evidence used for personalisation within ELEKTRA

Personalisation strategy	Game Evidence
1) Aid learners in clearly understanding their successes and failures at tasks through providing cognitive feedback	*TaskEvent (Success, Failure)*
2) Foster awareness of approaches learners use in solving problems through the use of meta-cognitive feedback	*TaskEvent (Success, Failure), ConfidenceDegreeEvent*
3) Encourage the students to act prudently and show confidence where appropriate through making them aware of their historical confidence and prudence	*TaskEvent (Success, Failure), ConfidenceDegreeEvent*
4) Continually motivate learners where they are struggling through the use of affective feedback relevant to problematic skills	*TaskEvent (Success, Failure), SkillEvent*
5) Encourage participation with experiments where excessive pauses are observed	*TaskEvent (Start, End) +duration*
6) Provide appropriate task guidance when a learner is struggling with an experiment	*TaskEvent (Start, End) +duration*
7) Present a suitable challenge to encourage mastery through the use of task repetition	*TaskEvent (Success, Failure)*

Examples of the personalisation rules used to implement the above personalisations appear in Appendix A to this thesis. Some of the diverse ways in which these rules access the learner model are given below as they illustrate how it possible to easily interpret the learner model in many ways.

Accessing Learner Model Data

In order not to limit the way in which the data in the learner model is accessed the design of ALIGN does not impose a rigid learner model schema. Whereas this adds flexibility in how the learner model is interpreted, rules are needed to extract data from the learner model. Some examples of possible ways to view a user model are: typologically, chronologically, or pattern based. The predominant approach to user modelling using hierarchical structures such as XML or ontologies cannot easily and efficiently allow these multiple perspectives. However through using rules to process the learner model these perspectives can easily and efficiently be realised. In the following examples in Figure 74 it is shown how user facts can be accessed in varying perspectives using a set of rules.

```
rule "get every task success"
        when
                $successes: ArrayList() from collect
                         (TaskEvent(eventType == Task.TASK_SUCCESS))
        then
                // perform some action on $successes
end
```

```
rule "get the most recent task success"
        when
            $newestSuccess: TaskEvent(eventType == Task.TASK_SUCCESS,
                                      $newestTime:timeStamp)
            not TaskEvent(eventType == Task.TASK_SUCCESS,
                                      timestamp > $newestTime)
        then
                // perform some action on $newestSuccess
end
```

```
rule "get eventual success"
/* An eventual success in this example is a success at a task
following  four or more prior failures at the same task */
        when
                TaskEvent($id:id, eventType == Task.TASK_SUCCESS,
                                      timestamp > $successTime)

                $failures: ArrayList(size >= 4) from collect
                                (TaskEvent(id = $id,
                                 eventType == Task.TASK_SUCCESS,
                                 timestamp < $successTime))
        then
                // perform some action based on eventual successes
end
```

Figure 74. Example Learner Model Perspectives using Rules

The design decision to represent the ALIGN learner model as a set of facts allows not only efficient and flexible ways of interacting with the learner model it also allows for future adaptive rules to access the model in novel ways. Further to this the Drools rule engine provides a query mechanism that allows arbitrary facts to be retrieved. An example of such a query is given below in Figure 75. In this query all of the *SubTaskElementEvents* will be returned that have occurred since the task "example" started.

```
query "get all SubTaskEvents since the task ‘example’ started"
 TaskEvent(id == “example”, type == Task.TASK_START, $start:timestamp)
 $events:SubTaskElementEvent(id == “example”,
                                   timestamp >= $start)
end
```

Figure 75. Example Drools Learner Model Query

Although the majority of personalisation rules follow a synchronous cause-effect series of logic where learner model facts trigger a personalisation rule which consequently adapts the game, it is also possible for rules to operate asynchronously. The Drools rule engine provides the facility to author temporal rules, that is, rules that execute once a rule pattern holds true for a given period of time. These temporal rules can be used to make decisions based on learner model facts that remain unchanged for a period of time. The following example rule shown in Figure 76 will send a task hint to a learner if they have started but not completed a task after 30 seconds. The duration attribute of a rule indicates the duration in milliseconds that the rule conditions must remain true before it is executed.

```
rule "task completion hint"
duration 30000
  when
     TaskEvent($id: id, eventType == Task.TASK_START, $time:time)
     not TaskEvent(id = $id, eventType == Task.TASK_END, time > $time)
  then
     ruleInterface.sendRecommendationFor("task_hint",0, drools);
end
```

Figure 76. Example Temporal Rule

4.5.2.7 The Rule Interface

Due to the nature of how a Drools rule executes it is necessary to provide a global Java object that acts as an interface for rules to make changes outside of the rule engine. Within ALIGN the *RuleInterface* object provides this functionality and is inserted into the working memory (see Figure 69) when it is first created. This object provides a centralised method for the rules to 1) find *AdaptiveElements* that provide a certain outcome and 2) send a recommended *AdaptiveElement* to the game engine. In order to achieve this, the *RuleInterface* executes Drools queries to find appropriate *AdaptiveElements* and also interacts with the Networking and Message Parsing component. The query used to find appropriate *AdaptiveElements* is given below in Figure 77. As can be seen in this query, only *AdaptiveElements* that are still enabled after the constraint rules have executed are considered for selection.

```
query "get available desired outcomes" (String desiredOutcome,
                                         String desiredValue)
        element:AdaptiveElement(environmentEnabled == true,
                                strategyEnabled == true)
        outcome:AdaptiveElementOutcome(id == desiredOutcome,
                                value == desiredValue,
                                adaptiveElement == element)
end
```

Figure 77. Drools query to find desired AdaptiveElements

4.5.2.8 Adaptive Elements

The Adaptive Elements to be used by ALIGN are loaded at startup from an XML file describing the elements. The loaded elements are then converted to fact objects and inserted into the Drools working memory. The Document Type Definition (DTD)[28] describing the adaptive element XML file is given below in Figure 78. An example XML file conforming to this DTD is also shown below in Figure 79.

```
<!DOCTYPE elements [
<!ELEMENT element (outcome+,task-exclude*,task-req*,sub-task-req*)>
<!ATTLIST element id CDATA #REQUIRED>

<!ELEMENT outcome EMPTY>
<!ATTLIST outcome
      id CDATA #REQUIRED
      value CDATA #REQUIRED
>

<!ELEMENT task-exclude (#CDATA)>
<!ELEMENT task-req (#CDATA)>
<!ELEMENT sub-task-req (#CDATA)>
]>
```

Figure 78. Adaptive Element XML file DTD

```
<?xml version="1.0" encoding="UTF-8"?>
<elements>
      <element id="example_element">
            <outcome id="outcome1" value="0"/>
            <task-exclude>excluded_task</task-exclude>
            <task-req>required_task</task-req>
            <sub-task-req>required_sub_task_event</sub-task-req>
      </element>
</elements>
```

Figure 79. Example Adaptive Element XML file

4.5.2.9 Logging

The use of logging within the ALIGN system provides not only debugging and development feedback but also an essential record of learner activity for evaluation purposes. The Log4J library[29] was used for the logging of the inputs and outputs of ALIGN on a per learner basis. In order to achieve this, an extension for Log4J was developed to both create log files in XML and to also allow separate log files for each learner. A further extension to Log4J was developed to enable log files to be closed and loggers removed which is not possible with the standard Log4J implementation. The XML format of the log files allows them to be analysed using XQuery and transformed using XSLT. An example of a generated log file is given below in Figure 80.

---

[28] http://www.w3.org/TR/REC-xml/#dt-doctype

[29] http://logging.apache.org/log4j/1.2/

```xml
<?xml version="1.0" encoding="UTF-8"?>
<log>
<INFO timestamp="11145021" date="2010-02-10 14:28:32,883">
<user id="572145EC-AFF1-45EC-9019-938847E2844A" />
</INFO>
<INFO timestamp="11145034" date="2010-02-10 14:28:32,896">
<UserLogin>
      <username>user160</username>
      <id>user160</id>
      <time>20576428553515537</time>
      <timestamp>20576428553515537</timestamp>
</UserLogin>
</INFO>
<INFO timestamp="11186110" date="2010-02-10 14:29:13,972">
<SubTaskElementEvent id="dialog_request" timestamp="20576469636013352">
      <parameters>{charId=darkman, initial=true}</parameters>
</SubTaskElementEvent>
</INFO>
<INFO timestamp="11193716" date="2010-02-10 14:29:21,578">
<SubTaskElementEvent id="dialog_choosen" timestamp="20576477242039326">
      <parameters>{dialogContext=0:false,0:true,0:false,
nextDialog=start, correct=false, charId=darkman, rating=0, choosenId=3,
lang=en, oldDialog=start}</parameters>
</SubTaskElementEvent>
</INFO>
...
</log>
```

Figure 80. Example XML Log File

In order for the rules to have access to the logging functionality an instance of the custom logger was set as a global object in the working memory. This global object can then be used from within the rules. A single logging rule was used to select the facts to log as shown below in Figure 81. The *AdaptiveElement* and *AdaptiveElementOutcome* facts are excluded from logging as there is no need to record changes in these facts.

```
global Logger logger;

rule "Log all facts"
salience 100000
   when
        $fact:AbstractFact();
   then
        if(!($fact instanceof AdaptiveElement)
             && !($fact instanceof AdaptiveElementOutcome)){
                logger.info($fact.getXMLString());
        }
end
```

Figure 81. Universal Logging Rule

4.5.3 ALIGN Initialization

The initialization of the ALIGN system requires two key steps before clients can be accepted. In the first, the Drools rulebase must be loaded from the local file system. The loaded file is a serialized instance of a Drools rulebase. This single rulebase contains all of the rules used in the ALIGN system, including inference, pruning, constraint, and personalisation rules. As a convenience the ALIGN system periodically scans the rulebase file and will reload it when it is updated. This feature allows rule updates to be applied without the need to restart the entire ALIGN system. The reloaded rulebase is only applied to clients that subsequently connect; existing clients will continue to use the rulebase they started with for consistency.

In the second initialization step the Adaptive Elements must be loaded so that they can be inserted into the working memory for each user. The adaptive elements are stored on the local file system in an XML format described in the preceding section.

In order for the adaptive elements to be inserted into the working memory each 'element' node is parsed and converted into an *AdaptiveElement* instance with each 'outcome' being converted into and *AdaptiveElementOutcome* instance. All of these instances are then inserted into the working memory. The rationale behind separating the outcomes from the elements is so that rules and queries can reason about available outcomes, as opposed to just adaptive elements which in effect are just unique identifiers with task dependencies.

4.5.4 Technical Integration with the ELEKTRA game

In the evaluation of the ELEKTRA game the ALIGN system is installed alongside the game on the same PC and starts when the game is started (Figure 82).

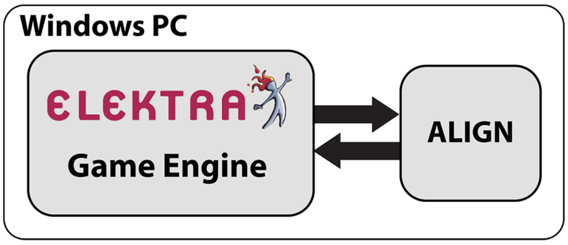

Figure 82. ELEKTRA Game and ALIGN Architecture

Despite the ALIGN system and the game running on the same hardware, communication is still achieved over a TCP/IP socket. In this scenario as the socket connection is achieved over the local loopback connection minimal network latency is encountered keeping response times very low. This is of significance as 3D first-person perspective games require split second responses with low latency.

4.5.4.1 ELEKTRA Evaluation Features

The evaluation of ALIGN with the ELEKTRA game employs a technique called 'yoked control design' (Church, 1964). This technique is used to evaluate adaptive systems by matching learners based on their ability and having one of the pair use the adaptive system but receive the adaptations that were presented to the other learner. The rationale of this technique is in that it allows a researcher to determine whether it is the nature of the adaptations, or the process of selecting the adaptations that is beneficial, if at all. This technique is further elaborated on in the subsequent chapter addressing the evaluation of the ELEKTRA game.

In order to technically achieve yoked control design the ALIGN system was extended to allow the adaptations recorded in a learner's log file to be played back to a second learner, in effect giving the second learner the adaptations intended for the first learner. The log file to be replayed is specified through the use of an *Option* fact sent from the ELEKTRA game. This option fact causes adaptations to be replayed at the appropriate times in the game when an adaptation would have been performed.

4.6 Summary

In this chapter the research methodology used within this research was introduced. The influences of the Action Research methodology throughout the structure of the research, and this thesis, was detailed.

This chapter then continued with the design of the ALIGN system where it was presented with details of the separation of game and personalisation logic it provides, as well as the four stage approach to non-invasive personalisation it embodies. The design of ALIGN was followed by the introduction of the ELEKTRA game, the first educational game to be integrated with ALIGN. The game design and educational merits of the ELEKTRA game were presented as well the personalisation that ALIGN provides within the game, and the adaptations made possible by the game. The final section of this chapter presented the technical implementation of the ALIGN system and technical rules required to effectively personalise the ELEKTRA game.

5 Action, Observation, and Reflection - Evaluation of the ELEKTRA Game

5.1 Introduction

The main objectives of this thesis as detailed in chapter 1 are to (i) research and identify strategies that can effectively combine educational games and adaptive instructional systems, (ii) develop a flexible game agnostic software system that can non-invasively personalise the educational experience within an educational video game, (iii) develop contrasting educational video games that can be integrated with the developed personalisation system in order to enable a real world evaluation of the software system, and to (iv) evaluate the ability of the developed system to provide non-invasive personalisation that is beneficial to the learning experience, facilitates the independent authoring of games and personalisation systems, and eases the reuse of these systems across contrasting educational games.

The ALIGN system was designed and implemented in order to address these objectives. The aim of this chapter is to give details of the initial experiment performed using the ALIGN system to evaluate its ability to achieve the above objectives. As a piece of technology the ALIGN system can technically be evaluated to ascertain if it provides the non-invasive personalisation it is designed for. However, in line with the action research methodology the ALIGN system must be trialled in a real world scenario where it can be evaluated whether it meets these objectives in a normal context of use. Through the use of the ELEKTRA game it becomes possible to perform these evaluations in a realistic usage scenario.

The goal of this chapter is to detail the experiments undertaken to evaluate the ALIGN system as well as an analysis of the results emerging from them. As the first trial of the ALIGN system this experiment focuses on the feasibility of separating personalisation logic from game engine it adapts. This separation must first be considered before further evaluating the effectiveness and benefits of the ALIGN system. As a further consideration of the feasibility of separation, this experiment will evaluate the ability of ALIGN to provide a variety of personalisation to an educational game. The ability to provide this variety is additionally an indicator of flexibility provided by ALIGN and how it may be applied to further games.

This chapter continues with the experimental objectives, the evaluation metrics employed, the experimental methodology, the user trials conducted, and the experimental results. In line with the Action Research methodology this chapter will conclude with a summary of the ELEKTRA evaluation and a reflection on the outcomes of the experiment. This reflection will consider the design of ALIGN and areas where it can be enhanced for the subsequent experiment introduced in chapter 6.

5.2 Experiment Objectives

The separation of the personalisation logic from the game engine provides the potential for the reuse of adaptation logic across multiple educational games. However, in doing this the process of adapting the educational experience is less integrated into the game and as such may have less context on which to perform the adaptation, and resultantly may be less effective. Accordingly the first objective of this experiment is to determine the feasibility of separating the personalisation provided by ALIGN, from the game engine.

The second objective of this experiment is determine how well ALIGN can deliver a variety of adaptations to the ELEKTRA game. This objective forms part the evaluation of the generality of the ALIGN system as the ability to provide a variety of personalisations is indicative of its ability to adapt a variety of games.

The third and final objective of this experiment is to determine how effective ALIGN is at personalising the learning experience and in providing this personalisation in a manner that is effective and beneficial to the learning experience. This final objective however plays a minor part in this experiment as extensively evaluating it without knowing the outcome of the first objective, the feasibility of separation, would be inappropriate as the separation could negatively impact the personalization and confound its evaluation.

5.3 Evaluation Metrics Employed

In determining the feasibility of separation in it first important to clarify what feasibility means in this context. As per the first objective the feasibility relates to how effective personalisation must be achieved despite the separation of the personalisation and the game. The cause of ineffective personalisation is predominantly due to the reduced context on which to base the personalisation, and to a lesser extent, the timeliness at which the adaptations can be achieved. Accordingly this evaluation must first examine if ALIGN can capture sufficient information about the game and learner to perform acceptable adaptations, and secondly to examine if these adaptations are provided in a timely manner so as not to negatively affect the gaming experience. Although by design the exact data being received by ALIGN and the adaptations being performed is known, the ultimate indicator of their acceptability lies in the opinions and perceptions of the learners experiencing the adaptations. For this reason qualitative metrics are appropriate in evaluating this objective. In consideration that within the ELEKTRA game the majority of the adaptations are realised through the Galileo NPC, the acceptability of the adaptations performed is evident through the learners' perception of the Galileo character. The acceptability of the adaptations relates to how well the adaptations are in line with the learner's expectations and understanding of how the Galileo character normally acts. Accordingly the metrics employed are learner satisfaction with, and the perceived invasiveness of, the Galileo NPC. In particular the metrics of flow experience, cognitive load, the usefulness of the hints provided, and the likeability of the Galileo NPC are considered.

Although the evaluation of timeliness of adaptations can be evaluated qualitatively as well, it is highly subjective with people's perception of time passing often being inconsistent. For this reason the quantitative analysis of the learners' log files objectively indicates the timeliness of adaptations provided. The metric employed will be the time taken from a learner's action that triggers an adaptation to that adaptation being received by the game engine.

The second objective of evaluating the variety of adaptations provided can similarly be determined through log file analysis. A comparison of the adaptations provided against the adaptations available will provide a metric of the diversity of adaptations delivered by the ALIGN system.

The metrics required to evaluate the third objective will be both quantitative and qualitative in nature. In determining the effectiveness of the personalisation the performance of individual learners following an adaptation is a key indicator as to the effectiveness of the personalisation.

Figure 83. The ELEKTRA slope device experiment

Within the ELEKTRA game the majority of interactions by the learners and the adaptations received occur when using the slope device, shown above in Figure 83. For this reason the accuracy of a learner's setup of the slope device subsequent to an adaptation is an appropriate metric of adaptation effectiveness. A further metric in determining the effectiveness of the personalisation is the affect the adaptations have on the cognitive load of the learners as they play the ELEKTRA game.

5.4 Experiment Methodology

The evaluation of adaptive systems can be particularly challenging when relying on qualitative metrics. The inherent freedom provided by virtual worlds coupled with the varying learner experiences due to the adaptations provided complicates the evaluation of any qualitative metric. The game based nature of this experiment further compounds these challenges due to the pre-existing preferences and perceptions the learners have of video games.

In light of the significant role that the adaptations play in the ELEKTRA game the comparison between a non-adaptive version and an adaptive version of the game is of little benefit for evaluation purposes as the learning experiences are so different they are not comparable (De Bra, 2000). Further to this, the comparison to a non-adaptive game gives little insight into whether it is the nature of the adaptation (i.e. how is it realised in the game engine) or the selection of the adaptation that is causing the effect. To address this challenge a Yoked-control design (Church, 1964) approach was adopted for this experiment. The premise of yoked control design lies in matching pairs of users that are of similar ability and so should perform similarly in learning tasks. One of each matched pair then plays through the adaptive game. The second member of the pair then plays through the game however, where appropriate they receive the adaptations that were intended for the first member of the pair. This experimental setup ensures that both learners experience the same content through adaptations (i.e. the nature of the content is the same) however for only the first member of the pair are the adaptations personalised. Through this approach the benefits of the personalisation can be determined. To achieve the yoked-control design the participants in the user trials were paired based on their classroom performance as was determined by their teacher. This approach aims to allow the evaluation of the effectiveness of how the adaptations were selected as opposed to how they are realised within the game.

Despite the benefits of yoked control design it can be problematic as an evaluation technique. Not only is there a requirement to effectively match two learners based on their ability, there is also the technical challenge of replaying appropriate adaptations at the correct time. In light of these challenges the comprehensive logging provided by ALIGN was relied upon to provide insight into the evaluation should yoked control design prove ineffective.

5.4.1 Design of the experiment

The experiment involved a group of secondary school students aged between 12 and 14 years playing through the ELEKTRA game under the supervision of their teachers. In order to gather the required metrics for this experiment a pre and post questionnaire were used. The pre-questionnaire gathered personal data including age, gender, current grades in maths and physics, experience with video games, preferences for video game styles, and a pre-test relating to physics. The post questionnaire included questions relating to flow experience, opinions of the game's NPCs, general opinions of the game, and a post-test. The complete pre and post questionnaires are available in Appendix C to this thesis.

The process involved in conducting the user trials consisted of the following steps:

1. All students completed the pre-questionnaire.
2. The students were then divided into pairs of similar ability with the first member of each pair playing through the adaptive game. The second members of each pair were taken to another room so they would not interfere with or see any of the game.
3. Once the first member of each pair completed the game the second member of the pair took over the computer and played through a yoked adaptive version of the game. The first members of each pair were similarly taken to another room to avoid distraction and bias.
4. All students completed the post-questionnaire.
5. The generated log files from all of the used computers were gathered.

During the trial the students were not made aware of the adaptive nature of the game or that their pairings were to enable yoked control design.

5.5 User Trials

As part of the overall ELEKTRA project several user trials were conducted throughout the project focussing on several different aspects of the game and the overall game design. In total 152 students (87 male, 65 female) were involved in the user trials. Despite the large number of overall students involved, the ELEKTRA user trials individually focused on several aspects of the project's research questions. As well as the evaluation of the non-invasive personalisation provided by ALIGN, the evaluations additionally covered a broad variety of aspects relating to learning. These aspects included game design preferences, adaptations for socio-motivational and cognitive variables, adaptations for learning performance, and the emotional reactions to the visual realism of NPCs. For this reason only a subset of the user trials performed were sufficiently focused to be of benefit in evaluating ALIGN.

Of the entire user trials completed, a group of 75 students (39 male, 36 female) were involved with evaluating the ELEKTRA game version as described in the preceding chapter.

The students involved were from the following two schools in Paris, France.

- Paul Klee public school, Thiais, Paris. (52 students)
- ORT France[30] private school, Villiers-le-Bel, Paris. (23 students)

Within this user trial 35 of the students played through the game without any adaptation and 40 students received adaptations. The group that received the adaptations were further broken into two groups in line with performing a yoked control experiment. The trials at the two schools were conducted in January 2008.

5.5.1 Logistical Challenges

The evaluation of ALIGN with the ELEKTRA game presented a number of logistical challenges. The most prominent challenge being the usage of French within the game, and the corresponding requirement for all user trials to be conducted with native French speaking students. The sophistication of the game engine also imposed considerable challenges due to the high-end PCs required to run the game. As early surveys of the computing resources available within schools showed them to be insufficient, laptops were purpose bought to perform the evaluations. The game accordingly was optimised to run on these laptops for the evaluations, and in doing so limiting its usage on other PCs.

The combination of the technical requirements of the ELEKTRA game and the limiting nature of the game's French language restricted the extent to which the game was evaluated in terms of ALIGN. However, the user trials that were conducted were deemed sufficient to achieve the objectives of the experiment and provide sufficient findings to influence subsequent experiments with ALIGN.

5.5.2 Log File Analysis

A key method of evaluating the ALIGN system is through analysis of the log files generated. Although the log files are in a convenient XML format this is of limited use when analysing the results of an entire user trial. For this reason a log file convertor utility was developed to convert log files into Excel spreadsheets where the date can be more readily analysed. The developed application shown in Figure 84 below makes use of XQuery and the JExcel[31] library to convert batches of log files into a single spreadsheet.

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[30] http://www.ort.asso.fr/accueil.html

[31] http://jexcelapi.sourceforge.net/

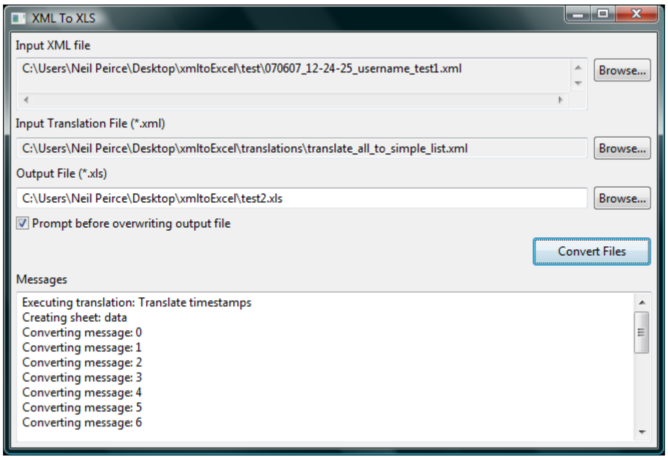

Figure 84. XML Log File Convertor Utility

5.6 Evaluation Results

The 75 students taking part in the user trial had an average age of 12.99 years (sd. 0.96) and 89.30% of the students indicated that they liked to play computer games at home. The mean years of gaming experience for the students was 6.83 years (sd. 2.34) with an average weekly time spent playing video games of 6.10 hours (sd. 7.65). A breakdown of frequency of game play for this group is shown below in Figure 85.

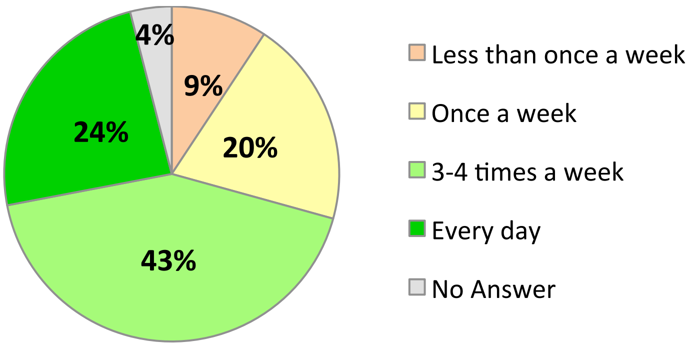

Figure 85. Frequency of video game play for ELEKTRA trial group

5.6.1 Feasibility of Separation

In evaluating the first objective of this experiment, the feasibility of separation, we first look at the qualitative metrics relating to the student satisfaction and experience with the Galileo NPC. To determine the impact of the adaptations on these metrics a comparison between the adaptive and non-adaptive versions of the game was conducted. The results of this experiment are presented below covering the metrics of flow experience (Table 18), cognitive load (Table 19), and the usefulness and likeability of the Galileo NPC (Table 20). In the following tables the results of the post questionnaires completed by the students are summarized. The mean and standard deviation (sd.) of their answers are presented. All of the answers were given on a seven point scale with 1 indicating 'not at all true' and 7 indicating 'very true'. The complete post questionnaire is available in Appendix C.

Table 18. ELEKTRA flow experience between adaptive and non-adaptive groups

Metric	Non-Adaptive	Adaptive
Flow Experience		
Flow	4.72 (sd. 0.93)	4.66 (sd.1.07)
Smoothness	4.68 (sd. 1.14)	4.45 (sd.1.31)
Absorbedness	4.80 (sd. 1.13)	4.99 (sd. 1.10)
Worry	3.59 (sd. 1.24)	3.76 (sd. 1.40)

Table 19. ELEKTRA cognitive load between adaptive and non-adaptive groups

Metric	Non-Adaptive	Adaptive
Cognitive Load		
Intrinsic Cognitive Load (ICL)	4.96 (sd. 2.65)	4.56 (sd. 2.07)
Germane Cognitive Load (GCL)	4.82 (sd. 2.68)	4.30 (sd. 2.36)
Extraneous Cognitive Load (ECL)	6.86 (sd. 2.24)	6.44 (sd. 2.00)
Expected success	5.09 (sd. 3.23)	4.40 (sd. 2.67)
Stress	3.66 (sd. 3.08)	3.01 (sd. 2.48)
Cognitive Load (Slope device)	5.21 (sd. 2.93)	5.57 (sd. 3.13)

Table 20. ELEKTRA Evaluation of Galileo between adaptive and non-adaptive groups

Metric	Non-Adaptive	Adaptive
Usefulness		
Communication with Galileo	5.73 (sd. 1.10)	5.30 (sd. 1.70)
Evaluation of game features		
Desire for more hints	4.40 (sd. 2.18)	5.15 (sd. 2.02)
Desire to skip hints	5.03 (sd. 2.16)	5.77 (sd. 1.92)
Desire for hints on demand	5.56 (sd. 1.74)	5.30 (sd. 1.96)
Likeability of Galileo	3.45 (sd. 1.56)	3.72 (sd. 1.55)

Although there were differences between the adaptive and non-adaptive groups in the qualitative metrics analysed above, these differences proved not to be statistically significant when using a t-test based on group membership[32]. This lack of a significant difference is evidence that the

[32] The details of the t-tests completed and their lack of significance formed part of the D5.3.1 deliverable "User Evaluation Report for Advanced Framework" submitted to the European Commission as part of the ELEKTRA project.

adaptations provided by ALIGN, despite it being separated from the ELEKTRA game, were none the less effective and did not detrimentally impact the gaming experience.

The second aspect of evaluating this objective lies in a quantitative analysis of the timeliness of the delivery of adaptations. In order to determine the timeliness of the adaptations provided each of the ALIGN log files for the adaptive group in the user trial were analysed. By identifying the piece of learner evidence that triggered an adaptation to be performed it was possible to calculate the delay until the adaptation was sent. Through analysing the log files of the adaptive group a total of 5,977 adaptations were identified across all of the users. The mean delay in delivering these adaptations was 27.68ms (sd. 26.36ms). The breakdown of adaptation delays is shown below in Figure 86 which indicates that 99.75% of adaptations were delivered in 200ms or less. In total only 12 adaptations took over 200ms to be delivered with the longest delay being 485ms.

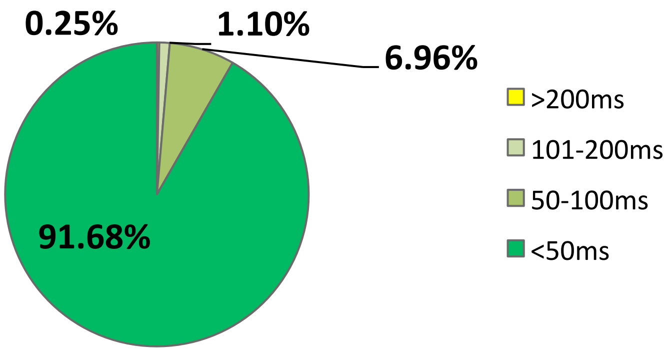

Figure 86. Timeliness of ALIGN adaptations being delivered

In addition to the time taken for ALIGN to deliver an adaptation the issue of network latency between ALIGN and the ELEKTRA game was also considered. Due to the configuration of this user trial both the game and ALIGN were running on the same physical PC. As a result the network latency was negligible and was measured to be consistently less than 1ms. The vast majority of adaptations were achieved in under 100ms and as such were deemed to be sufficiently responsive so as to not negatively impact the gaming experience. This result is in line with the findings on the effects of lag on performance in interactive systems (MacKenzie & Colin, 1993).

5.6.2 Variety of Personalisations

The second objective of this experiment was to determine the ability of ALIGN to deliver a variety of personalisations to the ELEKTRA game in order to demonstrate the flexibility of the ALIGN system. The diversity of adaptations provided can be quantitatively determined through examining the log files generated by the 40 students in the adaptive group. The analysis of the 5,977 adaptations delivered showed that of the 197 possible adaptive elements, 124 of them were used at least once giving a coverage of 62.94%. Further to this a breakdown of the types of adaptations delivered as well as the types of adaptations available is given below in Figure 87 and Figure 88 respectively.

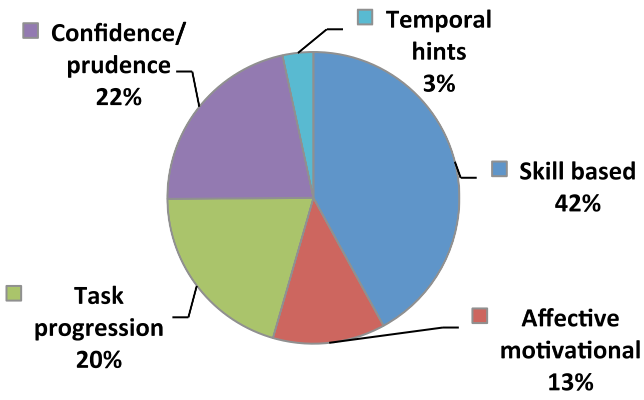

Figure 87. Variety of adaptations delivered to the ELEKTRA game

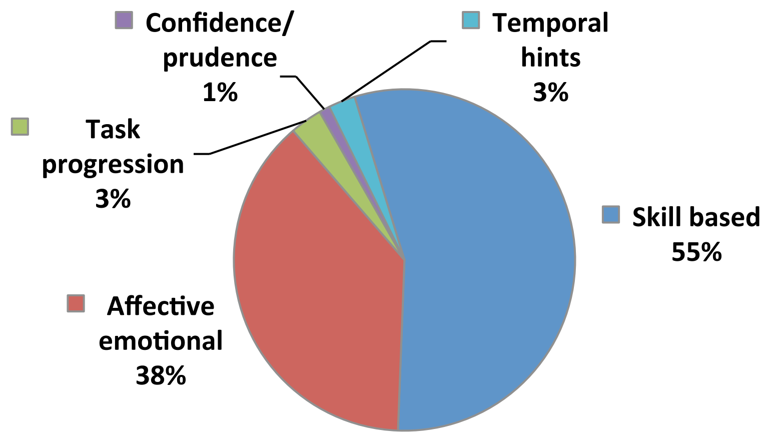

Figure 88. Variety of Adaptive Elements available to the ELEKTRA game

Although it is evident from Figure 87 that a large variety of adaptations were delivered the frequency distributions of individual adaptive elements is more indicative of the broad diversity of Adaptive Elements used. In the case of the skill based adaptive elements the individual frequencies are shown below in Figure 89. A comprehensive table of the frequencies the adaptive elements were used is available in Appendix D to this thesis.

The descending slopes evident in Figure 89 above are a result of the round robin approach to adaptive element selection. As adaptive elements that provide the same outcome are placed adjacent to each other in this graph they manifest as clusters of similarly frequently used AEs. This phenomenon is also an indicator that the ALIGN system successfully provided a variety of AEs in line with preserving NPC consistency by not repeating dialogues nonsensically.

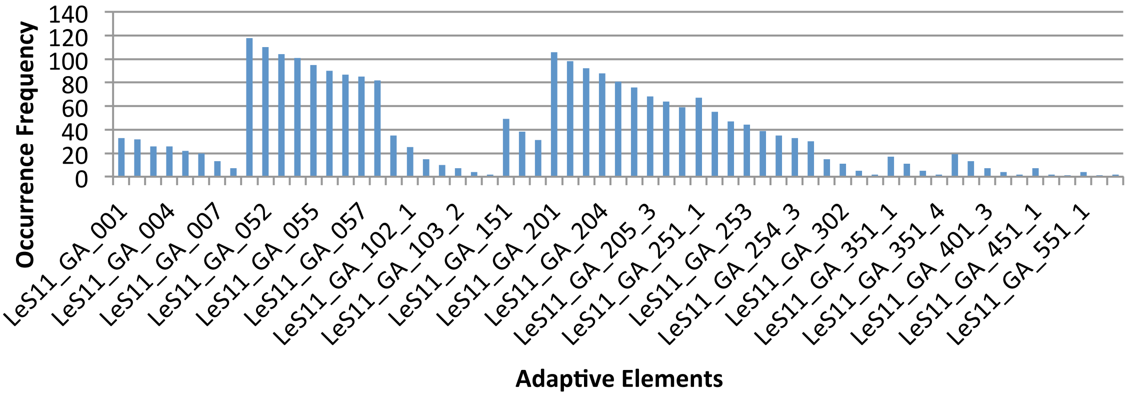

Figure 89. Frequency of skill based hints delivered

Whereas the patterns evident in the skill based hints are expected due to the order in which the slope device task are given, the varied delivery of affective and motivational hints are far more influenced by an individual learner's characteristics as is evident in Figure 90.

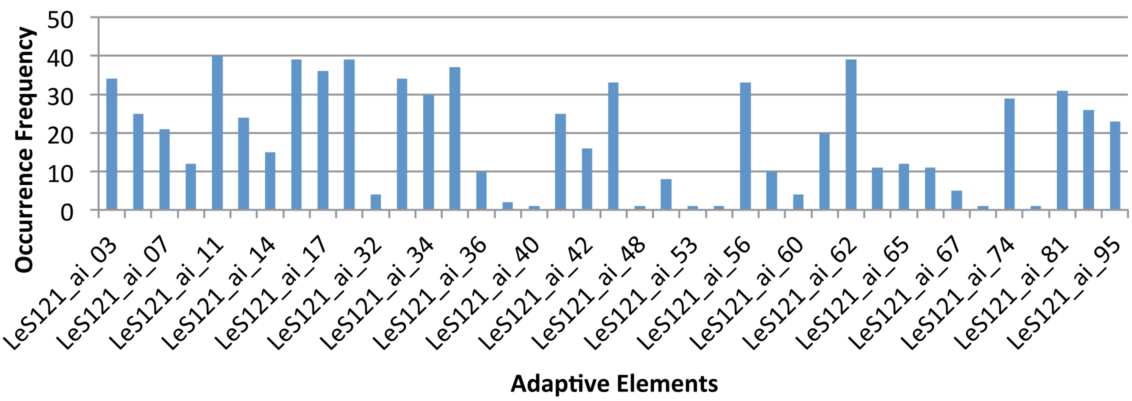

Figure 90. Frequency of affective motivational hints delivered

The occurrence of clusters of similarly frequent AEs is not as evident within the affective motivational AEs (Figure 90 above) for two reasons. Firstly these AEs are used less frequently than the skill based AEs and so there is less need to use the round robin selection, and secondly there is less variety of AEs providing the same outcome and so fewer clusters will form.

The most frequently used AEs within ELEKTRA are the AEs used to update the confidence and prudence sliders within the game's user interface. These two AEs alone occurred 1,298 times and accounted for 21.7% of AEs used as shown in Figure 91 . The significantly higher rate of prudence occurrences is attributed to changes in prudence occurring far more often when a learner incorrectly configures the slope device. The trial and error nature of the slope device task means that incorrect configurations occur more commonly than correct ones.

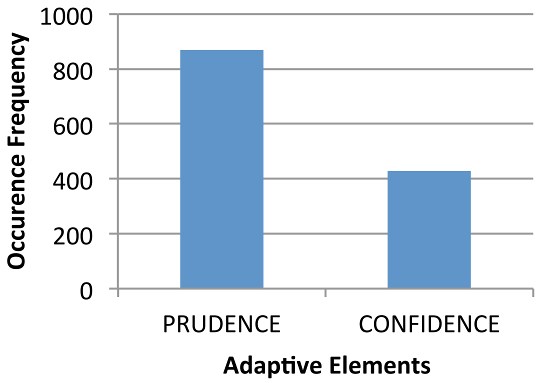

Figure 91. Confidence and Prudence Adaptive Element Occurrences

The frequency and variety of adaptations provided by ALIGN are evident in the results presented above. The usage patterns of the various AEs are representative of the personalisation strategies, the adaptation constraints, and the nature of ELEKTRA game.

5.6.3 Effectiveness of the Personalisation

The third objective of this experiment was to determine how effective ALIGN was at providing a personalised learning experience. As a metric to determine this objective the performance of the learners within the game was considered appropriate. More specifically the performance of the learners whilst using the slope device was considered as this was the learning task in which most of the adaptations were performed. The nature of the slope device experiment involves the learner configuring the slope device (see Figure 83 on page 139) with varying strengths of fan and magnetic power in order to get a ball into the target. The varying compositions of the ball including wood, plastic, and steel illustrate the varying density and magnetic properties of the materials. When the learner has completed their setup the ball is released and the realistic physical simulation results in the ball either hitting or missing the target on the right hand side. Following an attempt, adaptations in the form of dialogue from the Galileo NPC are delivered if appropriate. These adaptations are relevant to the learner's success or failure at the task and include hints as to how to improve the setup of the experiment. As these hints are personalised to the learner it is envisaged that they will positively affect the learner's subsequent attempt at the experiment. For this reason the metric of 'approach to correct solution' is an indicator of the effectiveness of the adaptations provided. As both the fan and magnetic intensity operate on a scale of 0 – 100 each approach will be within the range of 0 – 100.

The yoked control design of the user trial aimed to identify the benefits of the personalisation of the hints given as opposed to the actual content of the hints themselves. This approach would have been a reasonable approach, however following analysis of the log files after the trial it was evident that the yoked control design would not be a valid method of evaluation. The log file analysis as well as observations made during the trials revealed a number of inappropriate or incorrect adaptations were being delivered to both the adaptive and yoked groups. The incorrect adaptations were a result of mistakes made in both the authoring of the adaptive elements and within the game engine with the hints associated with an adaptive element id. Due to this confounding factor an analysis based on the yoked control design was deemed inappropriate.

Despite the absence of the yoked control comparison it was decided to manually analyse each of the log files and to identify which learners received appropriate and intended adaptations, and which received erroneous adaptations. The result of this analysis yielded four categories of hints that were delivered to the learners as given below. The analysis of the adaptations was conducted by two researchers working independently at the University of Graz who had knowledge of the nature of the adaptations and when they were delivered. The reliability between the two analyses was 81%.

- **Adaptive hints** (i.e., Galileo's statements that are beneficial for the learning or gaming progress, for example, "remember what I told you about the propagation of light" when trying to open a door by hitting a light sensor with a narrow beam of light).
- **Neutral hints** (i.e., statements that are always suitable and that do not have much positive or negative effects, for example, "well done, keep going")
- **Counter-adaptive hints** (i.e., statements that have a negative or confusing impact on learning or gaming, for example, "remember what I told you about the propagation of light" when the student is not dealing with a light based task).
- **No hint** (i.e. in a situation where an hint would normally be delivered no intervention was given as would occur with yoked adaptation)

In order to determine the impact of each of these hint categories the performance of the learners following each hint type was considered. The performance was determined based on the approach made using the slope device sliders to the correct slope device configuration following the hint. The approach value is the difference in slider positions between the learner's previous attempt and their current one. Positive approach values indicate an attempt closer to the correct answer, with a larger value indicating a greater adjustment towards the solution. The result of analysing mean approaches is presented below in Figure 92. Although the results indicate that the adaptive hints aided the learners in reaching the correct solution faster, due to the size of the study these results proved not to be statistically significant.

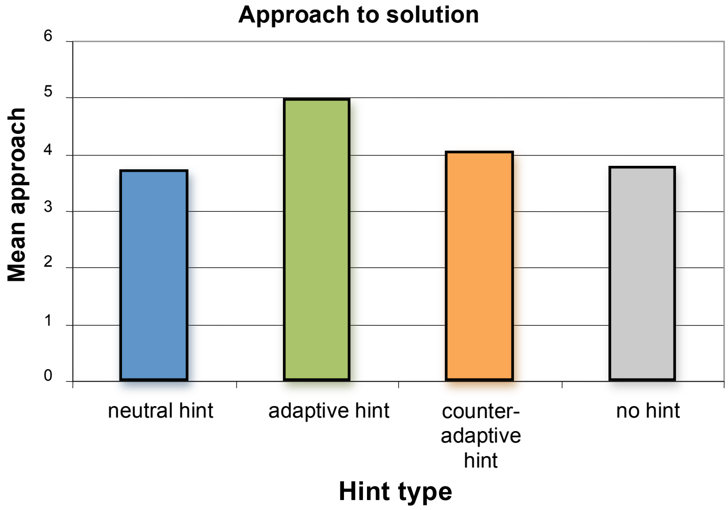

Figure 92. Mean approach to the correct solution based on hint type

In order to further ascertain the benefits of the adaptive hints a combined median split analysis was performed on the group who received the hints, i.e. the adaptive and yoked control students. This analysis effectively split the group into two extreme groups based on the percentage of adaptive hints received. The median percentage of adaptive hints received was 54%, and 27% for counter-adaptive hints. The two groups created were the "High Adaptivity" group, which was defined as those students who received more than 54% adaptive hints and 27% or less counter-adaptive hints. Conversely, the "Low Adaptivity" group was defined as receiving 54% or less adaptive hints and more than 27% counter-adaptive hints. The impact of the personalisation was then considered for these two extreme groups.

In examining the impact of the personalisation on a learner's performance it is important to consider their perception of how challenging the learning experience was. A key metric in determining this challenge is the subjective cognitive load experienced by the learner. In the case of the slope device task the cognitive load was assessed between the High Adaptivity and the Low Adaptivity groups. The results of this analysis are shown below in Figure 93 and indicate that there was significantly lower cognitive load associated with the High Adaptivity group ($t(25) = 2.07$; $p = .05$). Interestingly for these two groups there was no significant difference in how useful they found the slope device as is shown in Figure 94. This result shows that where the adaptation is realised correctly the slope device is equally useful yet less demanding to use. The results shown in Figure 93 and Figure 94 are based on data from only 27 students as due to an error during the setup of the trial, 13 of the students were not presented with the cognitive load and usefulness questions.

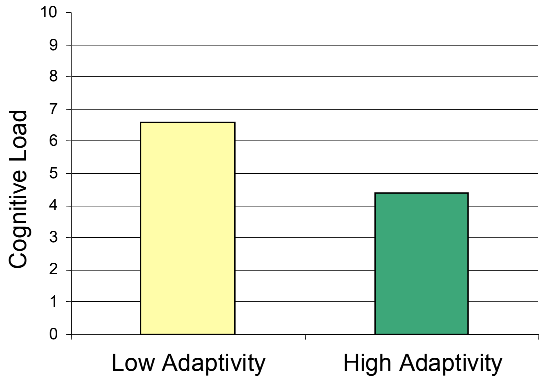

Figure 93. Cognitive load associated with of the slope device between adaptivity groups

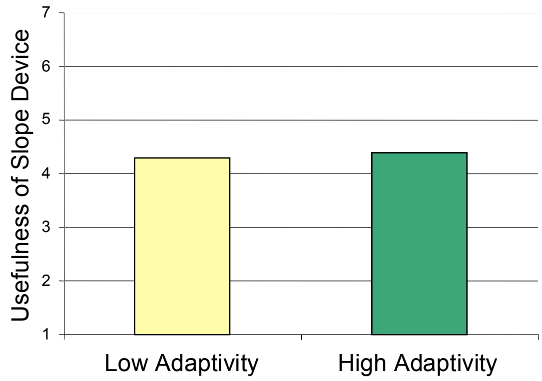

Figure 94. Usefulness of the slope device between adaptivity groups

In addition to the results already highlighted above the overall evaluation of the ELEKTRA game yielded a number of interesting results in regards to varying preferences based on gender. The game types preferred by the students contained notable variations depending on the student's gender as is evident in Figure 95 below. These results evidently present challenges in the design of educational video games as there are considerable gender preferences across game types. However, the game types of 'adventure', 'simulation', and 'roleplay' are of similar appeal across genders.

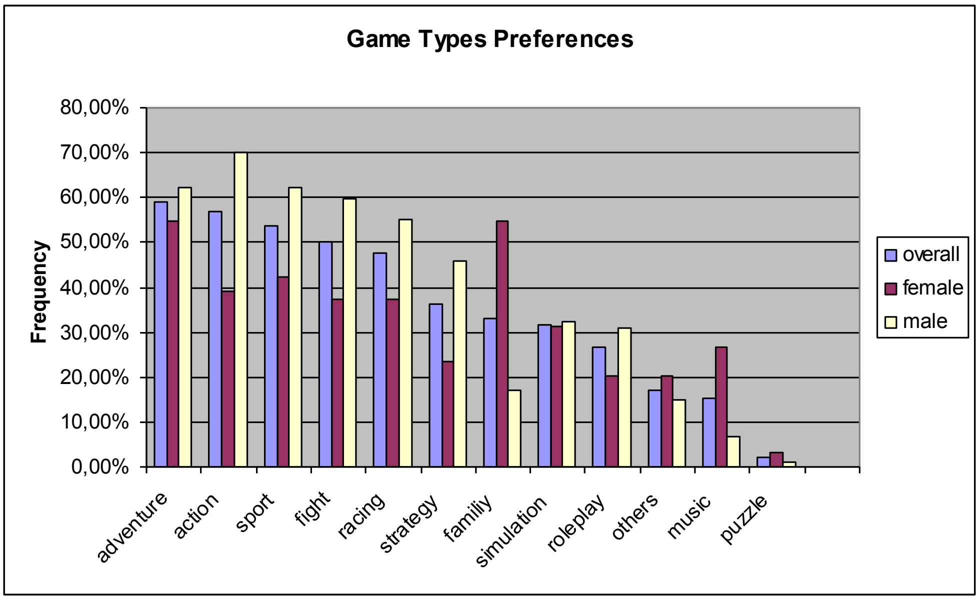

Figure 95. Gender differences of preferences for video game type.

A further notable difference between the male and female students was their preference for the game character they play as. Within the ELEKTRA game the players cannot choose the gender of the character they play as, a common feature in games that rely on a storyline. However, in an ELEKTRA user trial separate to the above experiment, involving 55 students (26 male and 29 female) it was found that there was a statistically significant preference for female players to play as a female avatar ($t(53) = 3,92$; $p < ,001$), see Figure 96 below. Importantly over 90% of the trial group reported playing video games regularly indicating that this preference is commonplace among regular female video game players.

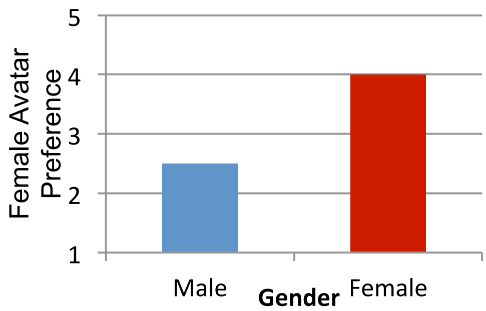

Figure 96. Preference for playing as a female avatar based on gender. (Scale: 1=strongly disagree, 5=strongly agree)

A final result that was informally gathered during the trials was that there was a desire amongst the students to be able to influence how much feedback they received from Galileo. This desire would be akin to a person in a conversation either interjecting to shorten the conversation of expressing further interest to lengthen the conversation.

5.7 Summary and Reflection

In this chapter the initial evaluation of the ALIGN system through the ELEKTRA experiment was discussed. Through the use of real world user trials the three experimental objectives of assessing the feasibility of separation, the variety of personalisations achieved, and the effectiveness of the personalisation were addressed.

The first objective was to consider how feasible it is to personalise an educational game that is separated from the personalisation logic. It was found that despite the separation used within the ALIGN system, the personalisation could be effectively achieved. Through identifying that there was no significant disruption of learners' flow experiences it was evident that the personalisations were realised in an acceptable manner. Further to this the consistency of cognitive load between non-adaptive and adaptive versions of the game indicates that the personalisation added no significant mental effort on the learner's part. As a final determinant of the feasibility of separation it was found that the efficient implementation and use of the Drools rule engine gave consistently fast response times. In consideration of the qualitative and quantitative results obtained it is clear that the separation of ALIGN from the game it is adapting is feasible both in regards to the ability to provide effective adaptations, and to provide these adaptations in a timely manner.

In considering the second objective of determining ALIGN's ability to deliver a variety of personalisation, the ELEKTRA experiment confirmed this variety is achievable by the system. The

Adaptive Element usage patterns that were highlighted are indicative that the ALIGN system does not just attempt to blindly use all of the possible adaptations but intelligently selects only the most appropriate adaptations to make for the given learners. In addition to this appropriate selection there was a considerable variety of adaptations provided indicating that not only can ALIGN deliver a variety of types of personalisation it also uses a diversity of adaptations within each personalisation type.

The strength of the system to leverage the available adaptations is a clear demonstration of its flexibility. Despite the coverage of the AEs obtained the number of AEs that were not used was 73. Evidently these AEs address particular edge cases of adaptations that had been anticipated at design time but were never encountered within the user trial. Although a larger trial may have achieved even greater coverage, the challenge of developing only the necessary and appropriate AEs is apparent.

The final experimental objective addressed within this chapter was that of the effectiveness of the personalisation achieved. Despite the problematic use of yoked control design it was found that personalisation achieved by ALIGN was both effective and beneficial to the learners. It was shown that learners made more accurate approaches to the correct solution in learning tasks following personalised hints. Although this is a positive result it proved not to be statistically significant. It is possible that this lack of significance is a result of the small sample size and the confounding impact of counter-adaptive hints.

Despite the challenges presented by the logistics of the user trial, it was observed that those students who received a greater number of personalised hints reported a lower cognitive load and effort when using the slope device. This is a positive outcome as it indicates that where personalised hints can be delivered they reduce the effort the students must apply. Interestingly as there was no significant difference in how useful the learners found the slope device it would suggest that the hints did not over simplify the experiment, but just made it easier to understand.

5.7.1 Reflection on the experiment

As a first experiment with ALIGN the user trials conducted with the ELEKTRA game form an initial step towards evaluating ALIGN. The nature of the ELEKTRA project and its associated evaluations evidently imposed limitations on this evaluation. In particular the logistics of running and rerunning user trials were by and far the greatest limitation of the experiment. The large number of stakeholders within the project further impacted the evaluation of ALIGN as each user trial typically had multiple objectives defined by multiple project partners. Despite these limitations the ELEKTRA project proved to be a successful initial experiment with the ALIGN system and the experimental objectives were achieved.

The ELEKTRA experiment presented a number of interesting findings in regards to the design of ALIGN and its components such as Adaptive Elements. The finding that only 63% of Adaptive Elements were used presents questions over how best to create AEs that will be used, and also how best to utilise the AEs that are exposed by the game. A further finding relating to the design of educational games is in the varying genre and avatar preferences between learner genders.

Despite the success of this experiment there is a need to further evaluate the ALIGN system in terms of the effectiveness of personalisation, the non-invasive nature of the personalisation, and in how it can be generalised to other games. In particular the use of an alternate game in a different genre and dealing with different learning content will highlight the elements of ALIGN's design that are truly generalised, and which are specific to the ELEKTRA game.

Although the design of the ELEKTRA game was largely undertaken with limited input from the author, it must be considered that the design of the game was none the less biased towards working effectively with the ALIGN system. For this reason the ELEKTRA game may not represent a typical educational game that is to be adapted and as such the experimental results should be considered within this context. Despite the limited input from the author in ELEKTRA's game design, the game does none the less adhere to many of the game design requirements derived in section 4.3.1.1. The notable requirement not explicitly addressed being that of catering for learning in informal contexts. The technical features of the ELEKTRA game effectively limit its use in informal contexts as it requires high end hardware that is not readily available.

In line with the action research methodology the outcomes of this experiment have been analysed and experimental refinements identified. The following are the direct refinements that have influenced the further evaluation of ALIGN.

- The number of Adaptive Elements developed should be reduced in order to ensure maximal coverage and to limit unnecessary development.
- The simplified logistics of evaluating a game should be a guiding principle of the games' technical implementation.
- Learners should have the ability to influence the amount of feedback they receive in order to support both self-directed learning and avoid learner frustration.
- Learners should be able to select the gender of the avatar they play as in respect of gender based preferences.
- The design of ALIGN should be considered in the context of an alternate game so as to ensure its features are relevant across diverse games.

6 Analysis and Planning - Design of ALIGN and the Language Trap Game

6.1 Introduction

In this chapter the Language Trap game is introduced as the second educational game integrated with the ALIGN system. The design of the game is detailed as well as its technical implementation and the personalisation strategy applied within the game. This chapter represents the beginning of the second action research cycle undertaken within this thesis. Accordingly the design of the Language Trap game and the implementation changes required in ALIGN represent the analysis and planning phases of this cycle.

In line with the third objective of this thesis, to integrate ALIGN with contrasting educational games, the design of the Language Trap game aims to be disparate from the ELEKTRA game with respect to game style, learning content, and personalisation. Further to this the game's design is influenced from the reflections made following the ELEKTRA experiment. These reflections influence the design to be logistically simple to evaluate, present a reduced number of Adaptive Elements, and allow the learner to select their avatar's gender as well as to influence the amount of feedback they receive.

Following the Language Trap game this chapter continues with the implementation changes to ALIGN that are necessary in light of this new game. These implementation changes aim to progress ALIGN towards being a more generic solution and not tied solely to one game.

6.2 The Language Trap Game

The Language Trap game is a single player online isometric style adventure game developed in Adobe Flash and playable in any web browser that supports the Flash player 9+ plugin. The learning aim of the game is to aid 16-18 year old students of German with their aural comprehension and vocabulary. In particular the game is based around the role-plays as prescribed for the German oral examination in the Irish Leaving Certificate.

The Language Trap game was developed as a second demonstrator game for the ALIGN system. It was developed entirely by the author including the game design, graphics, audio, game engine, and game logic. The rationale behind developing a game entirely from scratch rather than using an existing game was a result of the following factors:

- The limited number of suitable open-source educational games.
- The development effort required in retrospectively adding learning content to an existing non-educational open-source game.
- The development effort required in retrospectively enabling adaptation in an existing open-source game.
- The challenges associated with running user trials with games that require local installation and high-end computers.

6.2.1 Game Design

In developing the Language Trap game the following design requirements were considered in order to realise an effective educational game and also to demonstrate the generality and reusability of the ALIGN system. These requirements are codified in the form LT*n* and a summary of these requirements and all previous requirements are available in Appendix E.

LT1. The game should adopt a different game style to that of the ELEKTRA game to show the generality of ALIGN across game styles e.g. 3D, isometric style, 2D platformer, etc.

LT2. The learning content addressed should be significantly different to the ELEKTRA game to determine generality across learning content.

LT3. The game should apply best practices in educational game design

LT4. In line with the action research methodology the game should meet the needs of the end users and address a real world problem.

In addressing these requirements the Language Trap game is a casual style game that is playable online in a browser with an isometric visual style as shown in Figure 97 at the end of this section, addressing requirement LT1. The use of a casual game style attempts to consider how the simple controls, graphics, and short play periods of this style of game can still be personalised as effectively as a 3D game such as ELEKTRA.

The diversity of learning content as stipulated in requirement LT2 is addressed through having the game focus on language learning, in this case German, which is a contrast to the skill and knowledge based content of the ELEKTRA game. The choice of language learning presents a challenge of personalising a soft skill based learning experience. A challenge that the flexibility of ALIGN should be able to cater for. The contrasting features between the ELEKTRA and Language Trap games are summarised in Table 21 below.

Table 21. Contrasting ELEKTRA and Language Trap features

	ELEKTRA	Language Trap
Gaming Style	Hardcore/Casual Game	Casual Game
Visual Style	3D	Isometric (2.5D)
Learning Content	Physics of optics	German language learning
Personalisation	Predominantly cognitive, meta-cognitive, and affective feedback.	Predominantly challenge personalisation and performance feedback.
Target Audience	13-15 year olds	16-18 year olds

The third requirement LT3 is addressed firstly through choosing a role-playing adventure game genre that is both appropriate for the learning content and the target audience. This is secondly addressed through integrating the game's storyline and game mechanic with the learning content. In doing this the game genre promotes a conversation driven gaming experience. Through integrating the learning content in a manner relevant to the game's storyline the learning content becomes an integral component of progressing the game's storyline.

The final requirement LT4 is addressed both through the choice of learning content that is logistically difficult to address within school environments, and through the user driven design process of participatory design. The choice of German language learning focussing on the oral examination content addresses a real world challenge to students and teachers. The minority status of German as a foreign language studied in the Leaving Certificate as well the limited 1-to-1 conversations possible between teachers and students means that this area of the curriculum is often challenging to address. Through providing a game that is both curriculum conformant and provides a personalised learning experience, students can supplement their classroom tuition. All of the German dialogues used within the game and evaluation questionnaires were created by a secondary school teacher in Mount Temple Comprehensive School[33] who was experienced with conducting and assessing German oral examinations.

As part of the participatory design process a brainstorming session was conducted with seven 16-18 year old students of German in April 2009 at Mount Temple Comprehensive School. These students were selected as they would be participating in the evaluation of the game as is detailed in the following chapter. Through the brainstorming session with the students several design

[33] Mount Temple Comprehensive, Malahide Road, Clontarf, Dublin 3, Ireland.

requirements were elicited that had already been considered such as easy controls and online play. However, the following further game design requirements were elicited:

- LT5. It should be possible to hear the game characters speaking the dialogues to aid aural comprehension.
- LT6. The use of multiple choices to select dialogues is preferable to typing them.
- LT7. The game's storyline should be mature in nature and not childlike.
- LT8. The learner should be able to choose who they play as.

In addressing requirement LT5 the Language Trap game uses audible speech between the game characters to aid the learners' aural comprehension through familiarising them with German pronunciations. In consideration of the prohibitive cost associated with speech acting the game uses speech synthesis to verbalise the conversations. To achieve this the MARY TTS system (Schröder & Trouvain, 2003) was used in conjunction with several MBROLA (Dutoit, Pagel, Pierret, Bataille, & van Der Vrecken, 1996) voices to generate spoken dialogues for the 175 dialogues used in the Language Trap game. As a consequence of requiring speech within the game as well as the desirability for multiple choice dialogues as indicated in requirement LT6, the game employs a multiple choice dialogue system as can be seen in Figure 97.

Figure 97. The Language Trap Game

The main game interface as shown above contains multiple choice dialogues on the left with the conversation history shown on the right. The learner's character is shown in the centre of the screen in conversation with a NPC. The NPC in this case is expressing a puzzled emotion due to an inappropriate statement the learner has just chosen. The stars associated with each dialogue are an indication of the difficulty of the statement based on its grammar and vocabulary. For each appropriate statement chosen by the learner they receive the corresponding stars, however inappropriate statements cause the learner to lose stars. The difficulty and appropriateness of the dialogues can be set using the dialogue editor as is shown in Figure 102 in section 6.2.2.

As a further learning aid within the game all underlined words can be translated in exchange for one star. The low cost associated with a translation aims to encourage learners to translate problematic words but not to translate every word due to the cost involved. All purchased translations are stored in the learner's inventory for future reference.

6.2.1.1 Game Storyline

The game storyline for Language Trap was designed to both integrate the learning content within the game addressing requirement LT3 and also to be thematically interesting to the target age group addressing requirement LT7. Further to this the storyline integrates content from the curriculum and so addresses requirement LT4.

The storyline is based around the player taking the role of a newly qualified secret agent on their first mission. In line with the role of a secret agent the learner must play through the tasks assigned by their mysterious commander (see Figure 98) to uncover the game's story. As their first task the learner must uncover a German speaking double agent who is staying in a hotel with other German guests. In order to preserve their guise as a hotel employee the player must be subtle and appropriate in their conversations.

Figure 98. The Mysterious Commander (shown on right)

Figure 99. Agent White Jacket (shown on right)

Once the double agent has been discovered the mysterious commander challenges the player to gain the trust of the double agent by convincing him of their German skills in a restaurant setting.

Throughout the game you are accompanied by your companion "Agent White Jacket" (see Figure 99) who acts both as a character relevant to the storyline in the form of a mentor, but also as a pedagogical agent.

The two scenes encountered in the storyline, namely the hotel scene with guests, and the restaurant are both prescribed role-plays for the Leaving certificate examination. In this manner the learning content is both relevant to the curriculum and to game's storyline effectively integrating them. The design of the storyline presents the learner with goals, mystery, curiosity, as well as presenting a reasonable necessity to engage in German dialogues.

In addressing the final requirement LT8 the learner can choose to play as either a male or female character within the game. This simple choice aids in presenting a user-centric gaming and learning experience where the learner has a greater invested interest in the game character as they are actively choosing both their appearance and progress through the game.

The name of the Language Trap game was so chosen to both reflect the serious theme of the game's storyline as well as a play on the concept of the language trap as portrayed in (Millar & Nystrand, 1979). In this work the language trap is described as the focus on language as an object, whereas it is argued that effective communication must consider the usage of the language and in particular the intended audience being communicated to, as such it was decided that language trap would be an apt name for a personalised language learning game.

6.2.2 Game Technical Features

Based on the experiences with the ELEKTRA game, the Language Trap game was developed as a browser based casual game comprising of a thin Adobe Flash client component and a Java servlet based server component running on the Jetty[34] web server as is illustrated in Figure 100 below.

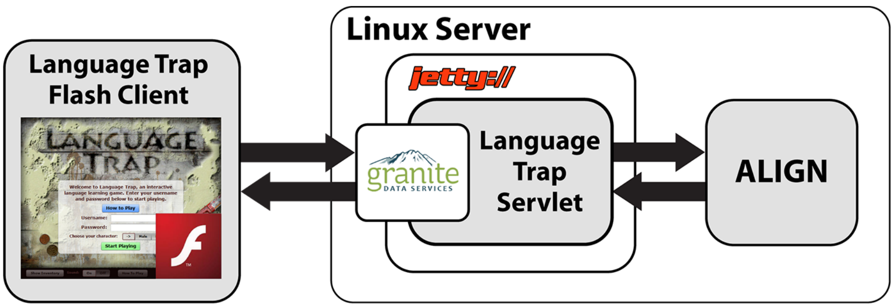

Figure 100. The Language Trap client- server architecture and ALIGN

[34] http://www.eclipse.org/jetty/

The client server communication is achieved using Granite Data Services[35] to provide efficient low latency and asynchronous communication between the Flash runtime and the Language Trap servlet. In this scenario the ALIGN system communicates with the server component over multiple TCP/IP sockets. The ALIGN system runs on the same server as the Java servlet in order to reduce network latency, however it can viably be hosted remotely.

The Language Trap game was developed in Adobe Flash Builder[36] for the client component and the Eclipse IDE[37] for the server side component. The graphics used in the game were either modelled and rendered in 3DStudio Max[38] or Blender[39] and touched up in Adobe Photoshop. Some additional graphics were used from the open source game FreedroidRPG[40]. The animations for the game characters were modelled and rendered in Blender and composited in Adobe After Effects to allow them to be loaded by Flash player.

The Flash game client is designed to be lightweight and quickly loaded. For this reason the functionality of the client is limited to rendering the game graphics, playing back audio, moving the game characters and capturing input from the learner. The entire client download is approximately 3.4MB consisting of 600kB Flash code, 1.1MB map graphics, and 1.7MB of character animations. As all of this data can be cached by the browser subsequent game loads are very quick. The audio used in the game is all streamed from the server on demand. This includes the background music and the speech files. The speech files load quickly as they are at most 15kB in size due to MP3 compression.

To facilitate development of the game both a map editor (Figure 101) and a dialogue editor (Figure 102) were developed to simplify the authoring of the game.

[35] http://www.graniteds.org/
[36] http://www.adobe.com/products/flash-builder.html
[37] http://www.eclipse.org/
[38] http://usa.autodesk.com/3ds-max/
[39] http://www.blender.org/
[40] http://www.freedroid.org/

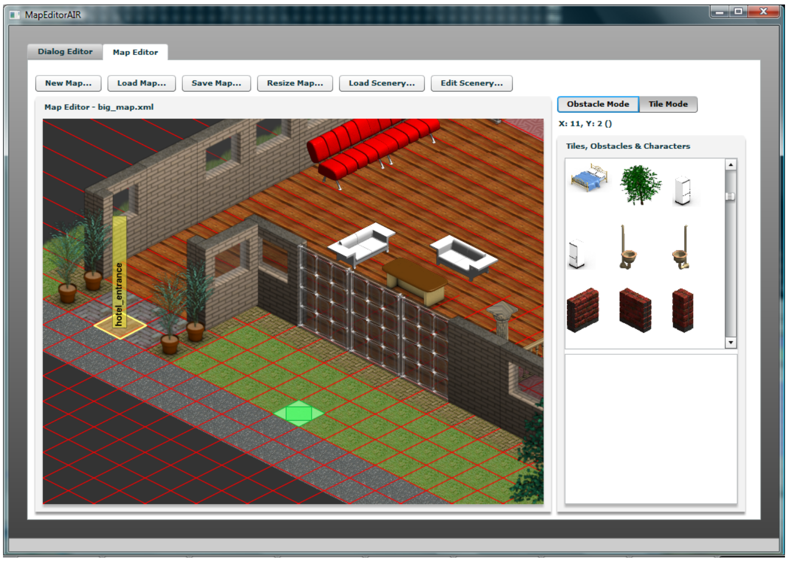

Figure 101. Language Trap Map Editor

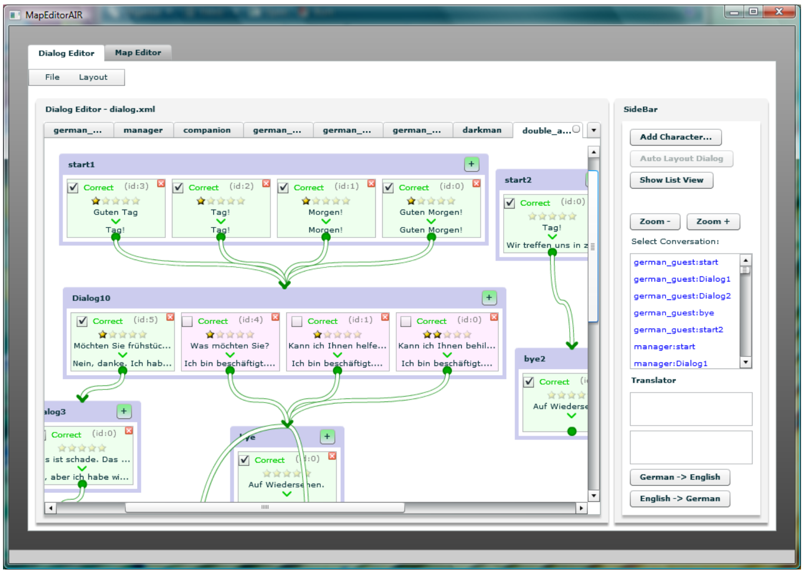

Figure 102. Language Trap Dialogue Editor

The server component of Language Trap is responsible for all of the game logic, the serving of audio assets, and the communication with ALIGN. In a manner similar to the ALIGN architecture the server component employs non-blocking IO techniques to allow it to scale to multiple simultaneous users. In initial benchmarks the server component could handle 5000 messages/second with response times of <100ms and a CPU load of 15-20%. In this benchmark a message reflects a single action within the game such as the movement of the learner or their selection of a statement. In consideration that a typical game client sends on average 1 message per second the performance of the server component was considered sufficient for any user trials that would be required.

6.2.3 Personalisation within Language Trap

The personalisation strategy adopted within Language Trap covers many aspects of the learning experience. The following six points reflect the high-level strategy employed within the game that are realised by ALIGN personalisation rules.

1) Present a suitable challenge to the learners through adapting the difficulty of conversation dialogues
2) Foster awareness of a learner's performance through providing emotional feedback from the NPCs based on the appropriateness of the learner's dialogue
3) Provide performance feedback based on the appropriateness of the learner's dialogue
4) Provide meta-cognitive feedback about the prudence of the decisions the learner has made
5) Encourage the learners through providing motivational support
6) Enable the learners to influence the frequency of feedback based on their preferences

The selection of the above personalisation strategies was influenced by the state of the art in adaptive educational games, the nature of the Language Trap game, and the desire to diversify the personalisation from what was achieved in the ELEKTRA game. In particular the increased use of personalised challenge was desirable due to it being an antecedent of a *flow* experience (Csikszentmihalyi, 1990), the use of emotional feedback to foster a sense of sociality with the NPCs, and the ability to influence feedback amounts as result of reflecting on the ELEKTRA experiment.

The implementation of the personalisation rules and the game evidence on which these rules are based is further discussed in *6.3.3 Personalisation Rules.*

6.2.4 Game Evidence

The Language Trap game provides predominantly implicit learner evidence to ALIGN. Due to the dialogue driven nature of the game, the dialogues that the learners choose is the predominant source of evidence. Throughout the game the learner is presented with multiple choices of statements they can say to the NPCs as shown below in Figure 103.

Figure 103. Multiple choice dialogue statements in Language Trap

When one of the statements is chosen, ALIGN is sent details of the chosen statement including its text, its star rating, and whether it is considered appropriate or not. The same details for the unchosen statements are also sent to ALIGN.

The most important characteristic of these dialogues is whether or not they are appropriate or inappropriate as this is an indication of the ability of the learner. Further to this when the difficulty of the chosen dialogues as well as the other available dialogue choices are considered, it becomes possible to infer the prudence with which the learner chooses their dialogues.

In consideration that the dialogues chosen by the learners may not accurately reflect their ability due the effects of guessing, erroneous clicks, and attempts to game the system, it is not appropriate to draw a direct link between dialogue choice and performance. However, over time the true ability of the learner will become evident. In order to accommodate for this a linear model is used to determine the difficulty of the statements to present to the learner.

Explicit Learner Evidence

The only form of explicit learner evidence that is received from ALIGN is the desire of the learner to receive more or less performance feedback from the Agent White Jacket NPC. The dialogue that corresponds to this explicit evidence is shown below in Figure 104.

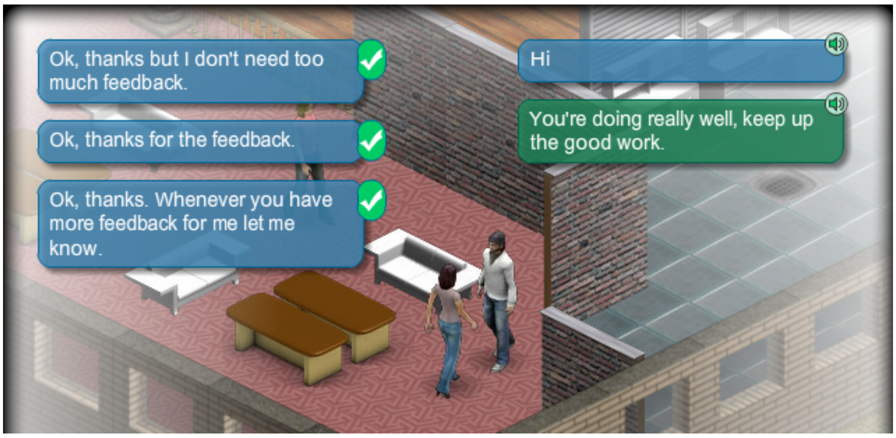

Figure 104. Feedback frequency dialogue with Agent White Jacket

6.2.5 Adaptive Elements

The Language Trap game provides 37 adaptive elements covering a total of 27 outcomes. Although from the ALIGN system's perspective these Adaptive Elements are similar to the ELEKTRA ones, they are realised in a very different manner due to nature of the Language Trap game. The following figures show how AEs for game difficulty (Figure 105), performance feedback (Figure 106), meta-cognitive feedback (Figure 107), emotional feedback (Figure 108) and motivational feedback (Figure 109) are realised.

Figure 105. Language Trap dialogue difficulty for a weak (left) and a strong (right) learner

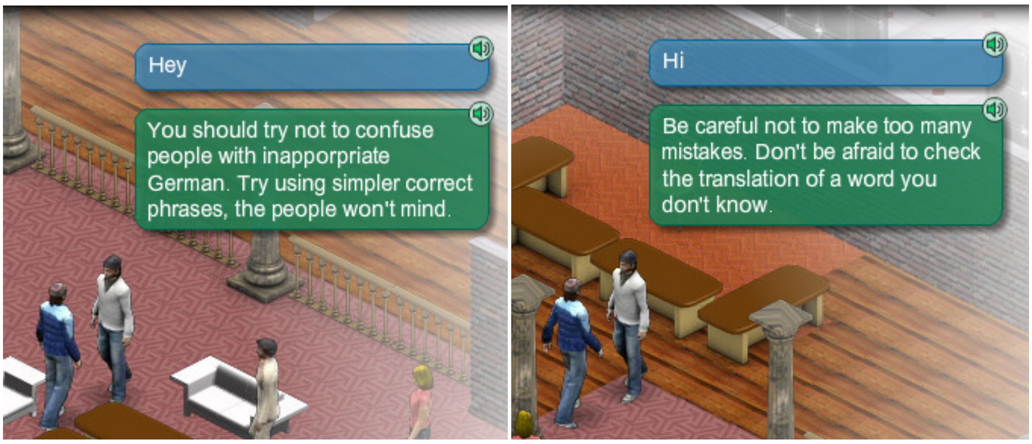

Figure 106. Personalised Performance Feedback from "Agent White Jacket"

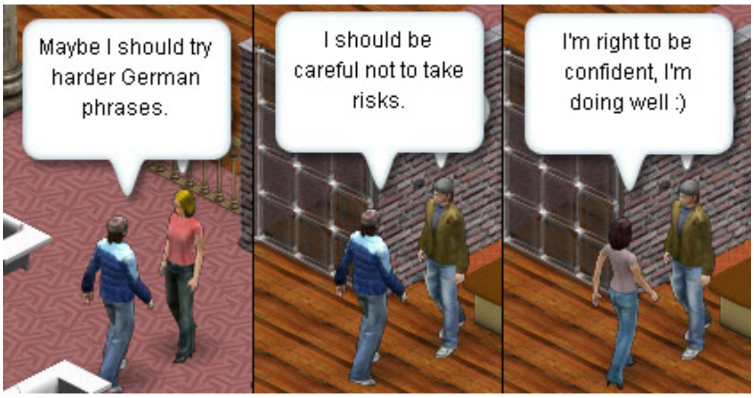

Figure 107. Meta-cognitive Feedback from the player's character

Figure 108. Emotional feedback of confusion from a game NPC

Figure 109. Motivational feedback of happiness from 'Agent White Jacket'

Examples of the associated XML encoded AEs are shown below in Figure 110 and Figure 111 for dialogue difficulty and performance feedback respectively. In Figure 110 it can be seen how varying values are used with the same outcome id to select varying difficulties of dialogue.

```
<element id="dialog_rating_0">
        <outcome id="dialog_difficulty" value="0"/>
</element>
<element id="dialog_rating_1">
        <outcome id="dialog_difficulty" value="1"/>
</element>
<element id="dialog_rating_2">
        <outcome id="dialog_difficulty" value="2"/>
</element>
```

Figure 110. Language Trap Adaptive Elements for Dialogue Difficulty

```
<element id="performance_very_good_1">
        <outcome id="performance_very_good" value="0"/>
        <task-exclude>double_agent</task-exclude>
</element>
<element id="performance_very_good_2">
        <outcome id="performance_very_good" value="0"/>
        <task-exclude>double_agent</task-exclude>
</element>
```

Figure 111. Language Trap Adaptive Elements for Performance Feedback

6.2.6 Evaluation Technical Features

The degree of freedom allowed within the Language Trap game allows players to explore and interact with game characters in the order in which they prefer. This freedom however limits the possibility of using evaluation techniques such as yoked control design as each learner's experience is considerably different. In such a scenario it can useful to evaluate the differences of varying types of personalisation and their sophistications. In order to achieve this the Language Trap game can send on *Option* message to ALIGN indicating whether basic or advanced adaptations should be used.

A further technical feature required for evaluations with the Language Trap game is the ability to support multiple simultaneous players. As the ALIGN system was designed to cater for multiple concurrent game users the Language Trap game takes advantage of this and makes multiple TCP/IP connections to ALIGN ensuring that the maximum number of threads are used. Both the Language Trap server component and the ALIGN service are deployed on a Ubuntu Linux virtual machine with 2GB of RAM and access to two quad-core Intel Xeon processors (2.5GHz) to ensure ample capacity for connecting clients.

6.3 Implementation changes to ALIGN

The nature of the Language Trap game necessitated a number of changes in the implementation of ALIGN as is discussed in this section. The key factor that necessitated these changes was the need for ALIGN to support multiple concurrent games being played at the same time. As these changes relate only to how ALIGN communicates with game engines no changes are required in terms of how ALIGN uses the Drools rule engine.

In order to make ALIGN as efficient and scalable as possible the revised networking and message parsing takes advantage of the following features of the Java language: Non-blocking Input/Output (NIO), Efficient Byte Buffers, Thread pools and Executors, and Concurrent Data Structures.

6.3.1 Networking and Message Parsing

The initial implementation of networking in ALIGN used a single dedicated thread to accept a single connection from a game engine representing a single learner. Whereas this approach worked for the ELEKTRA game it does not scale well in a server environment as a new instance of ALIGN is needed for each game engine and learner. To address this the networking was re-implemented to be more scalable and flexible. The key changes are that multiple game engines can simultaneously connect to ALIGN and that game evidence about multiple learners can be sent on one single connection. Although this change is largely internal to the workings of ALIGN the process of connecting to ALIGN as given in chapter 4 remains the same except for the use of a slightly modified messaging format.

Whereas previously ALIGN had used blocking I/O this was changed to use a system of non-blocking I/O for increased efficiency. In the case of blocking I/O, a single thread blocks and waits when trying to send and receive data on a socket. The key downside of this is that when dealing with a large number of concurrent socket connections each connection requires a dedicated thread that results in greater thread scheduling overhead, and memory usage by each thread’s stack. In consideration of the nature of how ALIGN works the network sockets are idle for the majority of the time making blocking I/O an inefficient use of resources. The use of non-blocking I/O addresses this problem by using a small pool of threads to service all of the sockets. In this pattern a thread from the thread pool only reads or writes as much socket data as is possible without blocking. It is then returned to the thread pool for use elsewhere. If all of the data wasn't received or sent the socket is marked as being monitored and when more data can be sent or received it is serviced by another thread from the thread pool. Under this approach threads are only used for work and are never left blocking or idling.

The new approach to networking used within ALIGN can be broken into two phases, 1) the accepting of a new connection from a game engine, and 2) the receiving and sending of messages in the ALIGN message format. The first of these phases is illustrated in Figure 112 below. When a new game engine connects to ALIGN a new instance of a *GameServerConnection* is created to manage this connection and maintain a reference to the TCP/IP socket. The *ClientAcceptor* is responsible for accepting new connections and creating new *GameServerConnections*. Importantly the accepting of new connections occurs in a dedicated "Acceptor" thread so that new connections will always be promptly accepted.

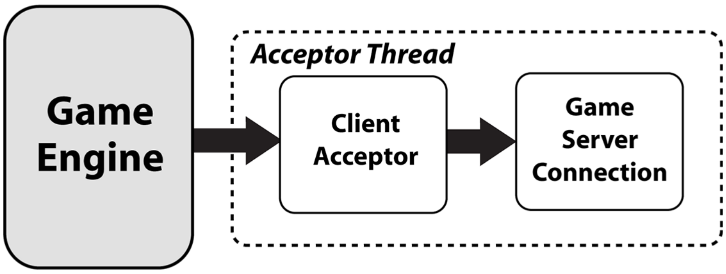

Figure 112. ALIGN Game Server Connection Process

The second phase of the new ALIGN networking involves monitoring all active connections for incoming messages and processing these messages accordingly. The *ClientDispatcher* is responsible for monitoring these connections with a dedicated thread. When a new message is received the corresponding *GameServerConnection* is used to process the messages.

In order to best accommodate multiple connections from game engines, and to exploit modern multi-core processors, a pool of threads is used to execute the *GameServerConnections*. The *ClientDispatcher* essentially selects a *GameServerConnection* that has data to send or receive and executes it with a thread from the thread pool. This process of dispatching incoming data to the appropriate *GameServerConnection* is illustrated below in Figure 113.

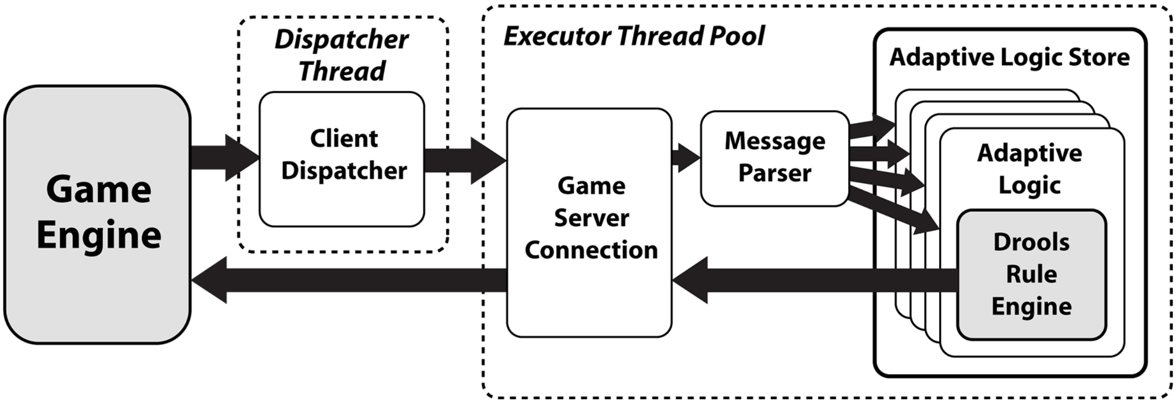

Figure 113. ALIGN Networking and Message Parsing Process

6.3.1.1 Message Parsing and Adaptive Logics

Once new data is received from any *GameServerConnection* a thread from the Executor Thread Pool is selected to process the data. Initially the *GameServerConnection* reads a message from the socket and passes it to the *MessageParser,* as is shown in Figure 113 above. If a complete message cannot be read the thread is returned to thread pool until more data arrives and is dispatched by the *ClientDispatcher.*

The role of the *MessageParser* is to convert the ALIGN messaging format into Java objects that can then be inserted into a Drools working memory. In order to separate the personalisation for each learner an *AdaptiveLogic* is created for each learner. Each *AdaptiveLogic* consists of a String learner id and a Drools working memory. The *AdaptiveLogicStore* is responsible for creating and retrieving *AdaptiveLogics* for each learner. The creation of an *AdaptiveLogic* consists of a new Drools working memory being created and all of the Adaptive Elements being inserted into it. Once an AdaptiveLogic has been created each message is parsed and a Java object as appropriate is inserted into the working memory.

6.3.1.2 Changes To the ALIGN Messaging format

The structure of an ALIGN message was changed to intentionally always start with the length of the entire message. This feature becomes necessary when using non-blocking I/O as it is common for only a partial message to be received, as is the nature of non-blocking I/O. In such a situation the message length can be used to determine if an entire message has been received or if message parsing should be deferred until more data is received. In addition to the reordering of the message structure a new field representing a learner's id is added to the message structure as is shown in Figure 114 below. This extra field becomes necessary as ALIGN will be dealing with multiple concurrent learners and it needs to know which learner the message relates to.

Old Message Structure
<message> = <message-type><message-length><message-body>
New Message Structure
<message> = <message-length>**<learner-id>**<message-type><message-body> <learner-id> = <string>
Example Message encoded using the new message format
Message: The learner "abc123" has succeeded at the task "task1"

<message-length>	<learner-id>	<message-type>	<message-body>
	"abc123"	4: TASK_SUCCESS	"task1"
0x00000013	0x0006 0x616263313233	0x00000004	0x0005 0x7461736b31

Complete message in hexadecimal (23 bytes):

00000013 0006 616263313233 00000004 0005 7461736b31

Figure 114. Changes to the ALIGN messaging format

Due to the new multi-user nature of ALIGN the effect of the SHUTDOWN message as defined in chapter 4 was changed. Whereas previously this message would cause ALIGN to completely shutdown it now only shuts down the *AdaptiveLogic* for the leaner id specified in the message. This change allows unused and old *AdaptiveLogics* to be removed from memory to free up resources.

6.3.1.3 Changes to Recommendation Fact Handling

Within the implementation of ALIGN Recommendation messages are sent from the game engine to indicate that an Adaptive Element has been used by the game engine. These messages are necessary in order to ensure ALIGN knows what Adaptive Elements have previously been used. Whereas this approach was effective with the ELEKTRA game, it could result in race conditions due to the way ALIGN works with the Language Trap game. As the Language Trap game operates over the internet it has potentially hundreds of milliseconds of latency between the game client and ALIGN and it is possible that multiple adaptations could be sent before Recommendation messages are received to disable the repeated use of AEs. In order to overcome this race condition the Recommendation facts are directly inserted into the working memory as soon as AEs are sent to Language Trap. This in effect ensures the accuracy of the adaptation constraint and also simplifies the Language Trap game as it does not have to send Recommendation messages. In accordance with this approach any Recommendation messages received are ignored as this evidence will already have been directly added to the working memory.

6.3.2 Inference Rules

In a similar manner to the rules authored for the ELEKTRA game, the rules authored for the Language Trap game are the inference and personalisation rules. Both the fact pruning rules and the adaptation constraint rules remain unchanged as they are common across both of the games.

The key inference rules required for the game involves the mapping of the dialogues undertaken within the game to *TaskEvents*. As the game itself does not have a concept of a task each dialogue statement that is chosen is sent to ALIGN as a *SubTaskElementEvent*. Each dialogue chosen by the learner is represented as a *SubTaskElementEvent* with the following parameters:

- **charId**: The name of the NPC the learner is conversing with.
- **choosenId**: The id of the statement that was chosen.
- **oldDialog**: The id of the previously chosen group of statements if any.
- **nextDialog**: The id of the next group of statements if any.
- **lang**: The language of the chosen statement, either “de” for German or “en” for English.
- **rating**: The difficulty rating (number of stars) of the statement from 0 to 5.
- **correct**: The appropriateness of the statement, either true or false.
- **dialogContext**: The ratings and correctness of the other statements that were presented to the learner as multiple choices.

The inference rules in this case create two types of *TaskEvents*, one to represent an entire conversation with a NPC that has a start and end (a dialogue task), and a second type of task event that represents the success or failure of responding to an individual statement made by a NPC (a statement task).

In addition to inferring *TaskEvents* there is an inference rule that detects a preference from the learner to the amount of performance feedback they would like to receive. This preference can occasionally be expressed in a dialogue with “Agent White Jacket” as was shown in Figure 104 on page 164. As all dialogues are represented as *SubTaskElementEvents* a rule is used to check for these particular dialogues and creates a *GenericFact* representing the learner’s preference for more or less feedback. The implementation of example inference rules is given in Appendix A to this thesis.

6.3.2.1 Linear Modelling

Due to there being no clearly defined skill structure for the learning content of the Language Trap game the use of CbKST was not appropriate. However, it is still useful to use statistical modelling techniques as they can accommodate for vague or imprecise learner evidence. Whereas ideally within Language Trap the learners would always truthfully and accurately choose dialogues there is a need to accommodate for learner guessing and accidental selections. To accommodate for this the use of linear modelling was chosen as an inference technique that can cater for this imprecise evidence.

In this scenario the linear model is used to estimate the German ability of the learners based on the dialogue statements they select. The sophistication of the linear models used determines how well the ability of the learner is estimated. As part of the evaluation of ALIGN with the Language Trap game both a basic and an advanced model were developed. These two models are used to ascertain the impact caused by using inference techniques of varying complexity, and is further discussed in the following evaluation chapter.

Basic Naive Linear Model

This initial linear model is effectively a weighted average of the difficulties of the previously chosen statements. It essentially assumes that the ability of the learner is directly related to the difficulty and correctness of the statements they choose. The learner's estimated ability is given by the formula below in Figure 115, which gives the expected statement difficulty that the learner can handle based on their previous 10 chosen statements.

$$d_{n+1} = \frac{\sum_{i=h}^{n} \begin{cases} c_i = true, d_i \\ c_i = false, -d_i \end{cases}}{n-h}$$

Figure 115. Naive linear model for estimating learner ability

d_n: The difficulty of the n^{th} chosen statement.

h:The oldest statement history recorded, at most the last 10 statements are considered, i.e. $h = max(0, n - 10)$

c_i: The correctness of the statement with difficulty d_i

Advanced Linear Model

Whereas the naive linear model only considers the difficulty and correctness of the statements chosen, the advanced model additionally considers the context in which the statements were chosen, i.e. how many easier, harder, correct and incorrect statements were also available to be chosen. The learner's estimated ability is given by the formula in Figure 116 below.

$$d_{n+1} = d_n + (d_c - d_n)o_c a$$

Figure 116. Advanced linear model for estimating learner ability

d_c: The difficulty of the chosen statement

o_c: The optimality of the chosen statement. The most optimal statement to choose is the most difficult correct statement. Statements that are not the hardest or are incorrect have lower optimality values. Optimality is a value between -1.0 and 1.0 where -1.0 is an incorrect statement and values from 0.0 to 1.0 are correct statements with 1.0 representing the most optimal statement. Optimality is calculated using the formula given in Figure 117 below and for chosen statements that are correct it is based on Bayes' Theorem. For a correct statement it is defined as the inverse of the probability of randomly choosing the chosen statement given the other statements that could be chosen.

$$o_c = \begin{cases} c = correct, & \dfrac{1}{P(choosing\ c \mid c\ is\ correct)} \\ c = incorrect, -1.0 & \end{cases}$$

Figure 117. Optimality formula used for the advanced linear model

a: The aggressiveness of the change to apply to the statement difficulty. The use of high values gives a responsive change, whereas low values have a damping effect and mitigates the effect of guesses. The value of 0.3 is used and this value was determined by simulation to give the best trade-off between responsiveness and damping effect. The graph shown below in Figure 118 illustrates the effects of varying aggressiveness values on the estimated ability after a series of correctly chosen statements.

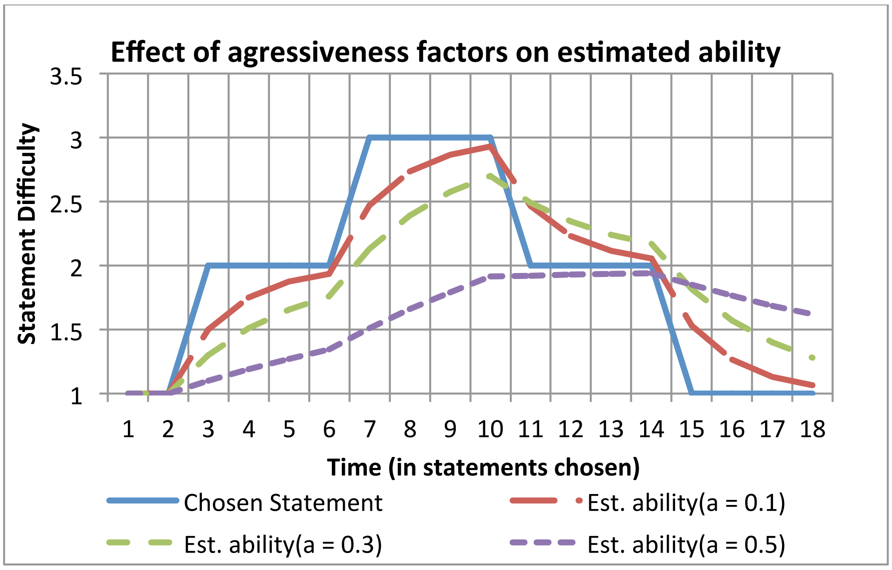

Figure 118. Effect of aggressiveness factors on estimated ability

The output of the linear modelling process is a *GenericFact* representing the estimated ability of the learner in terms of dialogue ratings. The use of the naive and advanced linear models is further discussed in the following chapter addressing the evaluation of the experiment performed using the Language Trap game.

6.3.3 Personalisation Rules

The personalisation rules used to adapt the Language Trap game address the six personalisation strategies for the Language Trap game. In table Table 22 below the mapping between game evidence used by the rules, and personalisation strategies is given.

Table 22. Mapping of personalisation strategies to game evidence

Personalisation Strategy	Game Evidence
1) Present a suitable challenge to the learners through adapting the difficulty of conversation dialogues	*TaskEvent (Success, Failure)* *GenericFact(Ability)*
2) Foster awareness of a learner's performance through providing emotional feedback from the NPCs based on the appropriateness of the learner's dialogue	*TaskEvent (Success, Failure)*
3) Provide performance feedback based on the appropriateness of the learner's dialogue	*TaskEvent (Success, Failure)*
4) Provide meta-cognitive feedback about the prudence of the decisions the learner has made	*TaskEvent (Success, Failure)*
5) Encourage the learners through providing motivational support	*TaskEvent (Success, Failure)*
6) Enable the learners to influence the frequency of feedback based on their preferences	*GenericFact(Feedback Preference)*

Examples of the personalisation rules used are given in Appendix A to this thesis.

6.3.4 Scalability and Fault Tolerance

The ALIGN system was designed to accommodate the adaptation of multiple learners playing games concurrently and with low latency in order to achieve timely adaptation. The new networking component of ALIGN helps to achieve this through the following technical features:

- Multiple concurrent *GameEngineConnections* can be handled by the ALIGN system allowing multiple socket connections from one or more game engines.
- Multiple *AdaptiveLogics* can be executed in parallel using multiple threads to fully exploit multi-core processors and to ensure minimal delays is delivering adaptations to multiple learners.

- The use of non-blocking IO and a dedicated dispatcher thread ensures that as soon as data is received by ALIGN it is immediately processed. Further to this, the use of a thread pool prevents individual threads waiting on I/O operations thus reducing the required number of threads and so reducing memory usage and thread scheduling overhead, enabling ALIGN to scale to hundreds or thousands of concurrent users.

In addition to supporting *GameServerConnections* from multiple Game Engines the ALIGN system supports and encourages the multiple connections from the same game engine. Through this approach ALIGN can use more threads to process messages and so give greater performance for multi-user games. Additionally due to the ALIGN messaging format having each message uniquely bound to an *AdaptiveLogic* the messages for any given learner can be received on any *GameServerConnection*.

Although ALIGN uses continuously open TCP connections it is tolerant to connections being dropped and re-established. In order to accommodate this, each time a recommendation message needs to be sent it is sent on the last connection from which it received a message for the learner in question. This approach ensures that if a connection is lost and a new connection subsequently created, the new connection will be used to send recommendations back to the game engine. This feature ensures ALIGN is tolerant of network connection failures.

A further fault tolerance feature of ALIGN is the *Governor* which operates periodically to purge *AdaptiveLogics* from memory that are no longer being used. The *Governor* works in its own thread and ensures that memory used by old *AdaptiveLogics* that weren't shutdown by a game engine are reclaimed after a period of inactivity.

6.4 Summary

In this chapter the Language Trap game was introduced as the second game integrated with the ALIGN system. In contrast to the ELEKTRA game, Language Trap presents an alternative game style, learning content, personalisation, and deployment. The design of the game followed both best practices in educational game design with tightly integrated learning content, a motivating and age appropriate storyline, and curriculum relevance. Further to this the use of participatory design with the students who would be trialling the game ensured the game addressed the needs and desires of the target audience.

In line with the Action research methodology the design of Language Trap also considered the findings of the previous experiment involving the ELEKTRA game. As a result of reflecting on the experiment the design of Language Trap was influenced to simplify its trialling through it requiring no installation and being trial-able in a local setting. Further to this the number of AEs authored for

Language Trap was considerably less than for ELEKTRA with the aim to increase coverage and avoid wasteful development of adaptations that aren't used.

This chapter concluded with a discussion on the enhancements and implementations required in ALIGN for use with this alternative game. Despite the novel nature of the game very few modifications were required beyond the anticipated authoring of inference and personalisation rules. Although changes were needed to the networking component to enable multiple concurrent users the fundamental architecture of ALIGN remained unchanged.

7 Action and Observation - Evaluation of the Language Trap Game

7.1 Introduction

This chapter continues the evaluation of the ALIGN system through the experiment conducted with the Language Trap game introduced in the previous chapter. In line with the objectives of this thesis this chapter aims to address both the ability of ALIGN to provide non-invasive personalisation as well as the reusability of ALIGN across diverse educational games. The experiment involving the ELEKTRA game examined the feasibility of separating ALIGN from a game engine, the variety of adaptations deliverable by ALIGN, and the effectiveness of the personalisation. This Language Trap experiment builds upon the ELEKTRA experiment by examining the variety of adaptations that can be delivered, evaluating the non-invasive nature of the personalisation, and evaluating the overall reusability of ALIGN. In consideration of the novel nature of the Language Trap game its effective design is also considered in order to ensure it is a reasonable game with which to evaluate ALIGN.

This chapter represents the final action and observation stages of the second action research cycle that has influenced the structure of this thesis. The goal of this chapter is to detail the second experiment undertaken to complete the evaluation of the ALIGN system as well as an analysis of the results emerging from the experiment. This chapter begins by detailing the Language Trap experiment in terms of the experimental objectives, details of the user trials undertaken, and a discussion on the results of the experiment. This chapter then continues with a discussion on the reusability of the ALIGN system in light of the overall experimental results as well as further uses of the ALIGN system beyond the scope of this thesis. A brief discussion on the comparison of ALIGN & Language Trap to existing adaptive educational games in then given. This chapter concludes with a summary and final reflections on the Language Trap experiment.

7.2 The Language Trap Game experiment

As the second experiment using the ALIGN system the focus of this experiment builds upon the successes of the ELEKTRA experiment and refines and extends the experimental objectives. In line with the action research methodology this experiment is a natural successor to the ELEKTRA experiment as its design reflects on the approaches and outcomes of the preceding experiment.

Whereas the ELEKTRA experiment was restricted by the many stakeholders in the ELEKTRA project the Language Trap game allowed for greater flexibility in both the game's design as detailed in the preceding chapter, and in its evaluation. The analysis and reflection on the

ELEKTRA experiment elicited desirable changes for the Language Trap experiment. In particular the technical requirements of the game should facilitate user trials by simplifying the technical requirements of running the game.

7.2.1 Experiment Objectives

The viability of separating ALIGN from the game engine was evaluated in the previous experiment. Whereas a variety of effective adaptations were realised in the ELEKTRA game there remains a desire to evaluate whether ALIGN can perform as effectively across varying game genres and learning content. The experiment with the Language Trap game presents such a scenario in which to evaluate the generality of the ALIGN system.

The evaluation of any personalised educational game must first consider how successfully the game has been designed as this is requisite to the success of any personalised game. Accordingly the first objective of this experiment is to determine whether the design of the Language Trap game created by the author was suitably acceptable to the end user as an educational game, and whether the game was beneficial to the students' language learning.

Following on from the general evaluation of the game design it is necessary to determine whether ALIGN has technically realised the adaptations it was intended to make. Further to this it is necessary to determine the variety of adaptations that were realised within this alternative game. Accordingly the second objective for this experiment is to determine whether ALIGN was able to realise a variety of adaptations in a game featuring an alternative game genre and learning content.

The third objective of this experiment is to determine whether ALIGN can effectively personalise the Language Trap game in a manner that is non-invasive to the gaming experience. This objective leads on from the success of the ELEKTRA experiment and is a key focus of this experiment. The effectiveness of the personalised learning experience provided by ALIGN is inextricably linked to how invasive the adaptations are to the gameplay. The more the adaptations disrupt the gameplay the worse the gaming experience and consequently the worse the learning experience. In order for the personalisation to maximize its learning benefit it must be realised in a non-invasive manner.

The final objective of this experiment is to determine the reusability of the ALIGN system across multiple games. A particular focus of this objective is the changes required to tailor ALIGN for use with the Language Trap game following its use with the ELEKTRA game.

7.2.2 Evaluation Metrics Employed

The metrics employed to evaluate the experimental objectives vary considerably across the four objectives stated above. In considering the first objective of determining the effective design of game the metrics used will be largely qualitative in nature. In particular the metrics of learner' likes, dislikes, and comparisons to other educational games are apt. Additionally through analysing the changes and improvements that were recommended by the users it becomes possible to determine the success of the game design. As a quantitative metric of successful design the improvement of each learner between pre and post-tests is used an indicator of the game's learning effectiveness.

In contrast to the first objective the metrics employed to determine the adaptations that were realised for the second objective are entirely quantitative. The metrics of the number of AEs delivered, the variety of personalisations achieved through the AEs used, and the percentage of the available AEs that were used are appropriate in determining the variety of adaptations that were achieved within the Language Trap game.

The third objective of determining the success of achieving non-invasive personalisation requires metrics that are both qualitative and quantitative. In considering non-invasiveness it must be considered that gameplay can be disrupted by technical issues such as delays in adaptations, as well as through poorly chosen adaptations. In the case of poorly chosen adaptations these can be caused by inaccurate learner modelling and in the use of adaptations that are inappropriate to the game context.

An approach to measuring overall invasiveness is to consider the qualitative metrics of user satisfaction and perception of invasiveness, however this objective can also be analysed in a quantitative manner through the examination of log files and their comparison with the questionnaire results. The quantitative metric of the timeliness of adaptations can be considered as an indicator of invasiveness caused by adaptation delays.

The assessment of a learner's ability within Language Trap is non-invasive by design, i.e. no explicit questions are asked of the learner. As with any implicit assessment it is important to determine how effective it is in comparison to explicit assessment. As the implicit assessment determines how the game is adapted, the worse the assessment the more likely the game is to be inappropriately adapted. Accordingly the metric of the correlation between the learner's ability (determined by the explicit post-questionnaire) and their calculated ability (determined by implicit assessment) is an indicator of how well the learner is being modelled. Where the modelling is inaccurate the personalisations may be inappropriate and potentially invasive to the learner's gaming experience, however when the modelling is accurate the personalisations will be suitable for the leaner and non-invasive to their gaming experience.

The fourth and final objective is to determine the reusability of the ALIGN system across multiple games. Whereas the preceding objectives rely on the results from individual learners playing the game, the final objective considers the game more holistically in terms of its success and also in terms of the preparatory work required to reuse ALIGN after the ELEKTRA experiment. Accordingly, the metrics used are more formative in nature and consist of the development effort in modifying rules, and the ease of configuring ALIGN for a different deployment.

7.2.3 Experiment Methodology

As was highlighted in the evaluation of the ELEKTRA experiment there is little benefit to be had from the comparison of adaptive and non-adaptive games as the end users will encounter considerably different experiences. Whereas in the ELEKTRA experiment the use of yoked control design was attempted, its use in with the Language Trap game was not deemed appropriate due to the degree of freedom the game offers. The use of yoked control design can be beneficial in determining the effect of personalisation however it is of little use in determining non-invasiveness, a key focus of this experiment. In fact the results of a yoked control design can confound invasiveness as inappropriate and invasive adaptations will in all likelihood be encountered by those playing a yoked game.

In consideration of the focus on evaluating non-invasive adaptation this experiment employs a comparative methodology between basic adaptation and advanced adaptation. Whereas both adaptations are delivered through ALIGN they should be both achieved non-invasively, however the effect of the basic adaptation may result in a poorer estimation of a learner's ability, leading to a less enjoyable gaming and learning experience.

Although many aspects of a learning game can be assessed quantitatively through log file analysis the metrics employed in this experiment intentionally utilise a hybrid of quantitative and qualitative data. The benefit of this approach lies in the importance of real world community experience over purely dispassionate log file metrics. Although log file analysis can present objective facts about a learner's experience it cannot capture their opinions of the experience. For this reason log files are not considered in isolation but in conjunction with subjective feedback provided through questionnaires. This avoidance of relying solely log files is an approach promoted by the noted game designer Will Wright (Wright & Laurel, 2003).

7.2.3.1 Design of the experiment

The experiment with the Language Trap game consisted of user trials with appropriate learners situated in their normal school environments. The user trials were broken into the following four stages:

1. The students were assigned an anonymous username and completed the pre-questionnaire.
2. The students played through the entire Language Trap game.

3. The students completed a post-questionnaire.
4. A debriefing and general discussion was held with the students.

Prior to running the user trials ethical approval was received from Trinity College Dublin to conduct the trials and gather the relevant learner data. For each trial, approval was also received from either the principal or school board where the trial was to be conducted. Parental consent forms and individual consent forms were also required for each student who participated in the trials.

In order to comply with ethical and privacy regulations each student was allocated an anonymous username to use in both the questionnaires and when playing the game. The questionnaires and game were setup so that the students only had to enter their assigned username once at the start of the trial. Prior to the user trials the students were informed that they would be playing an educational video game but they were not informed of the adaptive nature of the game. The details of the adaptations were only given in the post-trial discussion so that the students would approach the game as just another educational game and not with any pre-conceptions of what an adaptive game was. Additionally the students were not made aware that they were being randomly assigned to either the basic or advanced adaptation group. The debriefing and post trial discussion acted as both an information session for the students but also as a way of gathering informal feedback that was not given in the questionnaires.

7.2.3.2 Pre-questionnaire

The pre-questionnaire for the Language Trap game was completed by the learners prior to them seeing or playing the game. The purpose of this questionnaire was to gather characteristics about the learner, namely their attributes that may impact their use of the game, their experience with playing video games and educational video games, and finally their ability to recognise appropriate German phrases. The entire questionnaire is available in Appendix C to this thesis and was comprised of the following sections:

- Learner attributes
  - Age
  - Gender
  - School Year (4th, 5th, 6th)
  - Years studying German
  - Anticipated level of final exam (Ordinary or Higher level)
  - Reading difficulties (Dyslexia, Corrected Vision, Colour Blindness, Other)
  - Physical difficulty using computers
  - Hearing difficulty

- Video game experience
    - Frequency of game play
    - Game genres played
    - Experience with Edu-games
- German phrase test (using phrases found within the game)

7.2.3.3 Post-questionnaire

The post-questionnaire focused largely on the learner's subjective experience of playing the game. This focus on subjective aspects of the game was necessary in order to assess factors such as motivation, engagement, and fun. The post questionnaire additionally included the same German phrase test as the pre-questionnaire in order to assess any improvement that occurred whilst playing the game. The entire post-questionnaire is available in Appendix C to this thesis and was comprised of the following sections:

- Game opinion
    - Game Design
    - Usefulness, usability, playability, motivation
    - Comparison to other edu-games
- Invasiveness and Personalisation
    - Game companion opinion (invasiveness)
    - NPC evaluation (appropriateness)
    - Game dialogue difficulty (challenge personalisation)
    - Game overall difficulty and immersion
- Learning awareness
- German phrase test (the same test as used in the pre-questionnaire)

7.2.4 User Trials

The user trials with the Language Trap game took place between October 2009 and May 2010 in five secondary schools in counties Dublin and Wicklow. The following schools were involved in the trials:

- Mount Temple Comprehensive, Malahide Road, Clontarf, Dublin 3
- Blackrock College, Blackrock, Co. Dublin
- St. Dominic's College, Ratoath Road, Cabra, Dublin 7
- St. Kilian's German School, Roebuck Road, Clonskeagh, Dublin 14
- Coláiste Ráithín, Florence Road, Bray, Co. Wicklow

The selection of the schools was made based on the following criteria:

- Availability of German as a subject
- The gender balance of the students
- The diversity of socio-economic backgrounds

The pre and post-questionnaires were completed online using the LimeSurvey[41] open-source survey software. The pre-questionnaire was configured so that once it was completed the students were taken directly to the Language Trap game and logged in ensuring the appropriate survey was associated with each gaming session. For privacy each student was allocated an anonymous username that they used for the duration of the trials. This username was entered both in the questionnaires and when playing the game.

7.2.4.1 Logistical Challenges

The challenges encountered with this experiment were greatly reduced in comparison to the ELEKTRA experiment. The geographic location of the user trials within Ireland and the use of English speaking students significantly eased the execution of the trials. The online nature of the game and the need not to install software meant the trials could be run using the computers available within schools. Despite occasional issues with sound cards and intermittent network connections the trials were logistically simple to run and on a number of occasions were run solely by the author with the students under the supervision of their teacher. In order to simplify data analysis and to minimize transcription errors all of the questionnaires were completed online using the open source LimeSurvey software.

7.2.4.2 Log File Analysis

The analysis of the ALIGN log files was conducted in the same manner as in the ELEKTRA experiment using the same log convertor tool shown in section 5.5.2. An additional feature of this experiment is that the game engine itself also produces XML log files that give a more granular record of a learners actions and experience within the game. An extract of one of these logs is given below in Figure 119.


```
<INFO timestamp="2844418590" date="2010-05-10 13:10:44,886">
<location x="9" y="16" id="Player"/>
</INFO>
<INFO timestamp="2844418701" date="2010-05-10 13:10:44,997">
<dialog-request character="german_guest" initial="true" />
</INFO>
<INFO timestamp="2844425583" date="2010-05-10 13:10:51,879">
<stars-change change="2" />
</INFO>
<INFO timestamp="2844425583" date="2010-05-10 13:10:51,879">
<dialog-choosen  charid="german_guest"  choosenid="0"  olddialogid="start"
```


[41] http://www.limesurvey.org/

```
nextdialog="Dialog1" context="1:false,1:true" correct="true">
<statement correct="true" id="0" nextdialog="Dialog1" rating="2">
      <value>Guten Morgen!</value>
      <response>Guten Morgen!</response>
    </statement>
</dialog-choosen>
</INFO>
<INFO timestamp="2844425586" date="2010-05-10 13:10:51,882">
<align-recommendation>dialog_rating_1</align-recommendation>
</INFO>
<INFO timestamp="2844434787" date="2010-05-10 13:11:01,083">
<translation-choosen>
<input>geschlafen</input><output>slept</output></translation-choosen>
</INFO>
```

Figure 119. Example Language Trap log file

7.2.5 Evaluation Results

In total, six user trial sessions were completed in the five schools with a total of 83 students completing the trials. The user trial group consisted of 38 males (46%), 43 females (52%), and two students (2%) who choose not to answer the gender question. The average age of the students was 16.3 years with a standard deviation of 0.83 years. In the first trial session with 19 students the students played a shortened version of the game and were randomly divided into two groups, the first group (10 students) played the game with no adaptations, and the second group (9 students) played the game with basic adaptation. This initial trial group (Group A) was used to identify bugs and performance issues with the game. For all of the other user trials the remaining 64 students (Group B) were randomly assigned to an adaptation group, where they experienced either basic adaptation (31 students) or advanced adaptation (33 students).

The average duration of a game play session for group B was 15.96 minutes (sd. 4.85 minutes). The play duration for group A was expectedly shorter at 11.75 minutes (sd. 1.33 minutes). The frequency of video gameplay for all 83 students was noticeably less than the trial group for the ELEKTRA experiment as can be seen below in Figure 120.

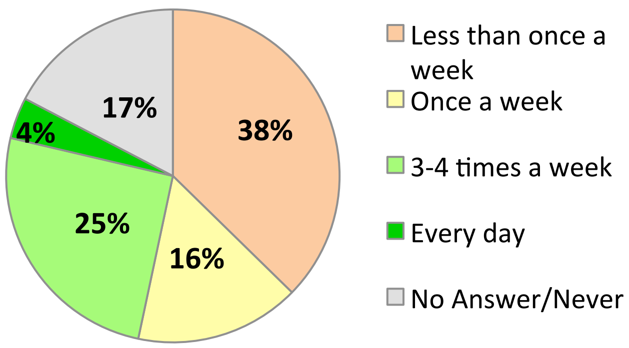

Figure 120. Frequency of playing video games

Although this result may be influenced by cultural and socio-economic factors it is most likely due to the varying ages of the students between the two experiments, an observation in line with reported video game usage whereby students play less video games the older they are (Desai, Krishnan-Sarin, Cavallo, & Potenza, 2010; Gentile, 2009).

7.2.5.1 Objective 1 – Successful Game Design

The metrics to determine the success of this objective are qualitative in nature and based upon the results of the post-questionnaire. In Table 23 below the responses to statements about the game design show an overall positive response. The average response to these questions is given based on a scale of 1-7 with 1 being strongly disagree and 7 being strongly agree.

Table 23. Responses to Language Trap Game Design Statements

Statement	Average Response
"I would play this game again"	4.95 (sd. 1.74)
"I felt the game was easy to control"	5.95 (sd. 1.41)
"I would recommend this game to someone learning German"	5.46 (sd. 1.55)
"The game is as fun as other educational games I have played"	4.84 (sd. 2.13)

The post-questionnaire additionally contained three free text sections to allow the users to express their likes, dislikes, and recommendations about the game in their own words. These sections were included to capture the users' overall impressions of the game and identify any serious deficiencies. In total 83 positive comments, 72 negative comments, and 48 recommendations were given. The positive comments were analysed and it was found they naturally clustered into the following four groupings:

- Game design features including music, storyline, graphics, and controls. (33 comments)
- NPC interaction, dialogues, and self-direction (33 comments)
- Learning content including the use of German and translations (16 comments)
- Other, "get out of class" (1 comment)

In the case of the negative comments the four emerging clusters were as follows:

- Game design features including character voices, music, and the storyline (45 comments)
- NPC interaction, dialogues, and self-direction (14 comments)
- Shortness of the game (9 comments)
- Bugs and technical issues (4 comments)

A more detailed examination of the negative game design comments revealed the following sub-clusters:

- Dislike of the synthesised character voices (18 comments)
- Difficulties and preferences for controls and movement (7 comments)
- Dislike of the storyline (4 comments)
- Dislike of the visual style, excitement, music or other features (18 comments)

The evident dislike for the synthesised voices was also observed informally during the user trials. However, the dislike was predominantly focused on the English synthesised speech which was of lower quality than the German speech and was described by the users as “robotic”, “annoying”, and “headacey[sic]”.

Despite the number of negative comments received the occurrence of comments indicating invasive adaptations, or even awareness of adaptations was minimal. This is a positive outcome considering the adaptive nature of the game. Further to this, the occurrence of nine negative comments indicating displeasure with how short the game was is a testament to the students’ enjoyment of the game.

The analysis of the recommendations resulted in the following five themes:

- Improvements to the story with the majority focussing on making the story longer. (16 comments)
- Changes to the game design, in particular improving the speech synthesis (14 comments)
- Changes to the game genre, e.g. more action, puzzles, etc. (11 comments)
- Changes to game interaction including more collectables and items to purchase with collected stars (4 comments)
- Improvements to the design of the game characters (3 comments)

The above recommendations indicated a positive acceptance of the game and a desire for an enhanced and extended version of the game.

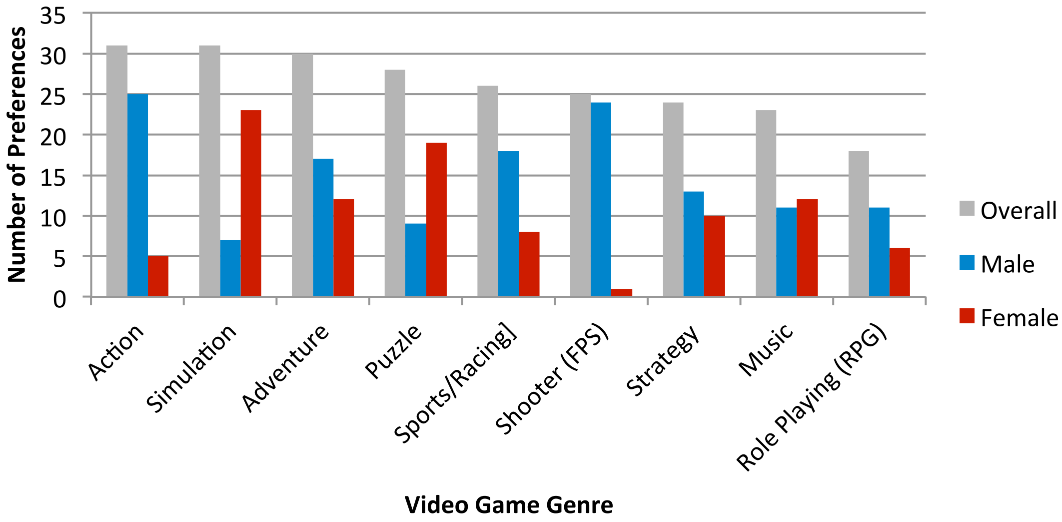

Figure 121. Video game preferences of the students in the Language Trap trials

The desire for a change of game genre was expected as the students liked a wide variety of video game genres as is shown above in Figure 121. The variation in game genre preferences between males and females is also evident in Figure 121. The decision to design the Language Trap game as an adventure role-playing game is positively supported as it is these genres that have similar preferences across genders, as opposed to the polarised Action, Simulation, and Shooter genres.

A further recognition of the appropriate game design of Language Trap was acknowledged when the game was awarded the European Language Label 2010[42] for its innovative approach to language learning. The European Language Label is a pan-European award that focuses on promoting innovation in language teaching and has the requirements that projects be comprehensive in meeting the students' needs, provide added value in the teaching and learning of languages, be motivational to the students, be original and creative, have a European emphasis, and be transferable to other language initiatives in different countries. The award was presented to the author at a ceremony in NUI Maynooth in September 2010.

The effectiveness of Language Trap as an educational tool is based on the knowledge gain of the students through comparing the results from the pre and post tests. In both the pre and post test the students were presented with identical tests that were marked on a scale of 0 – 20. Using a one-tailed paired t-test it was shown that a statistically significant score improvement occurred for both the group A and B students, these results are summarised below in Table 24.

---

[42] European Language Label Website: http://ec.europa.eu/languages/european-language-label/index_en.htm
Project award page: http://ec.europa.eu/education/language/label/index.cfm?fuseaction=ProjDetail &ID=8339&lang=EN&awardtype=P

Table 24. Average test score improvements for the Language Trap user trials

Trial Group	Average pre-test score	Average post-test score	Average improvement	T-test result
Group A	9.42 (sd. 5.15)	11.11 (sd. 5.45)	1.69 (+18%)	$t(18)=-3.05, p<0.01$
Group B	6.56 (sd. 3.37)	8.20 (sd. 4.48)	1.64 (+25%)	$t(63)=-3.50, p<0.001$

A further analysis of the adaptation groups in group B showed that the students experiencing the advanced adaptation had a higher average score improvement than the basic adaptation group as is shown below in Figure 122. However, this result proved not to be statistically significant with the sample sizes. Despite the lack of significance in this result it is of interest as there was no significant difference between the adaptation groups in the pre-test with average scores of 6.58 (sd. 3.40) and 6.55 (sd. 3.38) for the basic and advanced adaptation groups respectively. In addition to the improvements in test scores, 32% of the students in group A and 19% of the students in group B recorded new vocabulary they had learnt within the game in the post questionnaire.

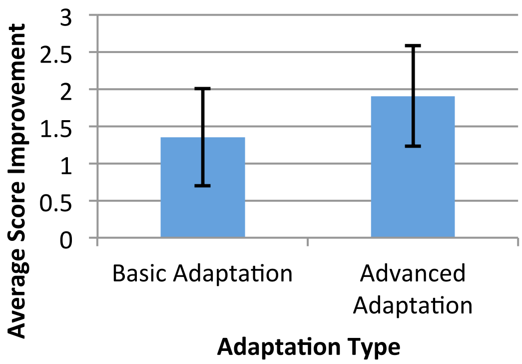

Figure 122. Average score improvement based on adaptation type showing error bars of the standard error

The combined qualitative and quantitative evaluation of the Language Trap game design shows that the game was both subjectively appealing and enjoyable to the students as well as objectively improving their level of German language. Although there are indications that the advanced adaptation was more beneficial to the learner's knowledge gain it was not as significant as expected, leading to questions as to whether the significant educational benefits of non-invasive personalisation lie in other areas such as motivation and attitudinal change.

7.2.5.2 Objective 2 – Variety of Personalisation

The variety of adaptations realised in the Language Trap game was determined through analysing the generated log files. In total 3,568 adaptations were made during the user trials. In determining the coverage of AEs used it was found that 21 different AEs were used within the game of a possible 30. This gave a coverage of 70% of the AEs that were possible to use. Although 37 AEs were encoded in the input XML file, seven of these provided outcomes that were never called from the adaptation rules and so were excluded from the coverage calculation. When further examining the nine unused AEs it was found that two of the AEs provided temporal hints that were never used as all of the students progressed through the game at a reasonable pace and without long delays.

The breakdown of the 3,568 adaptations as shown below in Figure 123 clearly illustrates the adaptations received by the students were predominantly related to the changing of the dialogue difficulty. The proportionately high percentage of these AEs (81%) reflects the times when these AEs can be used, i.e. within dialogue conversations, as opposed to after dialogues for the other AEs.

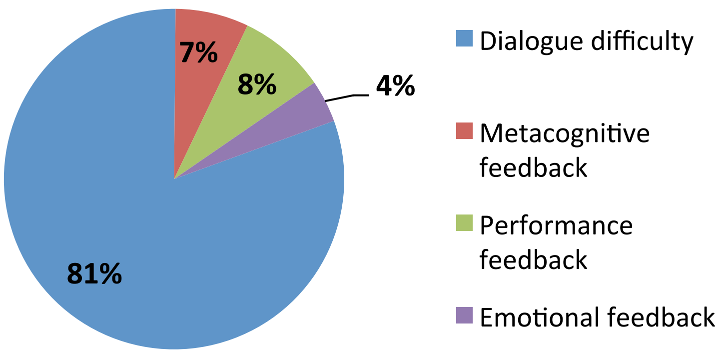

Figure 123. Breakdown of the adaptations delivered to users using Language Trap

A further examination of the dialogue difficulty AEs clearly shows a high frequency of adaptations to change the dialogue difficulty to one or two, as shown in Figure 124 below. The relatively low frequency of difficulty level three is most likely due to a combination of these dialogues being too challenging and also there being relatively few of these dialogues within the game. In the Language Trap game the dialogues were rated as difficulty one (45.6%), difficulty two (46.4%), and difficulty three (8%). A further breakdown of the specific AEs used is available in Appendix D.

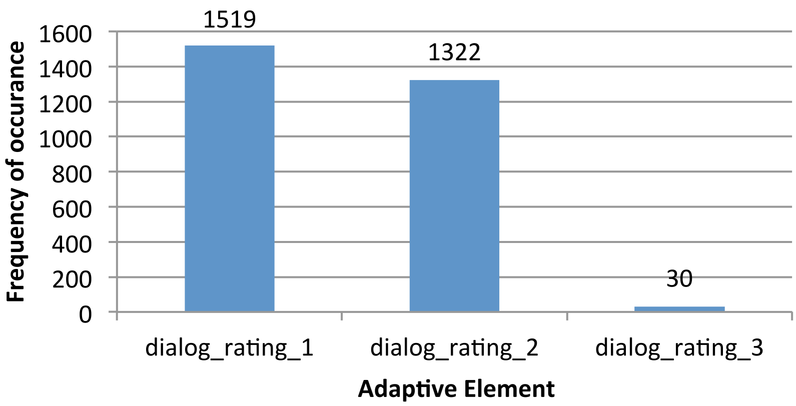

Figure 124. Frequency of dialogue difficulty adaptations

Despite the alternative game genre and learning content of the Language Trap game the ALIGN system was evidently able to provide both frequent and diverse adaptations to the game. The successful technical integration of ALIGN with the game is evident from the adaptations realised, however this does not consider the appropriateness of how and when these adaptations were realised and whether they were non-invasive to the gaming experience and effective. Accordingly the third objective of this experiment examines the non-invasive nature of these adaptations and the results of this evaluation are presented in the following section.

7.2.5.3 Objective 3 – Non-invasiveness

As is evident from the preceding section the technical integration of ALIGN and Language Trap was successful in creating a personalised educational game. However, the technical realisation of the personalisation does not indicate whether this personalisation was either beneficial or achieved in a non-invasive manner. In considering non-invasiveness and benefit the first metric to consider is whether the adaptations were realised in a timely manner and to ensure it is not a technical issue that is causing invasiveness. Through analysing the Language Trap log files it was possible to determine the delay between sending evidence to ALIGN and an adaptation being returned. It was found that of 3,568 adaptations sent the average delay was only 6.38ms (sd. 28.82ms). In total 99.61% of the adaptations were realised in under 200ms as is shown below in Figure 125. The recorded response times are considerably faster than for the ELEKTRA game due to the absence of the computationally expensive CbKST calculations.

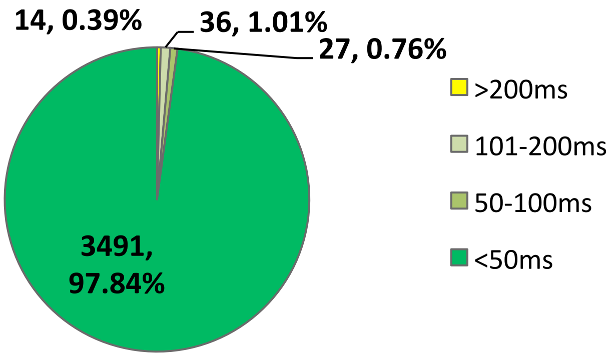

Figure 125. Breakdown in the delays of ALIGN generating an adaptation

The fast response times recorded for the ALIGN system are not considered to have added a noticeable or significant delay to the game play and so technically the ALIGN system was deemed not invasive due to its performance.

The delivery of non-invasive personalisation relies on both the ability to effectively model the learner and to provide adaptations that are appropriate to the current game context. Evidently if the user modelling is ineffective no matter how appropriate the chosen adaptations are, they are likely to be invasive. For this reason the effectiveness of the user modelling must be considered first as evidence of non-invasiveness. Within Language Trap the majority of the user modelling and adaptations surround adapting the dialogue difficulty as is evident in the AEs used (Figure 123). As ALIGN uses an implicit assessment technique it becomes possible to compare the computed ability of a learner with the result of the German test in the post-questionnaire. The correlation of these two values is then an indicator of the accuracy of the user modelling.

In examining the correlation for all of the 64 learners in the adaptive group it was found that there was surprisingly no correlation at all between calculated score and post-test result. However, on examining this effect further it was found that the correlation was dependent on the adaptation group, either basic or advanced. It was found that the advanced group had a weak positive correlation of 0.199, and the basic group had a weak negative correlation of -0.148. Despite the weak nature of these correlations there is evidence that the user modelling for the advanced group does reflect the learner's ability, albeit weakly. This result prompted a further examination of the differences between the basic and advanced user modelling. This examination resulted in two discoveries firstly that the basic adaptation underestimated the learners' ability and secondly that the correlation of the advanced adaptation improved with the more learner evidence observed. The underestimation of learner ability by the basic adaptation is evident when comparing Figure 126 and Figure 127 below. In these two scatter plots it is clear that the basic adaptation calculated a lower average dialogue difficulty for the majority of learners. This is of interest as the pre-test scores showed no significant difference between the average ability of the two groups when using a t-test, basic group 6.58 (sd. 3.40); advanced group 6.55 (sd. 3.38).

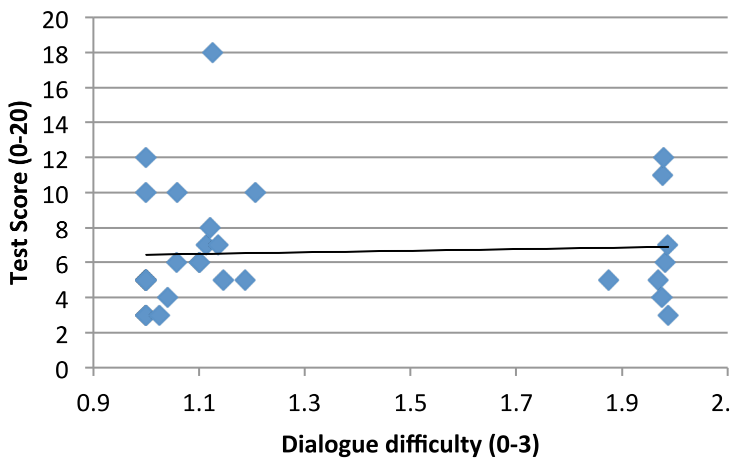

Figure 126. Scatter plot of pre-test scores against average dialogue difficulty for the basic adaptation group showing a linear trend line

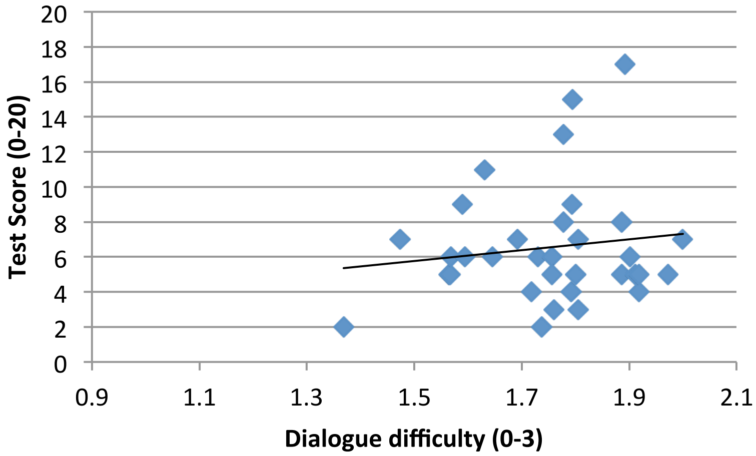

Figure 127. Scatter plot of pre-test scores against average dialogue difficulty for the advanced adaptation group showing a linear trend line

Although the correlation found for the advanced adaptation is only weakly correlated to the post-test scores there are four possible explanations for this weak correlation. In the first it is conceivable that the amount of evidence available to ALIGN was not sufficient to accurately model the learner, secondly that the post-test was not an accurate gauge of a learner's ability due to its limited scope, thirdly that the learner's choice of dialogues was not solely influenced by their ability, and fourthly that the algorithm used to determine ability was inaccurate.

In examining the first explanation of insufficient learner evidence it was observed that the correlation with the post-test scores had improved as more learner evidence was received. In Figure 128 below the correlation with the post-test score is plotted at four intervals where 40%, 60%, 80%, and 100% of each learner's evidence was observed.

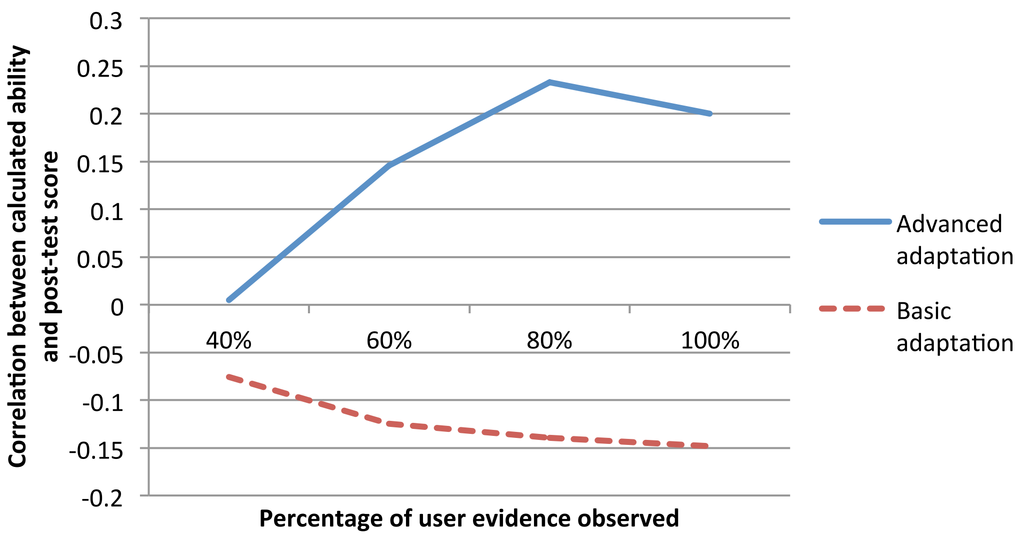

Figure 128. Correlation with post-test scores with varying user evidence observed

The learner evidence to generate the above graph was determined through log file analysis where the 40% interval represents the first 40% of the generated log files.

As is evident from Figure 128 the amount of learner evidence received directly impacts how well correlated the user modelling is, and accordingly how effective the personalisation will be. Although the correlation does improve with time it also appears to plateau suggesting that lack of evidence is not the only factor in the weak correlation.

The limited scope of the post-test with its 14 questions may also have contributed to the weak correlation as it may not have accurately assessed the ability of the learners. Although this may be a factor in explaining the weak correlation it was the beyond the scope of this experiment to perform a more rigorous and comprehensive post-test. Further to this the challenge of performing equivalent assessments of learner ability as is highlighted in (Conati et al., 2002) means that a more rigorous post-test may not be beneficial as in effect the post-test and user modelling are measuring different properties. For this reason the post-test is assumed to be accurate although further investigation of improved post-testing is a consideration for future work.

Although the statistical modelling technique used to model the learner can accommodate for mistakes or guesses by the learner, it cannot accommodate for non-skill based learner characteristics that influence dialogue choice. An example of such a characteristic would be where a learner consistently and intentionally chooses easier game dialogues than they are capable of. Evidently where a learner's approach to choosing dialogues varies between the game and the post-test there will be a low correlation between their estimated ability and post-test score. Although the reasons for exhibiting such a characteristic may be due to varying factors such as personality, motivation, and confidence, it is also possible that the low risk of failure presented within the game may also play a role. A closer inspection of the influences affecting dialogue choice within games is a consideration for future work, where the prevalence and impact of these factors can be examined in a detail not possible within the scope of this thesis.

The final explanation for the weak correlation may lie in the accuracy of the algorithm used to model the learner. The evident difference in correlations between the basic and advanced adaptations is due to the naivety of the basic algorithm. Although the advanced algorithm does improve upon the basic algorithm it none the less has room for improvement. However, the flexibility of the ALIGN system to help realise and identify the better algorithm is testament to how it can aid in improving personalised game based learning. In effect the ease at which alternative algorithms can be employed, that have tangible benefits, highlights the strengths of the ALIGN system.

The challenges of implicit assessment in educational games are similarly highlighted in (Conati et al., 2002) where a similar approach of considering the correlation of post-test scores with computed scores was used. As is also noted in (A. Corbett, McLaughlin, & Scarpinatto, 2000) there is considerable effort required in determining the reason for such low correlations. However, through the use of a system such as ALIGN, varying hypotheses to improve correlation can be trialled with minimal effort, allowing an iterative improvement of assessment accuracy.

The final determinant of invasiveness in adaptations lies in the subjective experiences of the learners playing the game. As the majority of adaptations are realised through the game characters their appropriateness, consistency, and the sensibility of their actions are indicators of invasiveness. Based on the post questionnaire the characters were perceived positively as is evident in the results shown below in Table 25. In this table the average results for both the basic and advanced adaptation are shown as well as the result of a one-tailed t-test to determine if the advanced adaptation was significantly better than the basic. The results are measured on a seven point scale with 1 indicating a strong disagreement to the statement and 7 indicating a strong agreement with the statement.

Table 25. Post-questionnaire questions relating to invasiveness

Statement	Average basic adaptation result	Average advanced adaptation result	T-test result
5.1 “I felt the characters reacted sensibly and intelligently to my actions.”	4.58 (sd. 1.69)	5.30 (sd. 1.59)	t(62)= - 1.76, p=0.042
5.3 “The game characters were consistent in what they did and said”	5.23 (sd. 1.43)	5.55 (sd.1.28)	No significant difference
6.5 “I felt the game dialogues changed inappropriately based on my actions.”	3.03 (sd. 1.78)	2.33 (sd. 1.74)	No significant difference

Further to the above direct evidence of invasiveness, the consideration of the learners’ ‘flow’ experience can be considered a broad indicator of a disrupted or invasive gaming experience. Due to the many constituents of a flow experience no single question can determine a ‘flow’ experience. In consideration of this the following post-questionnaire results were used to assess the antecedents of a flow experience, and consequently determine the likelihood of the game being conducive to creating a flow experience.

Table 26. Grid mapping factors in a flow experience to post-questionnaire statements

	Post questionnaire statement number											
Flow Antecedent	6.1	7.1	7.3	7.5	7.8	7.9	7.10	7.11	7.12	7.13	7.14	7.15
Being confronted with a task that is feasible to complete	X	X									X	
One's sense of the duration of time is altered			X									
The ability to concentrate on what one is doing				X								
There is deep but effortless involvement that removes one from everyday life					X	X	X			X		
Immediate feedback is provided							X		X			X
Concern for one's self disappears during the activity								X				
Sense of control over one's actions									X			
Clear goals are provided												X

The results of the flow evaluation are presented below in Table 27. As before the results are on a seven point scale with 1 indicating a strong disagreement with the statement and 7 indicating a strong agreement. The results of one-tailed t-tests assessing the added benefit of the advanced adaptation are also shown.

In all but one of the 12 statements given below there is evidence that the advanced adaptation was more conducive to a flow experience than the basic adaptation. Although the majority of these results do not show a significant benefit in the advanced adaptation, the statistical significance of statements 6.1 and 7.1 are particularly important as they contribute to the most vital pre-requisite of flow, that of a challenge suitable to a person's ability.

Table 27. Results of statements relating to a flow experience within Language Trap

Statement	Average basic adaptation result	Average advanced adaptation result	T-test result
6.1 "I felt the dialogues presented were always of a suitable difficulty"	4.52 (sd. 1.69)	5.46 (sd. 1.56)	t(61)=2.30, p=0.024
7.1 "The game was neither too easy nor too difficult."	4.74 (sd. 2.10)	5.73 (sd.1.42)	t(52) = -2.19, p=0.017
7.3 "I didn't recognize how time went by."	4.71 (sd. 2.13)	5.88 (sd. 1.52)	t(54) = -2.51, p=0.008
7.5 "I could easily concentrate on the game"	5.90 (sd. 1.17)	6.12 (sd. 1.02)	No significant difference

7.8 “I was deeply involved in the game activities”	4.39 (sd. 1.82)	5.27 (sd. 1.42)	$t(62) = -2.18$, $p = 0.017$
7.9 “The right thoughts came of their own volition”	4.97 (sd. 1.45)	5.36 (sd. 1.30)	No significant difference
7.10 “I exactly knew what I had to do”	5.26 (sd. 1.88)	5.30 (sd. 1.57)	No significant difference
7.11 “I was worried about my failure”	2.77 (sd. 2.06)	3.00 (sd. 1.82)	No significant difference
7.12 “I had the feeling of controlling the game”	5.00 (sd. 2.05)	5.30 (sd. 1.29)	No significant difference
7.13 “I was completely absorbed by the game and absent-minded”	4.32 (sd. 1.99)	5.03 (sd. 1.55)	No significant difference
7.14 “I felt stressed (insecure, discouraged, irritated, annoyed) whilst playing the game”	1.94 (sd. 1.55)	1.55 (sd. 1.15)	No significant difference
7.15 “I was aware of the progress I was making in the game”	5.32 (sd. 1.68)	5.18 (sd. 1.91)	No significant difference

The overall results from the evaluation of non-invasiveness give strong evidence of the non-invasive personalisation provided to the Language Trap game. Through examining non-invasiveness from both quantitative and qualitative perspectives the argument for ALIGN being able to support non-invasive personalisation is strongly supported.

7.3 Reusability of the ALIGN system

The reusability of the ALIGN system is an important aspect of any educational tool as it allows its benefits to be brought to other games with minimal or reduced development expense. The ALIGN system by design was developed to be flexible in three ways, firstly it runs as an independent service allowing multiple games to be integrated, secondly it supports a variety of personalisation such as adaptive challenge, motivational hints, and meta-cognitive feedback. Thirdly, the system supports a variety of inference techniques and adaptation strategies to deal with varying learner evidence and educational goals respectively.

The evaluation of the reusability of ALIGN is more formative across the ELEKTRA and Language Trap experiments as opposed to being summative of the data generated within the user trials. In line with this the development effort and ease of configuration are the key factors in evaluating the reusability of ALIGN.

The use of ALIGN with both the ELEKTRA and Language Trap games required that ALIGN cater for varying game genres, learning content, adaptations, and technical deployment. However, the redevelopment costs and reconfiguration required to make this transition were minimal. Due to the abstract nature of the game constraint and appropriateness constraint rules these can be reused across games without modification. However, due to the considerable differences between the two games the following changes were required to prepare ALIGN for use with the Language Trap game:

- The authoring of new inference rules due to the different learner evidence compared to the ELEKTRA game
- The authoring of personalisation rules to determine when and how to personalise the game
- The creation of Adaptive Elements appropriate to the Language Trap game

The above changes are considered to capture the three key variations in educational games, that of varying learner evidence (due to the nature of the game), the personalisation strategy suitable to the game, and the varying changes that can be made within the game. In consideration that novelty is a key factor in video game design in can be expected that these three factors must be considered within any adaptive educational game.

Whereas between ELEKTRA and Language Trap all three of these factors changed, it is conceivable that should two, one or none of these factors change it would be considerably easier to reuse ALIGN. The scenario where none of these factors have to be changed has been realised in a version of the Language Trap game dealing with Irish language learning as shown below in Figure 129.

Figure 129. Screen shot of the Irish version of the Language Trap game

This version of the game is being developed as part of research into the use of adaptive speech synthesis in Computer Aided Language Learning (CALL) being undertaken by Neasa Ní Chiaráin and Ailbhe Ní Chaisaide in the Centre of Language and Communication Studies at Trinity College Dublin (Ní Chasaide et al., 2011).

Despite this version of the game using a different language, different dialogues, and a different storyline, no changes at all were required to ALIGN to allow it to be personalised in the same way as the German version of the game. Both the German and Irish versions of the game integrate with the same instance of ALIGN without any modification. An evaluation of the Irish version of the game in the Centre of Language and Communication Studies is on-going with initial user trials taking place in Summer 2012.

A further technical element aiding the reusability of ALIGN is its Java based nature. As a Java application the transition from running on a Windows based platform desktop computer for ELEKTRA to a Linux based server for Language Trap was negligible with only minor changes to configuration files required to change file system paths.

The ALIGN system as used within ELEKTRA was also the basis for the Learning Engine component of the 80Days project (80Days-Project, n.d.). The game developed as part of the 80Days project is shown below in Figure 130.

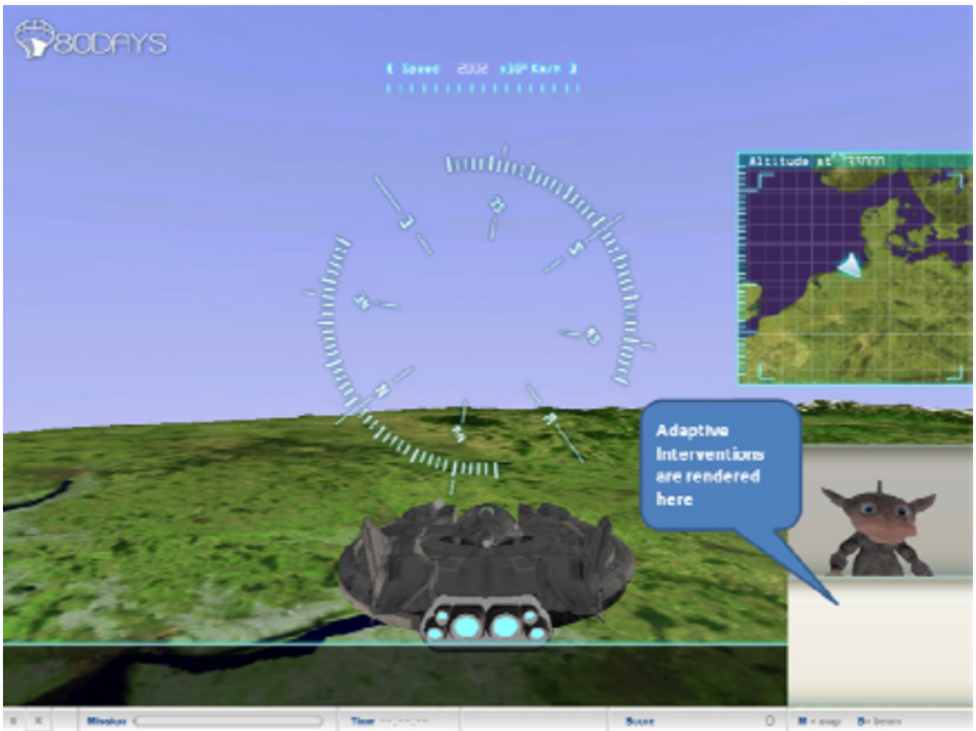

Figure 130. The 80Days game (Koidl, Mehm, Hampson, Conlan, & Göbel, 2010)

The 80Days project is a European Commission funded FP7 project and is the successor project to the ELEKTRA project. The 80Days game is a personalised educational game focused on geography and environmental issues. The personalisation strategy within the game is to provide appropriate cognitive, meta-cognitive, and motivational guidance to the learner. The adaptations used to realise this personalisation are realised through text, NPC dialogues, and videos within the game (Koidl et al., 2010).

The reusability of the ALIGN system has been demonstrated across both diverse and similar games and in both cases can be easily modified to cater for varying requirements. The potential for the reuse of ALIGN with future games is considerable as it has been demonstrated to cater for varying inference techniques and adaptation strategies, varying game engines, and vary deployment platforms.

7.4 Comparison with existing Adaptive Educational Games

The completion of the second experiment involving ALIGN has further refined the system to effectively personalise educational video games. In consideration of this the combination of ALIGN and Language Trap represents a viable personalised educational game and it is apt to compare it to existing Adaptive Educational Games.

From a game design perspective the Language Trap game compares favourably with existing games and it achieves the following:

- Tightly integrated learning content and gameplay
- The use of high level learning objectives such as problem solving.
- Suitably matched game genre for both the learning content and the learning objectives
- A thematic narrative and style suited to the audience due to the use of participatory design
- The use of personalised challenge to aid in creating a flow experience
- The use of narrative and sociality with game NPCs to foster engagement

In considering ALIGN and Language Trap as a whole, it not only provides for non-invasive personalised learning it also has the added benefit of this personalisation being reusable across multiple games. Whereas these features are found independently within contemporary AEGs their combination is somewhat unique as is evident in Table 28 below where a comparison is drawn with existing AEGs.

Table 28. Comparison between ALIGN & Language Trap and existing AEGs

	Pedagogical Approach	**Game Genre**	**Game Origin**	**Personalisation Technology**	**Learning Content Topics**
ALIGN + Language Trap	Experiential Learning, Situated Cognition	Isometric style, role-playing adventure	Academic research	Non-invasive micro-adaptive, rule based, statistical modelling, loosely coupled	German language learning
<e-adventure>	Game dependent, constructivist	2D point and click adventure	Academic research/ instructor authored	Macro-adaptive, learner model checking, loosely coupled	Various
Façade	Experiential learning	Role playing	Academic research	Micro-adaptive, interactive narrative, rule based	Interaction in social relationships
Prime Climb	Problem based learning	Puzzle	Academic research	Micro-adaptive, probabilistic modelling	Mathematics factorization
TLCTS	Problem based learning	Role playing	Academic research	Micro-adaptive, autonomous agent, implicit statistical modelling	Language learning, cultural awareness
VTC	Problem based learning	Unspecified story driven genre	Academic research	Macro-adaptive, graph based narratives	Social skills, project management
Ecotoons2	Unspecified constructivist learning	Puzzle, varying mini-games	Academic research	Macro-adaptive, rule-based	Mathematical reasoning
VR-ENGAGE/ VIRGE	Behaviourist conditioning, problem based learning	3D adventure	Academic research	Micro-adaptive, overlay modelling, inference rules, loosely coupled	Geography/ English
ELG	Dependent on authored game	2D Puzzle	Teacher authored	Macro-adaptive, rule based	Mathematics, nutrition, archaeology
S.M.I.L.E.	Problem based/ discovery learning	Role playing/ virtual world adventure	Teacher authored	Macro and micro-adaptive, statistical modelling	Mathematics, biology, chemistry
NUCLEO	Problem based learning, CSCL	Role playing	Academic research	Macro-adaptive, rule based	Computer programming
SCRUB	Experiential learning	Varies depending on the learner	Academic research	Macro-adaptive	Microbiology

7.5 Summary

In this chapter the second evaluation of ALIGN was discussed. The focus of this chapter was to evaluate ALIGN in terms of its non-invasive personalisation and reusability across varying educational games. The Language Trap game that formed the second game to be integrated with ALIGN was evaluated using authentic user trials conducted in five secondary schools in the vicinity of Dublin. The students involved in the trials were selected due to the relevance to them of the game's design and learning content. The game also presented a useful learning tool that was in line with the students' curriculum and so had tangible learning benefits to them.

The user trials conducted aimed to evaluate the game design of Language Trap and its ultimate suitability as a trial platform for ALIGN. The ability of ALIGN to provide a variety of adaptations to an alternate game, and to evaluate the non-invasive nature of the adaptations performed was considered. The design of the Language Trap game was favourably received and it proved to be an effective learning tool based on the pre and post tests. The ability of ALIGN to further deliver a variety of adaptations that were selected through non-invasive personalisation was supported by the user trial results. Despite the variety of factors that were considered in determining non-invasiveness the results obtained strongly support ALIGN's ability to deliver personalisation to educational games in a non-invasive manner.

The combination of ALIGN and Language Trap represents a complete personalised educational game and as such for completeness it was compared to existing adaptive educational games. The game compared favourably in terms of its game design and also in its combination of loosely coupled non-invasive personalisation, both features which are rare amongst contemporary systems.

The final section of this chapter addressed the reusability of the ALIGN in light of varying games, personalisation strategies, and learning content. Through the integration of ALIGN with a second disparate game in the form of Language Trap, there is strong evidence to support the reusability of ALIGN. Further to this the use of ALIGN with an Irish version of the Language Trap game and its role in the 80Days project support the flexible approach that ALIGN takes to personalisation.

8 Reflection - Conclusions and Future Work

8.1 Introduction

This thesis has presented research conducted into the *non-invasive personalisation of educational video games*. This innovative approach to combining personalised learning with educational video games has realised a methodological and practical approach to creating personalised educational video games. Through the development of the novel four-stage approach to non-invasive personalisation this research has facilitated the realisation of effective personalised learning whilst maintaining the intrinsically rewarding nature of video games.

The purpose of this chapter is to discuss how the goals and objectives of this thesis have been achieved. In addition to this, the contributions of the research undertaken to the State of the Art are highlighted. The chapter concludes with a discussion on the future work associated with this research including aspects of interest for further study, and possible future directions for research in this field.

8.2 Objectives and Achievements

The research question posed in this thesis is *what are the benefits – with respect to the learning experience, the ease of reuse, and the independent authoring of games and personalisation systems – of a non-invasive approach to loosely coupling video games and adaptive systems?*

The following four objectives were defined based on the above research question covering three distinct areas.

1) To research and identify strategies that can effectively combine educational games and adaptive instructional systems

2) To develop a flexible game agnostic personalisation software system that can non-invasively adapt the educational experience within an educational video game.

3) To develop contrasting educational video games that can be integrated with the developed personalisation system in order to enable a real world evaluation of the software system.

4) To evaluate the ability of the developed system to provide non-invasive personalisation that benefits the learning experience, facilitates the independent authoring of games and personalisation systems, and eases the reuse of these systems across multiple educational games.

In addressing objective 1 "*To research and identify strategies that can effectively combine educational games and adaptive instructional systems*" the state of the art review conducted into both educational video games and adaptive instructional systems was the predominant part of this research that achieved this objective.

Due to the emergent nature of adaptive educational video games as a research area the state of the art review focused on the separate areas of educational video games, and adaptive instructional systems. In considering the state of the art in educational video games the review started with the pedagogical affordances of video games as well as the strategies and theories currently being employed. This review was followed by an investigation into the approaches being used to design effective and engaging educational games and identified the significance of challenge and flow, sociality, narrative and game context as significant elements of effective design. These elements accordingly strongly influenced the design of the ALIGN system in terms of both the personalisations it provided, such as adaptive challenge, and in the manner it aimed to maintain plausible game narrative and social interactions. The challenge of integrating learning content within games was highlighted by the review and directly influenced the designs of both the ELEKTRA and Language Trap games. In particular the game genres used were so chosen to be appropriate to the learning content as well as having equal appeal across male and female players.

The state of the art review in adaptive instructional systems charted the progression of personalised learning environments through both the pedagogical strategies applied, and the medium in which the adaptation was being performed. This review highlighted the key areas of personalisation including user modelling, and the adaptation technologies used.

In addressing objective two "*To develop a flexible game agnostic personalisation software system that can non-invasively adapt the educational experience within an educational video game.*", the ALIGN system was designed based on the influences from the state of the art research and implemented in a flexible and reusable manner. As a key aim of the design it was desirable for ALIGN to be logically separate from the games it adapts in order to facilitate its reuse across multiple games and to facilitate the independent authoring of the game and the personalisation. In addition to this separation the desire for non-invasive personalisation required that an understanding of the game and the learner be considered in the design. In addressing this objective the novel four-stage approach to non-invasive personalisation was designed that effectively addressed both of these issues. Through the four stages of inference, context accumulation, adaptation constraint, and adaptation selection, the ALIGN system was designed to deliver non-invasive personalisation across diverse educational games. The design decision to encode the personalisation logic in an abstract manner enabled both the reuse of personalisation logic as it is not tied to a specific educational game, and the independent authoring of the game and the personalisation logic. Through the use of inference rules and statistical modelling it is possible to non-invasively model the learner through implicit evidence. Further to this the inference abstracts the learner evidence so that personalisation can be provided without reference to game specifics, allowing it to be used across a variety of games. This approach to providing personalisation in a generic manner that is abstracted away from game specifics requires greater complexity of inference techniques yet enables the reuse, independent authoring, and loose coupling of games and the personalisation that adapts them.

The implementation of the ALIGN system realised the four-stage approach and presented a scalable and reusable solution to providing non-invasive personalisation. Through the choice of implementation platform, inference techniques, and technological approach the ALIGN system further realised this second objective through its high-performance and flexible implementation. The reusability of the system was demonstrated through its integration with the diverse ELEKTRA and Language Trap games that addressed varying game styles, personalisation, learning content, and target audience.

In addressing objective three *"To develop contrasting educational video games that can be integrated with the developed personalisation system in order to enable a real world evaluation of the software system.",* the ELEKTRA and Language Trap games were developed and integrated with the ALIGN system. With the ELEKTRA game an immersive 3D adventure game was developed as part of the ELEKTRA project (ELEKTRA Project, n.d.) and focused on illustrating concepts relating to the optics of physics. Through the use of tightly integrated learning content, experiment based problem solving, and an engaging storyline the game engaged learners in the 13-15 year age group. Importantly the game was evaluated in a real world scenario with appropriate learners where the learning content was relevant to their curriculum and the game design was engaging and interesting.

As a contrasting game to be integrated with ALIGN, the Language Trap game was developed to challenge the assumptions made in the design of ALIGN and to ensure that it could be integrated with varying game styles, personalisation, platforms, and learning content. The Language Trap game accordingly focused on the soft-skill learning content of conversational German language. Through its design as a casual game played online with an isometric style the Language Trap game differs considerably from the ELEKTRA game yet was effectively integrated with, and personalised by, the ALIGN system. The design of the game took influence both from best practices in educational game design and the learners who would ultimately use the game. Through the use of participatory design the resultant game was effective, curriculum relevant, and stylistically appropriate for the learners used to evaluate the game. The diverse nature of games integrated with ALIGN as well as their real world relevance to the learners involved strongly supports the fulfilment of this objective.

Despite the contrasting nature of the ELEKTRA and Language Trap games it should be noted that both games are effectively of the same genre, that of adventure/role-playing. Although this genre was chosen for its aptness for the learning content and learning objectives it none the less limits the achievement of this third objective to this genre, and the ability of ALIGN to personalise games has thus been demonstrated solely within this genre. However, in consideration that this genre is typically narrative driven and highly social, ALIGN has shown effectiveness in arguably one of the more challenging genres in comparison to the puzzle, action, or reflex game genres.

The fourth and final objective of this thesis was *"To evaluate the ability of the developed system to provide non-invasive personalisation that benefits the learning experience, facilitates the independent authoring of games and personalisation systems, and eases the reuse of these systems across multiple educational games."* In addressing this objective there was an initial need to evaluate if the design decision to separate the game and personalisation was justified in terms of its feasibility. The examination of log files resulting from the two experiments showed that ALIGN technically realised a variety of adaptations to both games in a timely manner. This demonstrated the technical feasibility of the personalisation. Through further examining the effectiveness and variety of the personalisation provided to both the ELEKTRA and Language Trap games it was shown that this separation was also feasible from an effectiveness point of view. The achievement of personalised challenge, cognitive feedback, meta-cognitive feedback, and motivational support across these contrasting games justified the viability of logical and physical separation.

Once this diverse and effective personalisation was being achieved it was necessary to consider to what extent this personalisation was non-invasive to the gaming experience. Following on from the ELEKTRA experiment the evaluation of non-invasiveness was the predominant focus of the Language Trap experiment. The evaluation of non-invasive personalisation was considered from two perspectives, that of non-invasive learner modelling, and non-invasive adaptation. The use of inference rules and statistical modelling was shown to effectively model the learner based on implicit evidence from the learner. Although the accuracy of statistical modelling did not correlate highly with the learner's abilities it none the less demonstrated how ALIGN can flexibly accommodate a variety of learner modelling techniques. The ability of ALIGN to provide non-invasive adaptations was evaluated quantitatively through the timeliness of the adaptations, and qualitatively through plausible game character actions and overall flow experience. In both of these evaluations it was shown that ALIGN can deliver both non-invasive modelling and adaptations and so strongly supported the ability of ALIGN to provide non-invasive personalisation.

Despite the design of both the ELEKTRA and Language Trap games around best practice in educational game design it must be considered that the author will have influenced their design to favourably work with ALIGN. This bias evidently must be considered when determining the reusability of ALIGN as these games do not represent typical educational games. Additionally, despite the educational appropriateness of using adventure/roleplaying style games for the learning content covered, it must be considered that the reusability of ALIGN has ultimately only been demonstrated across this style of game. Whereas this gaming style was not intentionally the sole focus of ALIGN it is circumstantially the basis for its evaluation. In light of this, the reusability of ALIGN must be considered within this context of limited game styles.

As a final consideration in fulfilling this fourth objective a formative assessment of reusability was considered. Across the contrasting ELEKTRA and Language Trap games it was shown how ALIGN could be reused with minor technical changes. Although the varied nature of the two games required separate inference rules, personalisation rules, and Adaptive Elements this was an expected challenge to the reusability of ALIGN. However, the verbatim reuse of adaptation constraint rules was encouraging. Further to this it was shown that with the Language Trap game the learning content and storyline of the game could be changed without any need to modify ALIGN's rules. This verbatim reuse is testament to how ALIGN uses abstract personalisation logic and a logical separation to ease reuse across varying games as well as enabling the independent authoring of games and the personalisation rules that adapts them.

8.3 Contributions to the State of the Art

The primary contribution of this research to the state of the art is the four-stage approach to non-invasive personalisation. This approach as embodied in the ALIGN system, allows for the logical and physical separation of the game and its personalisation logic. The abstraction of personalisation that this approach advocates allowing a game to be loosely coupled with personalisation and in doing so both enables the reuse of the personalisation across diverse games and also the independent authoring of the game and the personalisation logic. The benefits of this approach were demonstrated with both the ELEKTRA and Language Trap games in chapters five and seven respectively. The delivery of non-invasive personalisation acknowledges the importance of maintaining fun and engagement in educational games. Whereas a personalised learning experience can result in faster skill acquisition, appropriate feedback and improved meta-cognitive skills, the effective combination of this with game based learning can present an intrinsically motivating experience. It is envisaged that this approach will contribute towards the greater use of personalisation within educational games due to its reusability. Further to this the personalisation provided by the system is non-invasive and so promotes the development of engaging and fun personalised educational games.

The research conducted for thesis has directly contributed to the State of the Art through the following six publications in books, conferences, and workshops. The significance of these publications is reflected in the achievement of one award for best full conference paper (Peirce, Conlan, & Wade, 2008) and a conference paper chosen as only one of eleven papers included in the book 'Leading Issues in Games-Based Learning Research' (Peirce & Wade, 2011).

- **Peirce, N**., & Wade, V. (2010). Personalised Learning for Casual Games : The ' Language Trap ' Online Language Learning Game. *European Conference on Game Based Learning (ECGBL 2010)*. Copenhagen, Denmark.
    - This paper was additionally one of 11 papers selected for publication in: *Leading Issues in Games-Based Learning Research*, edited by Thomas Connolly, 159-177. Reading, UK: Academic Publishing International Ltd, 2011.

- Conlan, O., Hampson, C., **Peirce, N.**, & Kickmeier-Rust, M. (2009). Realtime Knowledge Space Skill Assessment for Personalized Digital Educational Games. *2009 Ninth IEEE International Conference on Advanced Learning Technologies* (pp. 538–542). Riga, Latvia: IEEE. doi:10.1109/ICALT.2009.150

- **Peirce, N.,** Conlan, O., & Wade, V. (2008). Adaptive Educational Games: Providing Non-invasive Personalised Learning Experiences. *Digital Games and Intelligent Toys Based Education, 2008 Second IEEE International Conference on* (pp. 28–35). doi:10.1109/DIGITEL.2008.30
  [Awarded Best Full Paper]

- Albert, D., Hockemeyer, C., Kickmeier-Rust, M. D., **Peirce, N.,** & Conlan, O. (2007). Microadaptivity within Complex Learning Situations – a Personalized Approach based on Competence Structures and Problem Spaces. *Proceedings of the International Conference on Computers in Education (ICCE 2007).*

- Kickmeier-Rust, M., **Peirce, N.**, Conlan, O., Schwarz, D., Verpoorten, D., & Albert, D. (2007). Immersive Digital Games: The Interfaces for Next-Generation E-Learning? *Universal Access in Human-Computer Interaction. Applications and Services* (Vol. 4556, pp. 647–656). Springer Berlin / Heidelberg. doi:10.1007/978-3-540-73283-9_71

8.4 Future Work

Through the state of the art review conducted within this thesis, and the design and evaluation of the ALIGN system, three areas were identified for future research into personalised educational video games. These areas are highlighted below and include the further exploration of user modelling within personalised games, the further evaluation of the effects of personalisation, and the potential for personalisation within multi-player and collaborative learning games.

8.4.1 Learner Modelling

As a core component of any personalised system, learner modelling has been shown to be a key element in personalising educational video games. The approach taken to learner modelling within the ALIGN system allowed for flexible approach to user modelling that catered for a variety of inference techniques. As varying educational games require varying approaches to inference, as was seen with ELEKTRA and Language Trap, there is evident benefit for ALIGN to support further inference technologies. The use of Dynamic Bayesian Networks (Conati, 2002; Conati et al., 2002) is emerging as a significant technology in personalised educational games and would be a powerful inference component to be added to the ALIGN system. The use of Bayesian networks for both prediction and classification over diverse learner evidence is a desirable feature. In particular its usage in estimating learner ability is an area of future work on the ALIGN system. However, the use of Bayesian networks is not without its pitfalls and presents challenges in how the networks are initialised with reasonable starting values, and in their computational complexity.

The use of Bayesian networks for inference highlights the emerging concern of balancing user modelling accuracy with the timeliness of adaptations. Although improved user modelling is evidently beneficial, where this comes at a cost to the invasiveness (due to adaptation delays) its use must be carefully considered. A cost-benefit analysis of adaptation sophistication versus learning benefit is a significant aspect of future work in this research area. The work of (Augustin, Hockemeyer, Kickmeier-Rust, & Albert, 2011) in optimising CbKST for game based learning is a clear recognition of this emerging research problem.

The diversity of learner evidence available from educational games is a further consideration for future work, in particular the significance of game related actions undertaken within the game world.

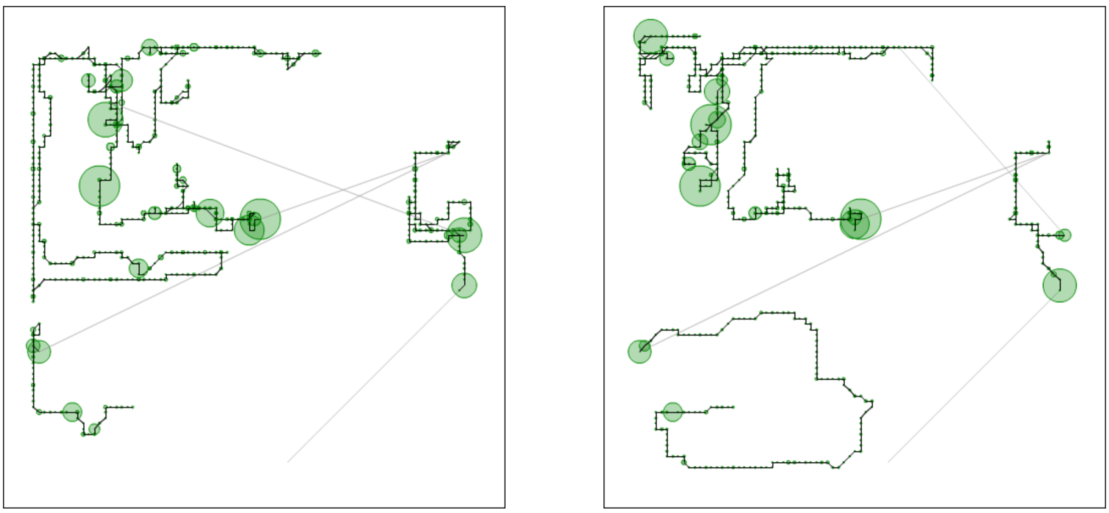

Figure 131. Visualisations of two players' movements and pauses

As the Language Trap game provided detailed logs of each learner's actions it is possible to objectively observe the different gaming experiences the learners had. These differences are apparent when visualised as is shown above in Figure 131 for two different game play sessions in the Language Trap game. In the above visualisations the learners' movements are traced and pauses associated with NPC conversations are shown as green circles. The greater the area of the green circles the longer the learner paused to have a conversation.

Although the significance of the different paths and experiences encountered is not yet known it is conceivable that the real-time analysis of this data could yield valuable evidence that can contribute to a more holistic user model. In particular deviations from average user behaviour could be a significant factor in providing adaptations. The determination of what common or average behaviour may look like is shown below in Figure 132 whereby a composite of all the Language Trap log files is shown alongside the game map. The darker lines indicate the most commonly traversed paths in the game.

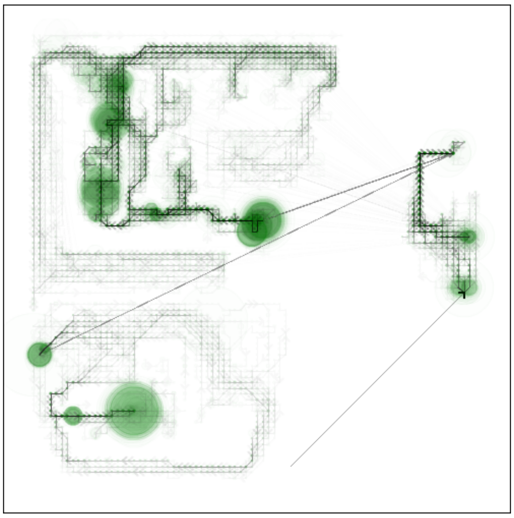

Figure 132. Composite of all player movements (left) and the Language Trap game map (right)

The final element of future work in the area of user modelling is in the persistence and exchange of user models. As was evident it the evaluation of the Language Trap game, the ability of ALIGN to infer a learner's ability improved with time. Evidently the use of persistent user models would avoid this cold start problem from personalised games that require multiple play sessions. Further to this the exchange of user models with educational games or Learning Management Systems would allow the personalisation to be bootstrapped to the learner's ability from the offset. This would present the learner with a personalised learning experience more tailored to them consistently from the start of a game.

8.4.2 Further studies on the effects of personalisation within games

Although the benefits of personalisation have largely focused on improved knowledge acquisition and speed to competency, there is increasing evidence that the benefits of personalised games extend beyond skill and knowledge acquisition. The early work of (Malone & Lepper, 1987) identified the impact personalised games could have on motivation and self-confidence and is a precursor to the holistic effects games can have on learning. Amongst the further learning benefits of personalised games there may be increased engagement both with the game's learning content and in subsequent formal education, attitudinal changes to learning content, and improved meta-cognitive skills. In consideration of the challenges faced in integrating knowledge based content into games it is conceivable that knowledge acquisition may not be the natural benefit of game based learning and it is an aspect that should be duly considered in future game based learning research.

8.4.3 Personalisation within collaborative learning games

The growing prevalence of online gaming is resulting in learners who are increasingly accustomed to engaging with multiplayer, collaborative and social games for entertainment. In line with this there is a growing desire for educational games that similarly offer rewarding experiences through peer interaction. This style of game presents interesting challenges for personalisation as any adaptation will not solely affect one individual learner. The potential for learning games that are personalised to individuals yet also adaptive to player groups would present a paradigm shift in immersive eLearning. Such games pose considerable research challenges and present a viable basis for future work in personalised game based learning.

8.4.4 Final Remarks

This thesis has presented a novel and significant contribution to game based learning and eLearning in general. Although the emerging research area of personalised educational games has numerous challenges it is also progressive and has self-evident benefits to learning. The diverse approaches being taken are evidence of both a growing and broadly scoped research area. In line with a changing gaming industry that is refocusing on casual, social and increasingly mobile games, the potential for innovative research in personalised game based learning has never been greater.

The ALIGN system presented in this thesis presents both a progressive and effective approach that is reusable across diverse games. This effectiveness and flexibility leaves this research area poised to cater for the ever diversifying gaming landscape, a significant step closer to the next generation of educational games wherein personalisation is a commonplace feature.

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Appendices

Appendix A – ALIGN Technical Details

Game Constraint and Appropriateness Rules

Game Constraint Rules

```
// Enable elements that are dependent on a certain dialogue being
// on going
rule "Enable Task Dependent Adaptive Elements"
salience 10000
no-loop
    when
        TaskEvent(id == "dialog", eventType == Task.TASK_START,
                  $cause:cause)
        $s:SubTaskElementEvent(self == $cause, $charId:charId)
        element:AdaptiveElement(environmentEnabled == false,
                                taskRequirements contains $charId)
    then
        element.setEnvironmentEnabled(true);
        logger.debug("Enabling environment for adaptive element: "
                     +element.getId());
        update(element);
end
```

```
rule "Disable Task Dependent Adaptive Elements"
salience 10000
no-loop
    when
        TaskEvent(id == "dialog", eventType == Task.TASK_START,
                  $cause:cause)
        $s:SubTaskElementEvent(self == $cause, $charId:charId)
        (or element: AdaptiveElement($elemId:id,
                                     environmentEnabled == true,
                                     numTaskRequirements > 0,
                                     taskRequirements excludes $charId)
            element: AdaptiveElement($elemId:id,
                                     environmentEnabled == true,
                                     taskExclusions contains $charId))
    then
        element.setEnvironmentEnabled(false);
        logger.debug("Disabling environment for adaptive element: "
                     +element.getId());
        update(element);
end
```

Appropriateness Rules

```
/* When a recommendation used event is received update the
corresponding adaptive element to indicate this */
rule "update Adaptive Elements after use"
salience 10000
no-loop
    when
         $rec:Recommendation($recId:id, $recTime:timeStamp)
        $element:AdaptiveElement(id == $recId, timeStamp < $recTime)
        $outcome:AdaptiveElementOutcome($outcomeId:id,
```

```
                                $adptElem:adaptiveElement == $element)
    then
        $element.updateTimeStamp();
        update($element);
        update($outcome);
end
```

```
/* Disable the more recently used Adaptive Element(s) */
rule "Round robin disable"
salience 1000
agenda-group "adpt_elem_phase1"
auto-focus
no-loop
    when
        $element:AdaptiveElement(strategyEnabled == true,
                        environmentEnabled == true,
                        $elemTime:timeStamp)
        $outcome:AdaptiveElementOutcome($outcomeId:id,
                        $outcomeValue:value,
                        $adptElem:adaptiveElement == $element)
        $element2:AdaptiveElement(strategyEnabled == true,
                        environmentEnabled == true,
                        timeStamp < $elemTime)
        $outcome2:AdaptiveElementOutcome(id == $outcomeId,
                        value == $outcomeValue,
                        $adptElem2:adaptiveElement == $element2)
    then
        $element.setStrategyEnabled(false);
        logger.debug("Disabling element(strategy): "+$element.getId());
        update($element);
        update($outcome); // Update the outcome as well
end
```

```
/* If a used element is enabled, and there exists disabled less recently
used element then swap their enabled states */
rule "Round robin enable"
salience 999
agenda-group "adpt_elem_phase2"
auto-focus
//no-loop // Important to let this loop so that it leaves
// only the oldest element enabled
    when
        $element:AdaptiveElement(strategyEnabled == true,
                        environmentEnabled == true, $elemTime:timeStamp)
        $outcome:AdaptiveElementOutcome($outcomeId:id,
                        $outcomeValue:value,
                        $adptElem:adaptiveElement == $element)
        $element2:AdaptiveElement(strategyEnabled == false,
                        environmentEnabled == true,
                        $elemTime2:timeStamp < $elemTime)
        $outcome2:AdaptiveElementOutcome(id == $outcomeId,
                        value == $outcomeValue,
                        $adptElem2:adaptiveElement == $element2)
    then
        $element.setStrategyEnabled(false);
        $element2.setStrategyEnabled(true);
        logger.debug("Enabling element(strategy): "+$element2.getId()
                        +", Disabling: "+$element.getId());
        update($outcome);
        update($element);
        update($outcome2);
        update($element2);
end
```

Example Inference Rules

ELEKTRA

The inference of confidence and prudence values requires the matching of a task attempt with the certitude degree given by the learner for that task. Based on the certitude degree (the prediction) and the actual experiment result values for confidence and prudence can be calculated as is detailed in Table 29 below. Both certitude and result are in the range 0-100. The results of the inference are two *GenericFacts* that contain the sum of all chosen correct confidence degrees and incorrect confidence degrees.

Table 29. ELEKTRA calculation of confidence and prudence

	Prediction (P)			
Result (R)	< 50		> 50	
< 50	***Prudence***	Increase $CCD = \sqrt{(R-P)^2}$	***Confidence***	Decrease $CCD = R$
> 50		Decrease $CCD = R$		Increase $CCD = 100 - \sqrt{(R-P)^2}$

(CCD = Chosen Confidence Degree)

```
rule "calc ccd and sumY and sumN"
ruleflow-group "confidence_prudence"
activation-group "use sum"
no-loop
      when
            SubTaskElementEvent(taskId:identifier, $params:parameters,

      theTime:timeStamp)
            conf: ConfidenceDegree( identifier == taskId,

      $confTime:timeStamp < theTime, prediction:value)
            not ConfidenceDegree( identifier == taskId,
                                  timeStamp > $confTime)
            correctSum:GenericFact(identifier == "CCD_CORRECT_SUM")
            incorrectSum:GenericFact(identifier == "CCD_INCORRECT_SUM")
      then
            int intResult = ruleInterface.getIntParam("RESULT",$params);
            int newCCD = intResult;
            if(prediction > 50){
                  if(intResult >= 50){
                        newCCD = 100 - Math.abs(intResult-prediction);
                  }
                  correctSum.setIntValue(correctSum.getIntValue()+1);
                  correctSum.setDoubleValue(correctSum.getDoubleValue()
                                                  +newCCD);
                  update(correctSum);
            }else{
                  if(intResult < 50){
                        newCCD = Math.abs(intResult-prediction);
                  }
```

```
                incorrectSum.setIntValue(incorrectSum.getIntValue()+1);
            incorrectSum.setDoubleValue(incorrectSum.getDoubleValue()
                                        +newCCD);
                update(incorrectSum);
            }
end
```

The following rule illustrates the inference needed to map a setup of the ELEKTRA slope device with a solid iron marble to the particular required and missing skills for use in the CbKST calculation.

```
rule "Solid Iron PosCat"
ruleflow-group "affective_feedback"
salience 50
      when
            SubTaskElement($id:identifier == "LU1_SET1_w2_LT1",
                                                $params:parameters)
      then
            double magnet0Min = 78.0; // Without fan
            double magnet0Max = 80.0;
            double magnet100Min = 74.0; // With fan
            double magnet100Max = 76.0;

            double delta = magnet0Max - magnet0Min;
            double fan = ruleInterface.getDoubleParam("FAN",$params);
            double magnet = ruleInterface.getDoubleParam("MAGNET",
                                                            $params);

            double minDiff = fan/(100.0*(magnet100Min - magnet0Min));
            double maxDiff = fan/(100.0*(magnet100Max - magnet0Max));

            // Select the appropriate required and missing skills for the
action
            if((magnet0Min + minDiff <= magnet)
                        && (magnet <= magnet0Max + maxDiff)){
                  insert(new PosCatSkills($id,
                        new String[]{"p04","g07"}, new String[]{}));
            }else if(((magnet0Min + minDiff - delta <= magnet)
                        && (magnet < magnet0Min + minDiff))
                        ||
                        ((magnet0Max + maxDiff < magnet)
                        && (magnet <= magnet0Max + maxDiff + delta))){
                   insert(new PosCatSkills($id,
                        new String[]{"g10","g07"}, new String[]{}));
            }else if (magnet < magnet0Min + minDiff - delta){
                   insert(new PosCatSkills($id,
                        new String[]{"g07"}, new String[]{"p04"}));
            }else if (magnet > magnet0Max + maxDiff + delta){
                   insert(new PosCatSkills($id,
                        new String[]{"g07"}, new String[]{"p04"}));
            }else{
                  //ruleInterface.sendDebugMessage("[No PosCat Skills]");
            }
end
```

Language Trap

The following inference rules map show how particular *SubTaskElementEvents* are mapped to task success, failures, starts, and ends. The inference of feedback preference amount is also determined based on particular *SubTaskElementEvents*. The final rule below updates the estimated dialog difficulty that the learner is capable of addressing based on the advanced linear model.

```
rule "task success"
salience 10
activation-group "success or failure"
      when
            $s:SubTaskElementEvent(id == "dialog_choosen",
                                    lang == "de", correct == true)
      then
            insert(new TaskEvent("dialog",Task.TASK_SUCCESS,$s));
end
```

```
rule "task failure"
salience 10
activation-group "success or failure"
      when
            $s:SubTaskElementEvent(id == "dialog_choosen",
                                    lang == "de", correct == false)
      then
            insert(new TaskEvent("dialog",Task.TASK_FAILURE,$s));
end
```

```
rule "add task start"
salience 1000
      when
            $s:SubTaskElementEvent(id == "dialog_request",
                              initial == "true",
                              charId in ("german_guest","german_guest2"
                                    "german_guest3","double_agent",
                                    "german_waiter"),
                              $t:time)
      then
            insert(new TaskEvent("dialog", Task.TASK_START, $s));
end
```

```
rule "add task end"
      when
            $s:SubTaskElementEvent(id == "dialog_choosen", lang == "de",
                                    nextDialog == "", $t:time)
      then
            insert(new TaskEvent("dialog", Task.TASK_END, $s));
end
```

```
rule "inference desired feedback amount"
      when
            $s:SubTaskElementEvent(id == "dialog_choosen",
                              charId == "companion",
                              oldDialog == "Dialog8", $cid:choosenId)
      then
            insert(new GenericFact("feedback_preference",
                                    Integer.parseInt($cid), 0, null));
end
```

```
rule "update dialog difficulty advanced"
no-loop
   when
      $te:TaskEvent(id == "dialog",
         eventType in (Task.TASK_FAILURE, Task.TASK_SUCCESS),
```

```
        $t:time, $c:cause )
      $difficulty:GenericFact(id == "dialog_difficulty",
                              $oldDifficulty:doubleValue, time < $t)
      Option(id == "adaptation", parameter == "advanced")
   then
     SubTaskElementEvent ste = (SubTaskElementEvent)$c;
     // Only consider dialogues with a rating greater than 0
     if(ste.getRating() > 0){
        // Note on "agressiveness" Higher values cause the adaptation
        // to very closely follow choosen ratings
        // Lower values have a dampening effect causing slower adaptation
        // but reducing the impact of choosing inappropriate dialogs
         double agressiveness = 0.3;

         double optimalFactor = calcRating($te, logger);

         double change = 0.0;
         if(optimalFactor >= 0){
            change = (ste.getRating() - $oldDifficulty)
                          * optimalFactor * agressiveness;
         }else{
            change = -1 * agressiveness;
         }
         double difficulty = $oldDifficulty + change;
         // Ensure appropriate difficulty range
         difficulty = Math.min(Math.max(difficulty, 1.0), 5.0);

         $difficulty.setIntValue((int)Math.round(difficulty));
         $difficulty.setDoubleValue(difficulty);
         update($difficulty);
      }
end
```

Example Personalisation Rules

ELEKTRA

```
rule "update confidence degree"
ruleflow-group "confidence_prudence"
activation-group "use sum"
salience 100
   when
      correctSum:GenericFact(identifier == "CCD_CORRECT_SUM",
intValue > 1);
   then
      int newConf = (int)Math.round(correctSum.getDoubleValue()
                                   /correctSum.getIntValue());
      ruleInterface.sendRecommendationFor("confidence", newConf, drools);
end
```

```
rule "LeS1.2.1 cognitive feedback1"
ruleflow-group "cognitive_feedback"
salience 100
   when
      SubTaskElementEvent(taskId:identifier == "LU1_SET1_w2_LT1",
                $params:parameters, theTime:timeStamp)
   then
      int intResult = ruleInterface.getIntParam("RESULT",$params);
      if(intResult >= 50){
```

```
         ruleInterface.sendRecommendationFor(
                              "cognitive_feedback_positive",0, drools);
      }else{
         ruleInterface.sendRecommendationFor(
                              "cognitive_feedback_negative",0, drools);
      }
end
```

```
rule "No Certitude after 5 seconds LU1_SET1_w2_LT"
duration 5000
   when
      Task(identifier == "LeS1.2.1", eventType == Task.TASK_START)
      (or SubTaskElement(theId:identifier == "LU1_SET1_w2_LT1_START",
                              theTime:timeStamp)
         SubTaskElement(theId:identifier == "LU1_SET1_w2_LT2_START",
                              theTime:timeStamp)
         SubTaskElement(theId:identifier == "LU1_SET1_w2_LT3_START",
                           theTime:timeStamp)
         SubTaskElement(theId:identifier == "LU1_SET1_w2_LT4_START",
                           theTime:timeStamp)
         SubTaskElement(theId:identifier == "LU1_SET1_w2_LT5_START",
                           theTime:timeStamp)
         SubTaskElement(theId:identifier == "LU1_SET1_w2_LT6_START",
                           theTime:timeStamp)
         SubTaskElement(theId:identifier == "LU1_SET1_w2_LT7_START",
                           theTime:timeStamp)
         SubTaskElement(theId:identifier == "LU1_SET1_w2_LT8_START",
                           theTime:timeStamp)
         )
      not (ConfidenceDegree( timeStamp > theTime))
   then
      ruleInterface.sendRecommendationFor("hint_5_sec",0, drools);
end
```

```
rule "Yoked affective feedback Rule1"
ruleflow-group "yoked_affective_feedback_meta_rules"
activation-group "metarules"
salience 11001
   when
      $posCat:PosCatSkills($id:identifier, $missing:missing,
                              $time:timeStamp)
      not PosCatSkills(timeStamp > $time)
   then
   NamedNodeMap params = (NamedNodeMap)ruleInterface.getReplayEvent($id);
      if(params != null){
         String skillHintType = params.getNamedItem("id").getNodeValue();

         boolean sendResult = ruleInterface.sendRecommendationFor(
                                             skillHintType, 0, drools);
         if(sendResult){
            ruleInterface.logMessage("<affective-hint id=\""
                              +skillHintType+"\" pos-cat-id=\""
                              +$id+"\" attempted=\"\" />");
         }else{
            // This shouldn't be possible
            ruleInterface.logMessage("<ai-hint-not-possible attempted=\""
                        +skillHintType+"\" pos-cat-id=\""+$id+"\" />");
         }
      }else{
         ruleInterface.logMessage("<ai-hint-not-possible attempted=\"\"
                                       pos-cat-id=\""+$id+"\" />");
      }
end
```

Language Trap

```
rule "recommend dialog difficulty"
      when
            GenericFact(id == "dialog_difficulty", $value:intValue)
      then
            ruleInterface.sendRecommendationFor("dialog_difficulty",
                                                $value, drools);
end
```

```
/*
Make each character give explicit performance feedback on failure (e.g.
emotion bubbles)
*/
rule "performance character feedback"
   when
      TaskEvent(id == "dialog", eventType == Task.TASK_FAILURE, $c:cause)
   then
      if($c instanceof SubTaskElementEvent){
         SubTaskElementEvent s = (SubTaskElementEvent)$c;
         String recType = "performance_negative_feedback_"+s.getCharId();
         ruleInterface.sendRecommendationFor(recType,0,drools);
      }
end
```

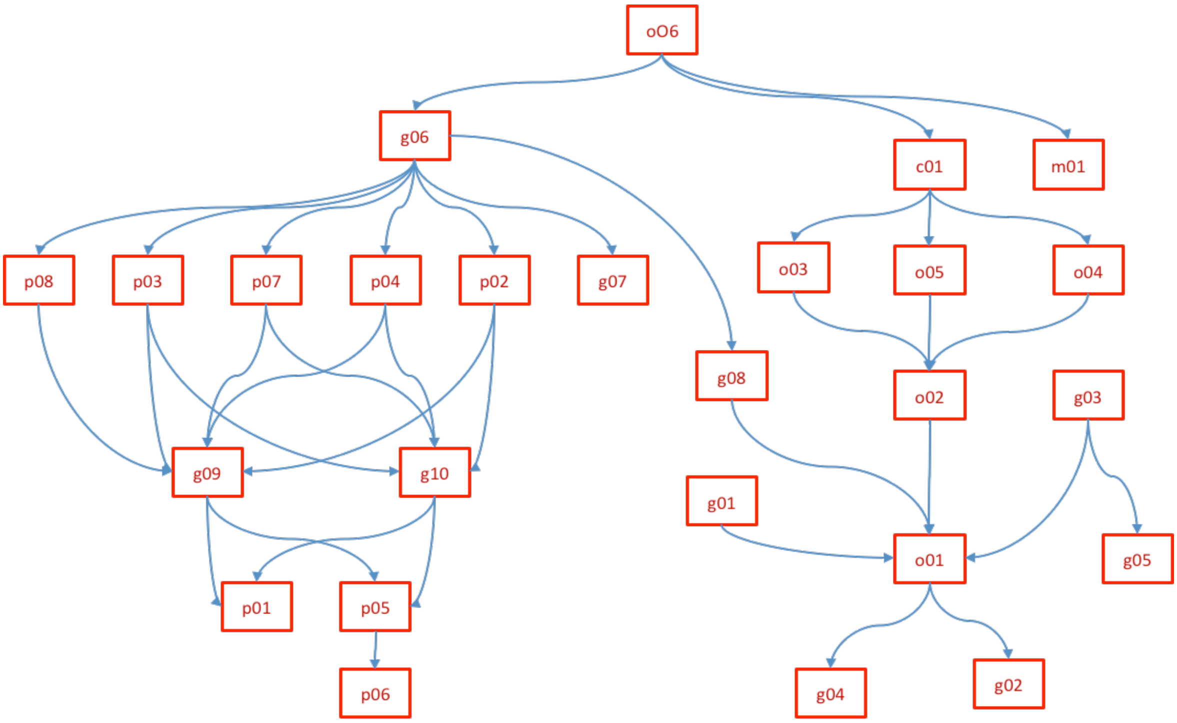
```
rule "performance feedback preference"
no-loop
   when
      GenericFact(id == "feedback_preference",
                     $preferenceValue:intValue, $t:time)
      GenericFact(id == "feedback_history",
                     $history:objectValue, time < $t)
      $fl:GenericFact(id == "feedback_level",
                     $feedbackLevel:intValue, time < $t)
   then
      LinkedList<Boolean> historyList = (LinkedList<Boolean>)$history;
      int newFeedbackLevel = 0;
      switch($preferenceValue){
      case 0:
         // Keep the current level of feedback
         newFeedbackLevel = $feedbackLevel;
      break;
      case 1:
         // Give less feedback
         newFeedbackLevel = Math.max(0,$feedbackLevel-1);
      break;
      case 2:
         // Give more frequent feedback
         newFeedbackLevel = Math.min(5,$feedbackLevel+1);
      break;
      }

      $fl.setIntValue(newFeedbackLevel);
      update($fl);
end
```

```
rule "performance feedback on failures"
no-loop
   when
      TaskEvent(id == "dialog", eventType == Task.TASK_END, $t:time)
      $tf:GenericFact(id == "task_failures", $numFailures:intValue,
                           $timeF:time < $t)
      $ts:GenericFact(id == "task_successes", $numSuccesses:intValue > 0,
                           $timeS:time < $t)
```

```
      $fh:GenericFact(id == "feedback_history", $history:objectValue,
                           time < $t);
      GenericFact(id == "feedback_level", $feedbackLevel:intValue);
   then
      LinkedList<Boolean> historyList = (LinkedList<Boolean>)$history;
      int listSize = historyList.size();
      Boolean giveFeedback = true;
      double feedbackPercent = 0.0;

      for(int i=0; i<listSize; i++){
         if(historyList.get(i)){
            feedbackPercent += 1.0;
         }
      }
      feedbackPercent = feedbackPercent/Math.max(1,listSize);

      // Possible Feedback levels
      // 4: MAX: Every possible time                  100%    1.0
      // 3: HIGH: 2 out of every 3 possible times         66%      0.666
      // 2: MEDIUM: 1 out of every 2 possible times      50%      0.5
      // 1: LOW: 1 out of every 3 possible times         33%      0.333
      // 0: VERY LOW: 1 out of every 4 possible times    25%    0.25
      switch($feedbackLevel){
         case 4:
            giveFeedback = (feedbackPercent < 1.0);
         break;
         case 3:
            giveFeedback = (feedbackPercent < 0.666);
         break;
         case 2:
            giveFeedback = (feedbackPercent < 0.5);
         break;
         case 1:
            giveFeedback = (feedbackPercent < 0.333);
         break;
         case 0:
            giveFeedback = (feedbackPercent < 0.25);
         break;
      }
   double successRatio = ((double)$numFailures)/((double)$numSuccesses);
      String desiredOutcome;

      if(successRatio > 0.3){
         desiredOutcome = "performance_very_bad";
      }else if(successRatio > 0.2){
         desiredOutcome ="performance_bad";
      }else if(successRatio > 0.1){
         desiredOutcome = "performance_medium";
      }else if(successRatio > 0.05){
         desiredOutcome = "performance_good";
      }else{
         desiredOutcome = "performance_very_good";
      }

      switch($numFailures){
         case 0:
            desiredOutcome = "performance_very_good";
         break;
         case 1:
            if(successRatio > 0.1){
               desiredOutcome = "performance_medium";
```

```
            }else if(successRatio > 0.05){
               desiredOutcome = "performance_good";
            }
         break;
         case 2:
            if(successRatio > 0.2){
               desiredOutcome ="performance_bad";
            }else if(successRatio > 0.1){
               desiredOutcome = "performance_medium";
            }else if(successRatio > 0.05){
               desiredOutcome = "performance_good";
            }
         break;
         default:
            if(successRatio > 0.3){
               desiredOutcome = "performance_very_bad";
            }else if(successRatio > 0.2){
               desiredOutcome ="performance_bad";
            }else if(successRatio > 0.1){
               desiredOutcome = "performance_medium";
            }else if(successRatio > 0.05){
               desiredOutcome = "performance_good";
            }
      }
      // Check if there is a suitable adaptiveElement available
      String availableRecommendation =
               ruleInterface.findRecommendation(desiredOutcome, 0);
      if(availableRecommendation != null){
         boolean result = false;
         if(giveFeedback){
            result = ruleInterface.sendRecommendationFor(desiredOutcome,
                                                               0,drools);
         }

         // Store the value of whether a feedback was given or not
         // The history is only stored when it is possible to send
         // a recommendation
         // Situations where it is desirable but not possible to send a
         // recommendation are ignored
         historyList.push(giveFeedback);

         if(listSize > 4){
            historyList.removeLast();
         }
         update($fh);
      }
end
```

ELEKTRA Skill Ontology



Nr.	Symbol	Abbreviation	Description
1	p06	Solid	Knowledge what a solid object is.
2	g02	Torch	Knowledge that a torch emits light.
3	g04	Spotlight	Knowledge that a spotlight emits light.
4	g05	Light sensor	Understanding of what a light sensor is.
5	p01	Gravity	Knowledge that gravity attracts all objects independent from their weight or material and makes them fall following a certain trajectory. Knowledge that gravity does not affect the propagation of light.
6	p05	Hollow	Knowledge what a hollow object is and that it is less heavy than a solid object.
7	o01	Light cone	Knowledge that light propagates in the form of a light cone.
8	g09	Fan	Knowledge that a Fan produces wind; the wind, in turn, may influence the trajectory of a falling object (countering gravity) depending on its weight and the fan's power.
9	g10	Magnet	Knowledge that a magnet attracts metals but no other materials; magnetic force may influence the trajectory of a falling metal object (countering gravity) depending on the magnetic power and the object's weight.
10	g08	Laser	Knowledge that a laser is a light source emitting a narrow beam of light instead of a light cone.
11	o02	Blind	Understand the mechanisms of a blind, i.e., to narrow a ray of light. This skill includes the knowledge that blinds must be ordered by a decreasing size of aperture (from the direction of the light source).
12	g01	Blind task / requ. light	Understand the task of LeS 1.3.1 (to narrow a light cone into a narrow beam of light) and understand that this task requires a light source.
13	g03	Door task / requ. light	Understand the task of LeS 1.3.3 (to open the door using a beam of light) and understand that this task requires a light source.

14	g07	Slope task	Understand the task of LeS 1.2.1 (making balls of different materials fall into a basket).
15	p02	Plastic_fan	Knowledge of what plastic is and that it is a light material, which can easily be influenced by wind.
16	p03	Wood_fan	Knowledge of what wood is and that it is medium heavy material, which can be influenced by wind.
17	p04	Iron_fan	Knowledge of what iron is and that it is a heavy material, which is little influenced by wind.
18	o03	Blind X	Understanding of the effects of moving a blind along the x axis (closer and farther from light source and screen).
19	o04	Blind Y	Understanding of the effects of moving a blind along the y axis (to the left and right in relation to light source and screen).
20	o05	Blind Z	Understanding of the effects of moving a blind along the z axis (up and down in relation to light source and screen).
21	m01	2D Model	Understand 2D representations of a situation. This knowledge includes understanding of different perspectives.
22	c01	Transfer	Being able to transfer the knowledge about blinds and the effects of manipulating blinds in the 3D space to another situation.
23	g06	Slope device	Being able to use the related knowledge to successfully operate the slope device (according to LeS 1.2.1).
24	o06	Straight prop. of light	Conscious understanding that light propagates in a straight line unaffected by gravity or other external forces such as magnetic force or wind. Knowledge about the blind concept and understanding of related 2D representations. Knowledge about the link between the straight and unaffected propagation of light and the blind concept.
25	p07	Stone_fan	Knowledge of what stone is and that it is a medium heavy material, which can be influenced by wind.
26	p08	Light_fan	Knowledge that the emission of light is not influenced by wind.

Appendix B – Extended Table of Game Design Aspects

	Challenge	**Context**	**Ownership, Control**	**User-centric**	**Environmental Support**	**Social**	**Uncertainty**
(Gee, 2005)	Progressive difficulty	Low risk of failure, relevance to overall system	Identity through character building	Co-design, customized gameplay	Movement and world interaction		
(Bartle, 1996)		World	Achievements	Players, socialising	Exploration	Interacting, Acting	
(Caillois, 2001)	Competition	Separate, unproductive (not work), make believe	Freedom		Simulation, Physical sensation		Uncertain, Chance
(Cowley et al., 2008)	Flow		Flow	Player Modelling	Game Structure		
(Thomas, Schott, & Kambouri, 2003)	Challenge & Mastery	Context		Adaptation		Community and collaboration	
(Pagulayan, Keeker, Wixon, Romero, & Fuller, 2002)	Different skill levels		Collection and completion	Interactivity	Narrative		
(Dickey, 2006a)	Character design & narrative		Character design, quest selection	User as the co-creator in the game	Narrative	Chat, collaborative quests	
(Kelly et al., 2007)			Creation of game characters	Users train agents within the game	Stylised but accurate simulations		
(Kiili & Lainema, 2008)	Flow theory and balancing challenge	Situated challenges			Importance of playability, ease of interaction		
(McGinnis et al., 2008)	Challenge, flow	Context, content clearly situated in overall learning material	Empowerment, control	user-centred design	structure	Social Identity	importance of interactive-feedback loop in coping with uncertainty
(Moreno-Ger et al., 2008)	Adaptation	Situated assessment		Adaptation			
(Pinelle, Wong, & Stach, 2008)				Customizable difficulty and speed	Intuitive and easy to use controls, predictable, repeatable		
(Rieber, 1996)	importance of Flow theory, progressive difficulty		Ability to reshape the world to explore varying ideas, 'learning by designing'	Support self-regulated learning, learners as designers	Emphasis on the completeness of the game world	Games as sociological agents, history of game in culture	
(K. Squire et al., 2003)		Knowledge is contextual, importance of narrative contexts	Provide choices within simulated worlds		Importance of simulated environments, support experimentati	Differentiate roles and distribute expertise, collaborative	

					on	play, transgressive play outside social norms	
(Van Eck, 2006)	Importance of flow in learning games	Importance of situating learning within the game world			Provide alternative viewpoints and perspectives,		
(Van Eck, 2006)					Cycles of learning		
(Hong et al., 2009)	Challenge, game complexity and the effect on playfulness	Equal opportunities for fair play	Flexibility in making decisions	User friendly systems reduce confusion and frustration		Competition and cooperation	Importance of uncertainty but not outcomes by chance
(Prensky, 2008)			Engaging nature of decision making	personalisation and meeting the student's needs, students as game designers	The games should be Fun	Cooperation and competition	
(Ang & Rao, 2008)	Ludus rules to provide challenge and goals		Paidea rules to provide control		Narrative to provide fantasy and curiosity		
(Garris et al., 2002)	Optimum level of difficulty		Active learner control	Importance of supporting self-directed learners	Importance of fantasy and mystery		Importance of uncertain goal attainment
(Amory et al., 1999)	Importance of challenge		Manipulation and exploration		Importance of exploration and discovery	Significance of competition	
(Champagnat et al., 2008)			User influences and controls the game narrative	Adapt to a player's abilities. Player takes an active role in the narrative.	Importance of game narrative		

Appendix C – Evaluation Details

ELEKTRA Questionnaires

Note: These questionnaires have been translated into English from the original French versions.

Pre-questionnaire

User Characteristics and Control Variables

Instruction:
Dear Participant,
Thank you for participating in our study! All of your answers will be treated confidential.

Name/ID:
I am a Boy/Girl:
Age :
Class :
School :
Country:
School grades: Overall average grade:
Math grade:
Physic grade:

Your gaming experience
In the following we ask you some questions about your experience with video games. There are no right or wrong answers, we only ask that you provide honest and accurate answers. All of your answers will be treated confidential.

Do you play computer games at home?
☐Yes ☐No

When did you start to play a computer game for the first time? _____ years ago.

How many hours per week do you play? ________hours

How often do you play?
- ☐ Every day
- ☐ Every 3-4 times a week
- ☐ Once a week
- ☐ Less than once a week

What type of games do you prefer?

☐ Action	☐ Adventure	☐ Fight (e.g., Quake)
☐ Family (e.g, The sims)	☐ Role playing	☐ Music
☐ Simulation	☐ Sports	☐ Strategy
☐ Racing	☐ Puzzle	Others:________________

Do you have any educational games at home?
☐Yes ☐No

Which one do you prefer?
- ☐ educational games
- ☐ other video games

Your physics experience

Physics attitude:
Do you like to learn physics?

Not at all	1 – 2 – 3 – 4 – 5	Very much

Character Evaluation: Self-Rating

Rate yourself!
Below you find several adjectives, arranged in couples as opposite extremes. Please rate yourself on the scale from 1 to 8, as you estimate yourself between the several extremes. There are no right or wrong answers, we only ask that you provide honest and accurate answers.

I estimate myself as:

			Scale*
literate	1 – 2 – 3 – 4 – 5 – 6 – 7 – 8	Illiterate	*S*
unkind	1 – 2 – 3 – 4 – 5 – 6 – 7 – 8	kind	*A*
active	1 – 2 – 3 – 4 – 5 – 6 – 7 – 8	passive	*D*
intelligent	1 – 2 – 3 – 4 – 5 – 6 – 7 – 8	unintelligent	*S*
cold	1 – 2 – 3 – 4 – 5 – 6 – 7 – 8	warm	*A*
talkative	1 – 2 – 3 – 4 – 5 – 6 – 7 – 8	shy	*D*
uneducated	1 – 2 – 3 – 4 – 5 – 6 – 7 – 8	educated	*S*
friendly	1 – 2 – 3 – 4 – 5 – 6 – 7 – 8	unfriendly	*A*
unaggressive	1 – 2 – 3 – 4 – 5 – 6 – 7 – 8	aggressive	*D*
smart	1 – 2 – 3 – 4 – 5 – 6 – 7 – 8	Not smart	*S*
unpleasant	1 – 2 – 3 – 4 – 5 – 6 – 7 – 8	pleasant	*A*
confident	1 – 2 – 3 – 4 – 5 – 6 – 7 – 8	unsure	*D*
unexperienced	1 – 2 – 3 – 4 – 5 – 6 – 7 – 8	experienced	*S*
unlikable	1 – 2 – 3 – 4 – 5 – 6 – 7 – 8	likable	*A*
energetic	1 – 2 – 3 – 4 – 5 – 6 – 7 – 8	lazy	*D*

*Note that the information about the corresponding subscale per item was not provided to the learners (Superiority S, Attractiveness A, Dynamism D)

Assessment of Learning

Questionnaire on Optics

In the following we ask you some questions on the domain of optics. Please indicate for each of the following statements if they are correct, incorrect or if you don't know the answer.
Questions Q1 to Q16f

1. Magnetic force attracts the trajectory of a falling object
☐ only in case that the object is made of metal
☐ only in case that the object is hollow
☐ only in combination with wind
☐-I don't know

2. If a light's trajectory is influenced by an external force (e.g., wind, magnetic field),
☐ the trajectory changes immediately
☐ the trajectory does not change
☐ the trajectory changes after a while
☐ I don't know

3. Physical objects are, in general, under influence of external forces
☐ correct
☐ incorrect
☐ I don't know

4. Hollow objects have always more weight than solid objects made from the same material
☐ correct
☐ incorrect
☐ I don't know

5. Given wind and magnetic power, a solid iron marble will mainly be influenced by the magnetic power
☐ correct
☐ incorrect
☐ I don't know

6. If light is going out of a blind's hole, the light immediately tries to fill in the whole space of room
☐ correct
☐ incorrect
☐ I don't know

7. Lorsqu'on dirige l'éclairage d'une lampe de poche vers un mur…
When lighting a wall with a torch…
- ☐ Plus on s'éloigne du mur, plus la zone éclairée sur le mur est grande
  Spot of light on the wall becomes bigger when you walk away from the wall
- ☐ Plus on s'éloigne du mur, plus la zone éclairée sur le mur est petite
  Spot of light on the wall becomes smaller when you walk away from the wall
- ☐ Quand on s'éloigne du mur, la zone éclairée sur le mur reste la même
  Spot of light on the wall keeps the same size when you walk away from the wall

☐ I don't know

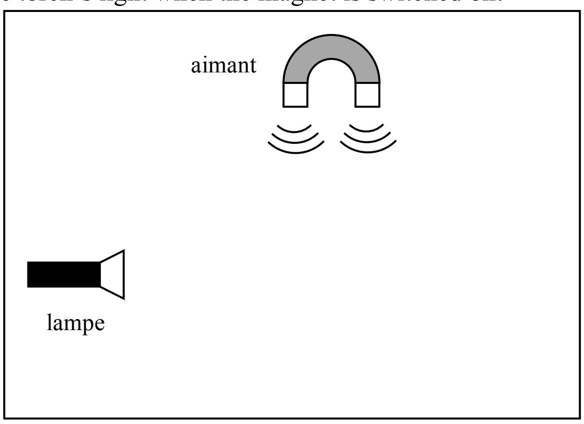
8. Light can be stopped by an opaque material
☐ correct
☐ incorrect
☐ I don't know

9. If the beam of light coming from a source of light goes through smaller and yet smaller holes, the beam
☐does not change in size
☐becomes smaller and yet smaller, too
☐ becomes bigger and yet bigger
☐I don't know

10. A beam of light can be represented by single rays of light
☐ correct
☐ incorrect
☐ I don't know

11. 3D models are
☐ more abstract then 2D models.
☐ more concrete than 2D models.
☐ less abstract than 2D models.
☐ I don't know

12. You are using a torch to emit light. A huge magnet has been switched on. Please indicate the trajectory of the torch's light when the magnet is switched on!



13. Blinds can be used for manipulating the beam of light.
☐ correct
☐ incorrect
☐ I don't know

14. A light cell is activated by sending light directly on it ☐ correct ☐ incorrect ☐ I don't know
15. An angle denominates the figure formed by two lines that origin from the same point. ☐ correct ☐ incorrect ☐ I don't know

16. Dans le tableau suivant, indique par des croix si les objets peuvent changer de trajectoire lorsqu'ils sont soumis à des différentes forces.
In the next table, put a cross when the objects may change of trajectory under influence of the mentioned forces.

Type d'objet (English: type of object)	Une puissante soufflerie (en: a powerful fan)	Un aimant puissant (en: a powerful magnet)	La gravitation (l'attraction de la Terre) (en: gravitation / Earth's attraction)	Une poussée avec les deux mains (en: a man pushing with his 2 hands)	I don't know
16a : Une balle de football (en: football ball)					
16b : Un caillou (en: a stone)					
16c : La lumière qui sort d'une lampe de poche (en: light going out of a torch)					
16d : Le son qui sort de la télévision (en: sound going out of a television)					
16e : Une fourchette en métal (en: a metal fork)					
16f : Une pièce d'1 euro (en: coin of 1 euro)					

Post-questionnaire

Intrinsic Motivation

Your experience with the game

The following questions concern your experience with the game you have just played. Below you find several statements. For each of the following statements, please indicate how true it is for you, using the scale from 1 to 7. 1 indicates, that the statement is not at all true for you, 7 indicates that the statement is very true for you

Item	**not at all true very true**	***Subscale****
1. I thought this was a boring game.	1 – 2 – 3 – 4 – 5 – 6 – 7	*Interest*
2. I think that playing that game could be useful.	1 – 2 – 3 – 4 – 5 – 6 – 7	*Value*
3. I didn’t try very hard to do well at this activity.	1 – 2 – 3 – 4 – 5 – 6 – 7	*Effort*
4. This game was fun to do.	1 – 2 – 3 – 4 – 5 – 6 – 7	*Interest*
5. I believe playing that game could be beneficial to me.	1 – 2 – 3 – 4 – 5 – 6 – 7	*Value*
6. It was important to me to do well at this task.	1 – 2 – 3 – 4 – 5 – 6 – 7	*Effort*
7. I would describe this game as very interesting.	1 – 2 – 3 – 4 – 5 – 6 – 7	*Interest*
8. I believe playing this game could be of some value for me.	1 – 2 – 3 – 4 – 5 – 6 – 7	*Value*
9. I put a lot of effort into this.	1 – 2 – 3 – 4 – 5 – 6 – 7	*Effort*

*Note that the information about the corresponding subscale per item was not provided to the learners

Flow-Experience

Your experience with the game:

The following questions concern your experience with the game you have just played. Below you find several statements. For each of the following statements, please indicate how true it is for you, using the scale from 1 to 7. 1 indicates, that the statement is not at all true for you, 7 indicates that the statement is very true for you

Items	**not at all true very true**	***Subscale****
1. The game was neither too easy nor too difficult.	1 – 2 – 3 – 4 – 5 – 6 – 7	*Flow*
2. My thoughts and activities were fluently and smooth.	1 – 2 – 3 – 4 – 5 – 6 – 7	*Flow*
3. I didn’t recognize how time went by.	1 – 2 – 3 – 4 – 5 – 6 – 7	*Flow*
4. There were important things for me at risk.	1 – 2 – 3 – 4 – 5 – 6 – 7	*Worry*
5. I could easily concentrate on the game.	1 – 2 – 3 – 4 – 5 – 6 – 7	*Flow*
6. My brain was completely clear.	1 – 2 – 3 – 4 – 5 – 6 – 7	*Flow*
7. I was not allowed to make mistakes.	1 – 2 – 3 – 4 – 5 – 6 – 7	*Worry*
8. I was deeply involved in the game activities.	1 – 2 – 3 – 4 – 5 – 6 – 7	*Flow*
9. The right thoughts came of their own volition.	1 – 2 – 3 – 4 – 5 – 6 – 7	*Flow*
10. I exactly knew what I had to do.	1 – 2 – 3 – 4 – 5 – 6 – 7	*Flow*
11. I was worried about my failure.	1 – 2 – 3 – 4 – 5 – 6 – 7	*Worry*
12. I had the feeling of controlling the game.	1 – 2 – 3 – 4 – 5 – 6 – 7	*Flow*
13. I was completely absorbed by the game and absent-minded.	1 – 2 – 3 – 4 – 5 – 6 – 7	*Flow*

*Note that the information about the corresponding subscale per item was not provided to the learners

Character Evaluation

Rate Galileo

The following questions concern your experience with Galileo, the old man who gave you advice in the game. Below you find several statements. For each of the following statements please indicate how true it is for you, using the scale from 1 to 7. 1 indicates that the statement is not at all true for you, 7 indicates that the statement is very true for you

In my opinion Galileo is:

			*Scale**
literate	1 – 2 – 3 – 4 – 5 – 6 – 7 – 8	Illiterate	*S*
unkind	1 – 2 – 3 – 4 – 5 – 6 – 7 – 8	kind	*A*
active	1 – 2 – 3 – 4 – 5 – 6 – 7 – 8	passive	*D*
intelligent	1 – 2 – 3 – 4 – 5 – 6 – 7 – 8	unintelligent	*S*
cold	1 – 2 – 3 – 4 – 5 – 6 – 7 – 8	warm	*A*
talkative	1 – 2 – 3 – 4 – 5 – 6 – 7 – 8	shy	*D*
uneducated	1 – 2 – 3 – 4 – 5 – 6 – 7 – 8	educated	*S*
friendly	1 – 2 – 3 – 4 – 5 – 6 – 7 – 8	unfriendly	*A*
unaggressive	1 – 2 – 3 – 4 – 5 – 6 – 7 – 8	aggressive	*D*
smart	1 – 2 – 3 – 4 – 5 – 6 – 7 – 8	Not smart	*S*
unpleasant	1 – 2 – 3 – 4 – 5 – 6 – 7 – 8	pleasant	*A*
confident	1 – 2 – 3 – 4 – 5 – 6 – 7 – 8	unsure	*D*
unexperienced	1 – 2 – 3 – 4 – 5 – 6 – 7 – 8	experienced	*S*
unlikable	1 – 2 – 3 – 4 – 5 – 6 – 7 – 8	likable	*A*
energetic	1 – 2 – 3 – 4 – 5 – 6 – 7 – 8	lazy	*D*

*Note that the information about the corresponding subscale per item was not provided to the learners (Superiority S, Attractiveness A, Dynamism D)

- Please indicate the tree attributes of George that you appreciate most: __________
- Are there other important attributes not listed in the rating above? If yes: which ones: ________

Rate Lisa

Now we are interested in your opinion about Lisa. Below you find several adjectives arranged in couples as opposite extremes. Please rate Lisa on the scale from 1 to 8 as you classify her between the several extremes. There are no right or wrong answers, we only ask you to provide honest and accurate answers.

In my opinion Lisa is:

			*Scale**
literate	1 – 2 – 3 – 4 – 5 – 6 – 7 – 8	Illiterate	*S*
unkind	1 – 2 – 3 – 4 – 5 – 6 – 7 – 8	kind	*A*
active	1 – 2 – 3 – 4 – 5 – 6 – 7 – 8	passive	*D*
intelligent	1 – 2 – 3 – 4 – 5 – 6 – 7 – 8	unintelligent	*S*
cold	1 – 2 – 3 – 4 – 5 – 6 – 7 – 8	warm	*A*
talkative	1 – 2 – 3 – 4 – 5 – 6 – 7 – 8	shy	*D*
uneducated	1 – 2 – 3 – 4 – 5 – 6 – 7 – 8	educated	*S*
friendly	1 – 2 – 3 – 4 – 5 – 6 – 7 – 8	unfriendly	*A*
unaggressive	1 – 2 – 3 – 4 – 5 – 6 – 7 – 8	aggressive	*D*
smart	1 – 2 – 3 – 4 – 5 – 6 – 7 – 8	Not smart	*S*
unpleasant	1 – 2 – 3 – 4 – 5 – 6 – 7 – 8	pleasant	*A*
confident	1 – 2 – 3 – 4 – 5 – 6 – 7 – 8	unsure	*D*
unexperienced	1 – 2 – 3 – 4 – 5 – 6 – 7 – 8	experienced	*S*
unlikable	1 – 2 – 3 – 4 – 5 – 6 – 7 – 8	likable	*A*
energetic	1 – 2 – 3 – 4 – 5 – 6 – 7 – 8	lazy	*D*

*Note that the information about the corresponding subscale per item was not provided to the learners (Superiority S, Attractiveness A, Dynamism D)

- Please indicate the tree attributes of Lisa that are the most important to you: _____
- Are there other important attributes not listed in the rating above? If yes: which ones: ___

Rate George

You played the game in the role of the hero George. Now we are interested in your opinion about George. Below you find several adjectives that are arranged in couples as opposite extremes. Please rate George on the scale from 1 to 8 as you classify him between the several extremes. There are no right or wrong answers, we only ask you to provide honest and accurate answers.

In my opinion George is:

			Scale*
literate	1 – 2 – 3 – 4 – 5 – 6 – 7 – 8	Illiterate	*S*
unkind	1 – 2 – 3 – 4 – 5 – 6 – 7 – 8	kind	*A*
active	1 – 2 – 3 – 4 – 5 – 6 – 7 – 8	passive	*D*
intelligent	1 – 2 – 3 – 4 – 5 – 6 – 7 – 8	unintelligent	*S*
cold	1 – 2 – 3 – 4 – 5 – 6 – 7 – 8	warm	*A*
talkative	1 – 2 – 3 – 4 – 5 – 6 – 7 – 8	shy	*D*
uneducated	1 – 2 – 3 – 4 – 5 – 6 – 7 – 8	educated	*S*
friendly	1 – 2 – 3 – 4 – 5 – 6 – 7 – 8	unfriendly	*A*
unaggressive	1 – 2 – 3 – 4 – 5 – 6 – 7 – 8	aggressive	*D*
smart	1 – 2 – 3 – 4 – 5 – 6 – 7 – 8	Not smart	*S*
unpleasant	1 – 2 – 3 – 4 – 5 – 6 – 7 – 8	pleasant	*A*
confident	1 – 2 – 3 – 4 – 5 – 6 – 7 – 8	unsure	*D*
unexperienced	1 – 2 – 3 – 4 – 5 – 6 – 7 – 8	experienced	*S*
unlikable	1 – 2 – 3 – 4 – 5 – 6 – 7 – 8	likable	*A*
energetic	1 – 2 – 3 – 4 – 5 – 6 – 7 – 8	lazy	*D*

*Note that the information about the corresponding subscale per item was not provided to the learners (Superiority S, Attractiveness A, Dynamism D)

- Please indicate the tree attributes of George that you appreciate most: _____
- Are there other important attributes not listed in the rating above? If yes: which ones: ______

Parasocial Interaction

Your experience with Galileo

The following questions concern your experience with Galileo, the old man who gave you advice in the game. Below you find several statements. For each of the following statements please indicate how true it is for you, using the scale from 1 to 7. 1 indicates that the statement is not at all true for you, 7 indicates that the statement is very true for you.

	not at all true very true	***Subscale****
1. I would describe interacting with Galileo as very enjoyable.	1 – 2 – 3 – 4 – 5 – 6 – 7	*int*
2. I tried hard to have a good interaction with Galileo.	1 – 2 – 3 – 4 – 5 – 6 – 7	*eff*
3. I felt really distant to Galileo.	1 – 2 – 3 – 4 – 5 – 6 – 7	*rel*
4. I would be willing to interact with Galileo again because it has some value to me.	1 – 2 – 3 – 4 – 5 – 6 – 7	*val*
5. I really doubt that Galileo and I would ever become friends.	1 – 2 – 3 – 4 – 5 – 6 – 7	*rel*
6. I thought Galileo was very boring.	1 – 2 – 3 – 4 – 5 – 6 – 7	*int*

7. I really feel like I could trust Galileo.	1 – 2 – 3 – 4 – 5 – 6 – 7	*rel*
8. I didn't put much energy into interacting with Galileo.	1 – 2 – 3 – 4 – 5 – 6 – 7	*eff*
9. I'd like a chance to interact more with Galileo.	1 – 2 – 3 – 4 – 5 – 6 – 7	*rel*
10. Interacting with Galileo was fun.	1 – 2 – 3 – 4 – 5 – 6 – 7	*int*
11. I'd really prefer not to interact with Galileo in the future.	1 – 2 – 3 – 4 – 5 – 6 – 7	*rel*
12. I put some effort into interacting with Galileo.	1 – 2 – 3 – 4 – 5 – 6 – 7	*eff*
13. I don't feel like I could really trust Galileo.	1 – 2 – 3 – 4 – 5 – 6 – 7	*rel*
14. I thought interacting with Galileo was important.	1 – 2 – 3 – 4 – 5 – 6 – 7	*val*
15. I think it's likely that Galileo and I could become friends.	1 – 2 – 3 – 4 – 5 – 6 – 7	*rel*
16. I feel really close to Galileo.	1 – 2 – 3 – 4 – 5 – 6 – 7	*rel*

*Note that the information about the corresponding subscale per item was not provided to the learners (interest int, effort eff, relatedness rel, value val)

Your experience with Lisa

Interaction with Lisa

The following questions concern your experience with Lisa, the girl who talked to you via the headset. Below you find several statements. For each of the following statements please indicate how true it is for you, using the scale from 1 to 7. 1 indicates that the statement is not at all true for you, 7 indicates that the statement is very true for you

	not at all true Very true	***Subscale****
1. I would describe interacting with Lisa as very enjoyable.	1 – 2 – 3 – 4 – 5 – 6 – 7	*int*
2. I tried hard to have a good interaction with Lisa.	1 – 2 – 3 – 4 – 5 – 6 – 7	*eff*
3. I felt really distant to Lisa.	1 – 2 – 3 – 4 – 5 – 6 – 7	*rel*
4. I would be willing to interact with Lisa again because it has some value to me.	1 – 2 – 3 – 4 – 5 – 6 – 7	*val*
5. I really doubt that Lisa and I would ever become friends.	1 – 2 – 3 – 4 – 5 – 6 – 7	*rel*
6. I thought Lisa was very boring.	1 – 2 – 3 – 4 – 5 – 6 – 7	*int*
7. I really feel like I could trust Lisa.	1 – 2 – 3 – 4 – 5 – 6 – 7	*rel*
8. I didn't put much energy into interacting with Lisa.	1 – 2 – 3 – 4 – 5 – 6 – 7	*eff*
9. I'd like a chance to interact more with Lisa.	1 – 2 – 3 – 4 – 5 – 6 – 7	*rel*
10. Interacting with Lisa was fun.	1 – 2 – 3 – 4 – 5 – 6 – 7	*int*
11. I'd really prefer not to interact with Lisa in the future.	1 – 2 – 3 – 4 – 5 – 6 – 7	*rel*
12. I put some effort into interacting with Lisa.	1 – 2 – 3 – 4 – 5 – 6 – 7	*eff*
13. I don't feel like I could really trust Lisa.	1 – 2 – 3 – 4 – 5 – 6 – 7	*rel*
14. I thought interacting with Lisa was important.	1 – 2 – 3 – 4 – 5 – 6 – 7	*val*
15. I think it's likely that Lisa and I could become friends.	1 – 2 – 3 – 4 – 5 – 6 – 7	*rel*
16. I feel really close to Lisa.	1 – 2 – 3 – 4 – 5 – 6 – 7	*rel*

*Note that the information about the corresponding subscale per item was not provided to the learners (interest int, effort eff, relatedness rel, value val)

If you have the choice, would you prefer to have more interaction with Lisa or with Galileo?

With Galileo ☐   with Lisa ☐

Identification

Your experience with George

The following questions concern your experience with George, the character that you played within the game. Below you find several statements. Please indicate the extent to which you agree or disagree to each of the following statements using the scale from 1 to 5. 1 indicates that you strongly disagree to the statement, 5 indicates that you strongly agree to the statement.

	Strongly disagree		Strongly agree
1. George is the sort of person I want to be like myself.		1 – 2 – 3 – 4 – 5	
2. Sometimes I wish I could be more like him.		1 – 2 – 3 – 4 – 5	
3. George is someone I would like to emulate.		1 – 2 – 3 – 4 – 5	
4. I would like to do the things he does in the game.		1 – 2 – 3 – 4 – 5	
5. I would never want to act the way he does in the game.		1 – 2 – 3 – 4 – 5	
6. I would prefer to have a female character instead of George.		1 – 2 – 3 – 4 – 5	

Cognitive Load

How demanding was the game for you?

In the following you will be asked to indicate how demanding you found several aspects of the game you just played. In order to answer each of the following questions, please place an "X" on the line under each question.

1. How much mental and physical activity was required (e.g., thinking, remembering, looking, searching etc.)? That is, was the game and the tasks within easy (simple) or demanding (exacting)?

easy demanding

2. How hard did you have to work in your attempt to understand the contents of the game?

not hard at all very hard

3. How successful do you think you were in your attempt to understand the contents of the learning environment?

not successful very successful

4. How much effort did you have to invest in order to navigate through the game (e.g. finding your way around)?

low effort high effort

5. How stressed (insecure, discouraged, irritated, annoyed) did you feel during the game?

not stressed at all very stressed

6. Apart from the handling of the game, how much were you distracted by the background music?

not distracted at all
very distracted

7. How easy or demanding was it to handle the headset for the communication with Lisa?

easy
demanding

8. How easy or demanding was it to handle the sandglass?

easy
demanding

9. How easy or demanding was it to handle the experimental table with the blinds?

easy
demanding

10. How easy or demanding was it to handle the slope device?

easy
demanding

Assessment of Learning

Questionnaire on Optics

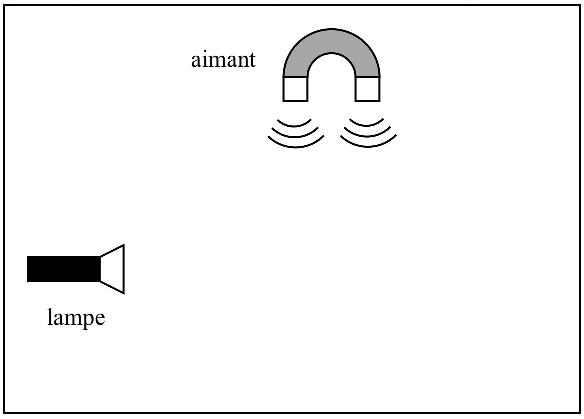
In the following we ask you again some questions on the domain of optics. Please indicate for each of the following statements if they are correct, incorrect or if you don't know the answer.
Questions Q1 to Q16f

1. Magnetic force attracts the trajectory of a falling object ☐ only in case that the object is made of metal ☐ only in case that the object is hollow ☐ only in combination with wind ☐-I don't know
2. If a light's trajectory is influenced by an external force (e.g., wind, magnetic field), ☐ the trajectory changes immediately ☐ the trajectory does not change ☐ the trajectory changes after a while ☐ I don't know
3. Physical objects are, in general, under influence of external forces ☐ correct ☐ incorrect ☐ I don't know
4. Hollow objects have always more weight than solid objects made from the same material ☐ correct ☐ incorrect ☐ I don't know
• 5. Given wind and magnetic power, a solid iron marble will mainly be influenced by the magnetic power ☐ correct ☐ incorrect • ☐ I don't know
6. If light is going out of a blind's hole, the light immediately tries to fill in the whole space of room ☐ correct ☐ incorrect ☐ I don't know
7. Lorsqu'on dirige l'éclairage d'une lampe de poche vers un mur… When lighting a wall with a torch… ☐ Plus on s'éloigne du mur, plus la zone éclairée sur le mur est grande Spot of light on the wall becomes bigger when you walk away from the wall ☐ Plus on s'éloigne du mur, plus la zone éclairée sur le mur est petite Spot of light on the wall becomes smaller when you walk away from the wall ☐ Quand on s'éloigne du mur, la zone éclairée sur le mur reste la même Spot of light on the wall keeps the same size when you walk away from the wall ☐ I don't know
8. Light can be stopped by an opaque material ☐ correct ☐ incorrect ☐ I don't know
9. If the beam of light coming from a source of light goes through smaller and yet smaller holes, the beam ☐does not change in size ☐becomes smaller and yet smaller, too ☐ becomes bigger and yet bigger ☐I don't know
10. A beam of light can be represented by single rays of light ☐ correct ☐ incorrect

☐ I don’t know

11. 3D models are
☐ more abstract then 2D models.
☐ more concrete than 2D models.
☐ less abstract than 2D models.
☐ I don’t know

12. You are using a torch to emit light. A huge magnet has been switched on. Please indicate the trajectory of the torch’s light when the magnet is switched on!



13. Blinds can be used for manipulating the beam of light.
☐ correct
☐ incorrect
☐ I don’t know

14. A light cell is activated by sending light directly on it
☐ correct
☐ incorrect
☐ I don’t know

15. An angle denominates the figure formed by two lines that origin from the same point.
☐ correct
☐ incorrect
☐ I don’t know

16. Dans le tableau suivant, indique par des croix si les objets peuvent changer de trajectoire lorsqu’ils sont soumis à des différentes forces.
In the next table, put a cross when the objects may change of trajectory under influence of the mentioned forces.

Type d’objet (English: type of object)	Une puissante soufflerie (en: a powerful fan)	Un aimant puissant (en: a powerful magnet)	l'attraction de la Terre) (en: gravitation / Earth's	avec les deux mains (en: a man pushing with	I don’t know
16a : Une balle de football (en: football ball)					
16b : Un caillou (en: a stone)					
16c : La lumière qui sort d’une lampe de poche (en: light going out of a torch)					
16d : Le son qui sort de la télévision (en: sound going out of a television)					
16e : Une fourchette en métal (en: a metal fork)					
16f : Une pièce d’1 euro (en: coin of 1 euro)					

Usability and Evaluation of Different Game Features

Your opinion about different game elements

Usefulness of different game elements
The following questions concern your experience with several elements of the game you have just played. Please indicate how useful you find the listed elements, using the scale from 1 to 7. 1 indicates, that the specific element was not useful at all, 7 indicates that the element was very useful for you.

	not at all useful very useful
Headset (for communicating with Lisa)	1 – 2 – 3 – 4 – 5 – 6 – 7
Sandglass	1 – 2 – 3 – 4 – 5 – 6 – 7
Experimental table with the blinds	1 – 2 – 3 – 4 – 5 – 6 – 7
Slope device	1 – 2 – 3 – 4 – 5 – 6 – 7
Lisa's comments	1 – 2 – 3 – 4 – 5 – 6 – 7
Galileo's comments	1 – 2 – 3 – 4 – 5 – 6 – 7
Possibility to ask questions	1 – 2 – 3 – 4 – 5 – 6 – 7
Technical hints in the game (e.g., press key)	1 – 2 – 3 – 4 – 5 – 6 – 7

Your opinion about several game features
Now we have some more specific questions on some game features. Below you find several statements. For each of the following statements, please indicate how true it is for you, using the scale from 1 to 7. 1 indicates, that the statement is not at all true for you, 7 indicates that the statement is very true for you.

	Not at all true very true	***Indices****
1. I would prefer to get more hints within the game.	1 – 2 – 3 – 4 – 5 – 6 – 7	*More hint*
2. I want to have more interaction with Galileo.	1 – 2 – 3 – 4 – 5 – 6 – 7	*Liking Galileo*
3. I want to have more interaction with Lisa.	1 – 2 – 3 – 4 – 5 – 6 – 7	*Liking Lisa*
4. I would like to have the option to skip the comments and hints by Lisa and Galileo	1 – 2 – 3 – 4 – 5 – 6 – 7	*Skip hints*
5. I like Galileo	1 – 2 – 3 – 4 – 5 – 6 – 7	*Liking Galileo*
6. I like the story of the game.	1 – 2 – 3 – 4 – 5 – 6 – 7	*Evaluation of music*
7.I would recommend this game to a friend.	1 – 2 – 3 – 4 – 5 – 6 – 7	*Evaluation of blinds*
8. I would prefer to be able to get hints by Lisa and Galileo on demand	1 – 2 – 3 – 4 – 5 – 6 – 7	*Hints on demand*
9. I really like the music within this game.	1 – 2 – 3 – 4 – 5 – 6 – 7	*Liking Galileo*
10. I enjoyed the communication with Galileo.	1 – 2 – 3 – 4 – 5 – 6 – 7	*Liking Galileo*
11. I would have needed more advise how to handle the table with the blinds	1 – 2 – 3 – 4 – 5 – 6 – 7	*Blinds*
12. I would play this game again.	1 – 2 – 3 – 4 – 5 – 6 – 7	*Evaluation of blinds*
13. I dislike Lisa.	1 – 2 – 3 – 4 – 5 – 6 – 7	*Evaluation of music*
14. I would have needed more advise how to handle the slope machine	1 – 2 – 3 – 4 – 5 – 6 – 7	*Slope device*
15. I enjoyed the communication with Lisa.	1 – 2 – 3 – 4 – 5 – 6 – 7	*Liking Lisa*
16. I easily understood how to handle the table with blinds	1 – 2 – 3 – 4 – 5 – 6 – 7	*Blinds*
17. I was engaged in saving Lisa.	1 – 2 – 3 – 4 – 5 – 6 – 7	*Liking story*
18. I enjoyed this game as much as I enjoyed the other video games that I play at home.	1 – 2 – 3 – 4 – 5 – 6 – 7	*Liking game*
19. I don't want to have Galileo's respect.	1 – 2 – 3 – 4 – 5 – 6 – 7	*Liking story*
20. I easily understood how to handle the slope machine	1 – 2 – 3 – 4 – 5 – 6 – 7	*Slope device*

21. I would really like to play the next episode of this game	1 – 2 – 3 – 4 – 5 – 6 – 7	*Liking story***
22. I am very curious about how the adventure will be continued	1 – 2 – 3 – 4 – 5 – 6 – 7	*Liking story***
23. Sometimes the comments by Galileo were irritating and disturbed the gameplay	1 – 2 – 3 – 4 – 5 – 6 – 7	*Invasiveness****
24. The comments by Galileo were well integrated in the gameplay	1 – 2 – 3 – 4 – 5 – 6 – 7	*Invasiveness****
25. Sometimes I had the impression that Galileo's comments were more or less random	1 – 2 – 3 – 4 – 5 – 6 – 7	*Invasiveness****
26. I had the impression that the interaction with Galileo was fluent and intelligent.	1 – 2 – 3 – 4 – 5 – 6 – 7	*Invasiveness****

*Note that the information about the indices was not provided to the learners

** These items were only asked within demonstrator versions AFM5.3.10.5 and AFM5.3.10.6
***These items were only asked within demonstrator versions AFM5.3.10.5 and AFM5.3.10.6

Evaluation of the Hand of the Avatar

"Please indicate whether George's hand was swithed on or off "
☐ = switched on
☐ = switched off

Your opinion about the hand of George

I prefer the game
☐ with the hand of George
☐ without the hand of George

	not at all true very true
I don't like the presence of the hand of George	1 – 2 – 3 – 4 – 5 – 6 – 7
The animation of George's hand should be more authentic and smooth	1 – 2 – 3 – 4 – 5 – 6 – 7
I like the appearance of George's hand	1 – 2 – 3 – 4 – 5 – 6 – 7
I have appreciated to have the option to switch off the hand of George	1 – 2 – 3 – 4 – 5 – 6 – 7

Recommendations and Remarks by the Users

What are your overall impressions of playing this game?

___

___

What did you like most?

___

___

What did you dislike most?

___

___

Further recommendations or remarks that come up to your mind and that may help us to improve the game?

___

___

Language Trap Questionnaires

Pre-questionnaire

The following questionnaire was exported from the online LimeSurvey software. The question codes (shown in square brackets) were not visible when completing the online questionnaire. Formatting changes have been applied in conversion from the HTML format.

Language Trap - Pre Questionnaire

This questionnaire forms part of the evaluation study of the Language Trap game.
If you have any difficulties with this questionnaire please contact the supervisor of the study.

This questionnaire consists of four sections and should take no more than **10 minutes** to complete.

- Please answer all sections as honestly and accurately as possible.
- All of the information in this questionnaire will be recorded anonymously and will be held confidentially.
- Participation in this study is voluntary. You may opt-out of any question you would prefer not to answer.

There are 39 questions in this survey

General Information

Please answer all sections as honestly and accurately as possible.
All of the information in this questionnaire will be recorded anonymously and will be held confidentially.

1 [username]Your anonymous username is: {TOKEN}

2 [age]Age (in years) *
Please write your answer here:

3 [gender]Gender: *
Please choose **only one** of the following:

- ○Female
- ○Male
- ○Prefer Not To Answer

4 [schoolyear]School Year *
Please choose **only one** of the following:

- ○4th year
- ○5th year
- ○6th year

5 [years german]Number of years studying German *
Please choose **only one** of the following:

- ○4 years
- ○5 years
- ○6 years
- ○7 years or more

6 [leaving certificate]At what level do you expect to take the German Leaving Certificate exam? *
Please choose **only one** of the following:

- ○Ordinary Level
- ○Higher Level
- ○Don't Know
- ○Prefer Not To Answer

7 [reading difficulty]Is there any reason why you may experience difficulty reading or seeing text in a computer game? *

Please choose **only one** of the following:

- ○Yes
- ○No

8 [reading diff reason]Please specify one or more reasons for this

Only answer this question if the following conditions are met:

° Answer was 'Yes' at question '7 [reading difficulty]' (Is there any reason why you may experience difficulty reading or seeing text in a computer game?)

Please choose **all** that apply:

- ☐Dyslexia
- ☐Corrected vision
- ☐Colour blindness
- ☐Prefer not to answer
- ☐Other:

9 [playing difficulty]Is there any reason why you may experience difficulty playing a computer game with a keyboard or mouse? *

Please choose **only one** of the following:

- ○Yes
- ○No

10 [playing diff reason]Please specify one or more reasons for this

Only answer this question if the following conditions are met:

° Answer was 'Yes' at question '9 [playing difficulty]' (Is there any reason why you may experience difficulty playing a computer game with a keyboard or mouse?)

Please choose **all** that apply:

- ☐Physical difficulty with mouse/keyboard
- ☐Inexperience using computers
- ☐Prefer not to answer
- ☐Other:

11 [hearing difficulty]Is there any reason why you may experience difficulty hearing sounds and dialogues in the computer game? *

Please choose **only one** of the following:

- ○Yes
- ○No

12 [hearing diff reason]Please specify one or more reasons for this

Only answer this question if the following conditions are met:

° Answer was 'Yes' at question '11 [hearing difficulty]' (Is there any reason why you may experience difficulty hearing sounds and dialogues in the computer game?)

Please choose **all** that apply:

- ☐Deafness
- ☐Prefer not to answer
- ☐Other:

Previous Computer Game Experience

In the following section we ask you some questions about your experience with computer games. There are no right or wrong answers, we only ask that you provide honest and accurate answers. All of your answers will be treated confidentially.

13 [play games at home]Do you play computer games at home? *
Please choose **only one** of the following:
- ○Yes
- ○No

14 [game frequency]How often do you play computer games?
Please choose **only one** of the following:
- ○Every day
- ○3-4 times a week
- ○Once a week
- ○Less than once a week
- ○Never

15 [game genre pref]What types of computer games do you prefer?
Please choose **all** that apply:
- ☐Action
- ☐Adventure
- ☐Shooter (FPS)
- ☐Puzzle
- ☐Simulation (e.g. The Sims)
- ☐Music
- ☐Strategy
- ☐Role Playing (RPG)
- ☐Sports/Racing
- ☐Other:

Educational Computer Game Experience

16 [edugames played]Have you ever played an educational computer game? *
Please choose **only one** of the following:
- ○Yes
- ○No

17 [edugame subjects]If Yes above, what subjects did the educational game or games deal with?

Please write your answer here:

18 [edugames titles]Please list any educational games you have played
Please write your answer here:

19 [edugames genres]What types of educational computer games have you played?
Please choose **all** that apply:
- ☐Action
- ☐Adventure
- ☐Shooter (FPS)
- ☐Puzzle
- ☐Simulation (e.g. The Sims)
- ☐Music
- ☐Strategy
- ☐Role Playing (RPG)

- ☐Sports/Racing
- ☐Other:

20 [edugames opinion]The following questions relate to your experience playing educational computer games.
<u>Please give your opinion of the educational games you have played under the following headings.</u>

21 [edugame difficulty]Game Difficulty *
Please choose **only one** of the following:
- ○Too easy
- ○About right
- ○Too hard
- ○*Prefer Not To Answer*

22 [edugame complexity]Game Complexity *
Please choose **only one** of the following:
- ○Too simple
- ○About right
- ○Too complex
- ○*Prefer Not To Answer*

23 [edugame duration]Game Duration *
Please choose **only one** of the following:
- ○Too short
- ○About right
- ○Too long
- ○*Prefer Not To Answer*

24 [edugame content]Learning Content *
Please choose **only one** of the following:
- ○Too little
- ○About right
- ○Too much
- ○*Prefer Not To Answer*

25 [edugame relevance]Relevance to Learning Content *
Please choose **only one** of the following:
- ○Irrelevant
- ○Somewhat relevant
- ○Very Relevant
- ○*Prefer Not To Answer*

German Dialogue Phrases

The following section presents several phrases and possible responses.
You must select **ALL** of the responses that you feel appropriately follow the phrases.
There are no right or wrong answers to this section, we only ask that you provide honest and accurate answers. All of your answers will be treated confidentially and will not be used for class grades or assessment.
<u>Please tick **ALL** appropriate responses.</u>

26 [q1]A German tourist asks you:
<u>Sie sprechen gut Deutsch. Wo haben Sie es gelernt?</u>*
Please choose **all** that apply:

- ☐In der Schule.
- ☐Ich habe einen Deutschkurs gemacht.
- ☐Beim Goethe Institut.
- ☐Ich war in Bremen.
- ☐[None of the above]

27 [q1c]How confident are you that your answers above are correct? *
Please choose the appropriate response for each item:

	Not at all confident 1	2	3	4	5	6	Very confident 7
Your confidence	○	○	○	○	○	○	○

28 [q2]A German tourist asks you:
<u>Was gibt es in der Nähe zu sehen?</u> *
Please choose **all** that apply:

- ☐Es gibt viele alte Schlösser, wie das Dubliner Schloss, schöne Seen wie Glendalough. Es gibt einen schönen Park in der Nähe, den Phoenix Park.
- ☐Es gibt viel zu sehen: alte Schlösser, wunderschöne Seen, und einen groβen Nationalpark.
- ☐Es gibt viel zu sehen: Schlösser, Seen und einen Nationalpark.
- ☐Ich bin in der Nähe.
- ☐[None of the above]

29 [q2c]How confident are you that your answers above are correct? *
Please choose the appropriate response for each item:

	Not at all confident 1	2	3	4	5	6	Very confident 7
Your confidence	○	○	○	○	○	○	○

30 [q3]A waiter in a restaurant asks you:
<u>Und der Preis ist gut, nicht?</u> *
Please choose **all** that apply:

- ☐Ja! Der Menüpreis ist günstig, aber der Fisch ist schlecht.
- ☐Ja! Der Menüpreis ist günstig, aber ich kann den Fisch nicht essen.
- ☐Ja! Der Menüpreis ist günstig, aber der Fisch ist ranzig.
- ☐Nein! Der Menüpreis ist günstig.
- ☐[*None of the above*]

31 [q3c]How confident are you that your answers above are correct? *
Please choose the appropriate response for each item:

	Not at all confident 1	2	3	4	5	6	Very confident 7
Your confidence	○	○	○	○	○	○	○

32 [q4]A German tourist asks you:
<u>Muss man auch Irisch lernen?</u> *
Please choose **all** that apply:

- ☐Ja! Das müssen wir.
- ☐Ja! Es ist obligatorisch.
- ☐Ja! Irisch ist Pflichtfach.
- ☐[*None of the above*]

33 [q4c]How confident are you that your answers above are correct? *
Please choose the appropriate response for each item:

	Not at all confident 1	2	3	4	5	6	Very confident 7
Your confidence	○	○	○	○	○	○	○

34 [q5]A German tourist asks you:
<u>Kann man da Irisch lernen?</u> *
Please choose **all** that apply:
- ☐Ja! Es gibt Kurse für Jugendliche und Erwachsene.
- ☐Ja! Es gibt Sommerkurse für Jugendliche.
- ☐Ja! Es gibt Sommercamps für Schüler und Schülerinnen.
- ☐Ja
- ☐Nein
- ☐[*None of the above*]

35 [q5c]How confident are you that your answers above are correct? *
Please choose the appropriate response for each item:

	Not at all confident 1	2	3	4	5	6	Very confident 7
Your confidence	○	○	○	○	○	○	○

36 [q6]A German friend asks you:
<u>Wie lange lernen Sie Deutsch?</u> *
Please choose **all** that apply:
- ☐Seit 4 Jahren.
- ☐Seit 5 Jahren.
- ☐Seit 6 Jahren.
- ☐Seit einer langen Zeit.
- ☐Seit 5 Stunden.
- ☐[*None of the above*]

37 [q6c]How confident are you that your answers above are correct? *
Please choose the appropriate response for each item:

	Not at all confident 1	2	3	4	5	6	Very confident 7
Your confidence	○	○	○	○	○	○	○

38 [q7]A German tourist asks you:
<u>Können Sie mir ein Restaurant für heute Abend empfehlen?</u> *
Please choose **all** that apply:
- ☐Ihr eigenes Restaurant ist gut.
- ☐Ja, es ist ein guter Abend.
- ☐Das „Cistin“ ist gut zum Frühstücken.
- ☐Ich empfehle ein gutes Abendessen.
- ☐Heute empfehle ich gutes Können.
- ☐[*None of the above*]

39 [q7c]How confident are you that your answers above are correct? *
Please choose the appropriate response for each item:

	Not at all confident 1	2	3	4	5	6	Very confident 7
Your confidence	○	○	○	○	○	○	○

Submit your survey.
Thank you for completing this survey.

Post-questionnaire

The following questionnaire was exported from the online LimeSurvey software. The question codes (shown in square brackets) were not visible when completing the online questionnaire.

Language Trap - Post Questionnaire

This questionnaire forms part of the evaluation study of the Language Trap game. If you have any difficulties with this questionnaire please contact the supervisor of the study
This questionnaire consists of nine sections and should take no more than **15 minutes** to complete.

- Please answer all sections as honestly and accurately as possible.
- All of the information in this questionnaire will be recorded anonymously and will be held confidentially.
- Participation in this study is voluntary. You may opt-out of any question you would prefer not to answer.

There are 31 questions in this survey

Opinion of the Game Design

In the following section we ask your opinion on the computer game you have just played.

1 [username]Anonymous Username: {TOKEN}

2 [game design]Opinion of the Game Design
Please give your opinion about the following statements *
Please choose the appropriate response for each item:

	Not at all true 1	2	3	4	5	6	Very true 7	No Answer
I thought this was a boring game.	○	○	○	○	○	○	○	○
I think that playing that game could be useful.	○	○	○	○	○	○	○	○
I didn't try very hard to do well at this activity.	○	○	○	○	○	○	○	○
This game was fun to play.	○	○	○	○	○	○	○	○
I believe playing that game could be beneficial to me.	○	○	○	○	○	○	○	○
It was important to me to do well at this task.	○	○	○	○	○	○	○	○
I would describe this game as very interesting.	○	○	○	○	○	○	○	○
I believe playing this game could be of some value for me.	○	○	○	○	○	○	○	○
I put a lot of effort into this.	○	○	○	○	○	○	○	○

General Opinion

3 [general opinion]General Opinion of the Language Trap Game
Please give your opinion about the following statements *
Please choose the appropriate response for each item:

	Not at all true 1	2	3	4	5	6	Very true 7	No Answer
I liked the storyline of the game.	○	○	○	○	○	○	○	○
I liked the music within this game.	○	○	○	○	○	○	○	○
I would play this game again.	○	○	○	○	○	○	○	○
I think the game is a useful way to learn the German language.	○	○	○	○	○	○	○	○
I felt the game was easy to control.	○	○	○	○	○	○	○	○
I felt the game controls were intuitive.	○	○	○	○	○	○	○	○
I would recommend this game to someone learning German	○	○	○	○	○	○	○	○
I felt this game was more focused on the learning, than on the fun.	○	○	○	○	○	○	○	○
I would use this game at home to learn German.	○	○	○	○	○	○	○	○
I would like to see games like this for other languages.	○	○	○	○	○	○	○	○
I felt the spoken language was useful and beneficial.	○	○	○	○	○	○	○	○
I felt the game was stimulating and exciting.	○	○	○	○	○	○	○	○
I felt the game motivated me to learn German.	○	○	○	○	○	○	○	○
I am more aware of my German skills after playing the game.	○	○	○	○	○	○	○	○
I am more confident of my German language skills after playing the game.	○	○	○	○	○	○	○	○
The game helped me to think about how I learn languages.	○	○	○	○	○	○	○	○

Comparison to Other Educational Games

4 [compare edugames]Comparison to Other Educational Games
Please give your opinion about the following statements*
Please choose the appropriate response for each item:

	Not at all true 1	2	3	4	5	6	Very true 7	No Answer
This game is as fun as other educational games I have played.	○	○	○	○	○	○	○	○
This game is as fun as other non-educational games I have played.	○	○	○	○	○	○	○	○
This game is more focused on learning compared to other educational games I've	○	○	○	○	○	○	○	○

	Not at all true 1	2	3	4	5	6	Very true 7	No Answer
played.								
As I played the game I was always aware that it was an educational game.	○	○	○	○	○	○	○	○

Game Companion (Agent White Jacket)

5 [game companion]Game Companion (Agent White Jacket)
Please give your opinion about the following statements *
Please choose the appropriate response for each item:

	Not at all true 1	2	3	4	5	6	Very true 7	No Answer
I felt the comments made by my game companion were helpful.	○	○	○	○	○	○	○	○
The comments made by my game companion were irritating and disturbed the gameplay.	○	○	○	○	○	○	○	○
I had the impression that the interaction with my companion was fluent and intelligent.	○	○	○	○	○	○	○	○
Sometimes I had the impression that my companion's comments were more or less random.	○	○	○	○	○	○	○	○
The comments made by my companion were well integrated in the gameplay.	○	○	○	○	○	○	○	○
The comments made by my companion were well integrated in the storyline.	○	○	○	○	○	○	○	○
I felt I could relate to my game companion.	○	○	○	○	○	○	○	○
I would like more interaction with my game companion.	○	○	○	○	○	○	○	○
I felt my companion improved the game experience.	○	○	○	○	○	○	○	○
I felt the advice my companion gave me was always appropriate.	○	○	○	○	○	○	○	○

Game Character Evaluation

6 [character evaluation]Character Evaluation
Please give your opinion about the following statements *
Please choose the appropriate response for each item:

	Not at all true 1	2	3	4	5	6	Very true 7	No Answer
I felt the characters reacted sensibly and intelligently to my actions.	○	○	○	○	○	○	○	○
I felt the characters helped me where necessary.	○	○	○	○	○	○	○	○

	Not at all true 1	2	3	4	5	6	Very true 7	No Answer
The game characters were consistent in what they did and said.	○	○	○	○	○	○	○	○
I would prefer the companion character (agent White Jacket) to give me more hints and guidance.	○	○	○	○	○	○	○	○
There was always a dialogue choice available that I felt confident choosing.	○	○	○	○	○	○	○	○

Game Dialogues

7 [game dialogues]Game Dialogues
Please give your opinion about the following statements *
Please choose the appropriate response for each item:

	Not at all true 1	2	3	4	5	6	Very true 7	No Answer
I felt the dialogues presented were always of a suitable difficulty	○	○	○	○	○	○	○	○
I was aware of the difficulty of the dialogs changing as I played the game.	○	○	○	○	○	○	○	○
I felt the dialogues became too easy as the game progressed.	○	○	○	○	○	○	○	○
I was aware of the dialogs getting harder as I improved.	○	○	○	○	○	○	○	○
I felt the game dialogues changed inappropriately based on my actions.	○	○	○	○	○	○	○	○

8 [inapprop dialogues]Please list any inappropriate dialogues you remember from the game:
Please write your answer here:

Game Difficulty and Immersion

9 [game diff and immers]Game Difficulty and Immersion
Please give your opinion about the following statements *
Please choose the appropriate response for each item:

	Not at all true 1	2	3	4	5	6	Very true 7	No Answer
The game was neither too easy nor too difficult.	○	○	○	○	○	○	○	○
My thoughts and activities were fluently and smooth.	○	○	○	○	○	○	○	○
I didn't recognize how time went by.	○	○	○	○	○	○	○	○
There were important things for me at risk.	○	○	○	○	○	○	○	○
I could easily concentrate on the game.	○	○	○	○	○	○	○	○
My brain was completely clear when playing.	○	○	○	○	○	○	○	○
I was not allowed to make mistakes.	○	○	○	○	○	○	○	○
I was deeply involved in the game activities.	○	○	○	○	○	○	○	○

	Not at all true 1	2	3	4	5	6	Very true 7	No Answer
The right thoughts came of their own volition.	○	○	○	○	○	○	○	○
I exactly knew what I had to do.	○	○	○	○	○	○	○	○
I was worried about my failure.	○	○	○	○	○	○	○	○
I had the feeling of controlling the game.	○	○	○	○	○	○	○	○
I was completely absorbed by the game and absent-minded.	○	○	○	○	○	○	○	○
I felt stressed (insecure, discouraged, irritated, annoyed) whilst playing the game.	○	○	○	○	○	○	○	○
I was aware of the progress I was making in the game.	○	○	○	○	○	○	○	○

10 [game play time]How long (in minutes) do you think you were playing the game? *
Please write your answer here:

Learning Awareness

11 [learnAware]Learning Awareness in the Game
Please give your opinion about the following statements *
Please choose the appropriate response for each item:

	Not at all true 1	2	3	4	5	6	Very true 7	No Answer
Feedback within the game helped me understand how I learn German	○	○	○	○	○	○	○	○
My character's thoughts helped me understand my own abilities	○	○	○	○	○	○	○	○
I will take more risks in learning German in the future	○	○	○	○	○	○	○	○
My character's thoughts made me think about how I learn	○	○	○	○	○	○	○	○
I felt my game character's thoughts were relevant to me	○	○	○	○	○	○	○	○
I know more about how I learn German having played this game	○	○	○	○	○	○	○	○

Vocabulary

12 [vocabulary learnt]Do you feel the game has helped you learn new German vocabulary? *
Please choose **only one** of the following:

- Yes
- No

13 [vocabulary list]Please list up to five new German words you have learnt (including their translations)
Only answer this question if the following conditions are met:
° Answer was 'Yes' at question '12 [vocabulary learnt]' (Do you feel the game has helped you learn new German vocabulary?)

Please write your answer here:

German Dialogue Phrases

The following section presents several phrases and possible responses.
You must select **ALL** of the responses that you feel appropriately follow the phrases.
There are no right or wrong answers to this section, we only ask that you provide honest and accurate answers. All of your answers will be treated confidentially and will not be used for class grades or assessment.
Please tick **ALL** appropriate responses.

14 [q1]A German tourist asks you:
Sie sprechen gut Deutsch. Wo haben Sie es gelernt?*
Please choose **all** that apply:

- In der Schule.
- Ich habe einen Deutschkurs gemacht.
- Beim Goethe Institut.
- Ich war in Bremen.
- [None of the above]

15 [q1c]How confident are you that your answers above are correct? *
Please choose the appropriate response for each item:

	Not at all confident 1	2	3	4	5	6	Very confident 7
Your confidence	○	○	○	○	○	○	○

16 [q2]A German tourist asks you:
Was gibt es in der Nähe zu sehen? *
Please choose **all** that apply:

- Es gibt viele alte Schlösser, wie das Dubliner Schloss, schöne Seen wie Glendalough. Es gibt einen schönen Park in der Nähe, den Phoenix Park.
- Es gibt viel zu sehen: alte Schlösser, wunderschöne Seen, und einen groβen Nationalpark.
- Es gibt viel zu sehen: Schlösser, Seen und einen Nationalpark.
- Ich bin in der Nähe.
- [None of the above]

17 [q2c]How confident are you that your answers above are correct? *
Please choose the appropriate response for each item:

	Not at all confident 1	2	3	4	5	6	Very confident 7
Your confidence	○	○	○	○	○	○	○

18 [q3]A waiter in a restaurant asks you:
Und der Preis ist gut, nicht? *
Please choose **all** that apply:

- ☐Ja! Der Menüpreis ist günstig, aber der Fisch ist schlecht.
- ☐Ja! Der Menüpreis ist günstig, aber ich kann den Fisch nicht essen.
- ☐Ja! Der Menüpreis ist günstig, aber der Fisch ist ranzig.
- ☐Nein! Der Menüpreis ist günstig.
- ☐[*None of the above*]

19 [q3c]How confident are you that your answers above are correct? *
Please choose the appropriate response for each item:

	Not at all confident 1	2	3	4	5	6	Very confident 7
Your confidence	○	○	○	○	○	○	○

20 [q4]A German tourist asks you:
Muss man auch Irisch lernen? *
Please choose **all** that apply:

- ☐Ja! Das müssen wir.
- ☐Ja! Es ist obligatorisch.
- ☐Ja! Irisch ist Pflichtfach.
- ☐[*None of the above*]

21 [q4c]How confident are you that your answers above are correct? *
Please choose the appropriate response for each item:

	Not at all confident 1	2	3	4	5	6	Very confident 7
Your confidence	○	○	○	○	○	○	○

22 [q5]A German tourist asks you:
Kann man da Irisch lernen? *
Please choose **all** that apply:

- ☐Ja! Es gibt Kurse für Jugendliche und Erwachsene.
- ☐Ja! Es gibt Sommerkurse für Jugendliche.
- ☐Ja! Es gibt Sommercamps für Schüler und Schülerinnen.
- ☐Ja
- ☐Nein
- ☐[*None of the above*]

23 [q5c]How confident are you that your answers above are correct? *
Please choose the appropriate response for each item:

	Not at all confident 1	2	3	4	5	6	Very confident 7
Your confidence	○	○	○	○	○	○	○

24 [q6]A German friend asks you:
Wie lange lernen Sie Deutsch? *
Please choose **all** that apply:

- ☐Seit 4 Jahren.
- ☐Seit 5 Jahren.
- ☐Seit 6 Jahren.
- ☐Seit einer langen Zeit.
- ☐Seit 5 Stunden.

- ☐[*None of the above*]

25 [q6c]How confident are you that your answers above are correct? *
Please choose the appropriate response for each item:

	Not at all confident 1	2	3	4	5	6	Very confident 7
Your confidence	○	○	○	○	○	○	○

26 [q7]A German tourist asks you:
Können Sie mir ein Restaurant für heute Abend empfehlen? *
Please choose **all** that apply:

- ☐Ihr eigenes Restaurant ist gut.
- ☐Ja, es ist ein guter Abend.
- ☐Das „Cistin" ist gut zum Frühstücken.
- ☐Ich empfehle ein gutes Abendessen.
- ☐Heute empfehle ich gutes Können.
- ☐[*None of the above*]

27 [q7c]How confident are you that your answers above are correct? *

Please choose the appropriate response for each item:

	Not at all confident 1	2	3	4	5	6	Very confident 7
Your confidence	○	○	○	○	○	○	○

Recommendations and Remarks

28 [impressions]What are your overall impressions of playing this game?
Please write your answer here:

29 [like most]What did you like most?
Please write your answer here:

30 [dislike most]What did you dislike most?
Please write your answer here:

31 [recommendations]Do you have any further recommendations or remarks that may help us to improve the game?
Please write your answer here:

Submit your survey.
Thank you for completing this survey.

Appendix D

ELEKTRA Adaptive Element usage frequencies

AE ID	Count	AE ID	Count	AE ID	Count
LeS11_GA_001	33	LeS11_GA_303_1	5	LeS121_ai_64	11
LeS11_GA_002	32	LeS11_GA_303_2	2	LeS121_ai_65	12
LeS11_GA_003	26	LeS11_GA_351_1	17	LeS121_ai_66	11
LeS11_GA_004	26	LeS11_GA_351_2	11	LeS121_ai_67	5
LeS11_GA_005	22	LeS11_GA_351_3	5	LeS121_ai_72	1
LeS11_GA_006	20	LeS11_GA_351_4	2	LeS121_ai_74	29
LeS11_GA_007	13	LeS11_GA_401_1	19	LeS121_ai_77	1
LeS11_GA_008	7	LeS11_GA_401_2	13	LeS121_ai_81	31
LeS11_GA_051	118	LeS11_GA_401_3	7	LeS121_ai_88	26
LeS11_GA_052	110	LeS11_GA_401_4	4	LeS121_ai_95	23
LeS11_GA_053	104	LeS11_GA_401_5	2	LeS123_GA_009	3
LeS11_GA_054	101	LeS11_GA_451_1	7	LeS123_GA_011	14
LeS11_GA_055	95	LeS11_GA_451_2	2	LeS123_GA_012	3
LeS11_GA_056_1	90	LeS11_GA_501_1	1	LeS123_STAGE14	25
LeS11_GA_056_2	87	LeS11_GA_551_1	4	LeS123_STAGE15	12
LeS11_GA_057	85	LeS11_GA_601_1	1	LeS123_STAGE16	210
LeS11_GA_058	82	LeS11_GA_651_1	2	LeS131_04_022GA	11
LeS11_GA_101	35	LeS121_ai_03	34	LeS131_04_027GA	2
LeS11_GA_102_1	25	LeS121_ai_05	25	LU1_SET1_w2_HINT_20_SEC	5
LeS11_GA_102_2	15	LeS121_ai_07	21	LU1_SET1_w2_HINT_5_SEC	198
LeS11_GA_103_1	10	LeS121_ai_09	12	LU1_SET1_w2_STAGE13	32
LeS11_GA_103_2	7	LeS121_ai_11	40	LU1_SET1_w2_STAGE14	153
LeS11_GA_104	4	LeS121_ai_13	24	LU1_SET1_w2_STAGE18	26
LeS11_GA_105_1	2	LeS121_ai_14	15	LU1_SET1_w2_STAGE32	116
LeS11_GA_151	49	LeS121_ai_15	39	LU1_SET1_w2_STAGE36	19
LeS11_GA_152	38	LeS121_ai_17	36	LU1_SET1_w2_STAGE37	49
LeS11_GA_153	31	LeS121_ai_19	39	LU1_SET1_w2_STAGE4	323
LeS11_GA_201	106	LeS121_ai_32	4	LU1_SET1_w2_STAGE41	12
LeS11_GA_202	98	LeS121_ai_33	34	LU1_SET1_w2_STAGE8	33
LeS11_GA_203	92	LeS121_ai_34	30	LU1_SET1_w2_STAGE9	210
LeS11_GA_204	88	LeS121_ai_35	37	PRUDENCE	870
LeS11_GA_205_1	81	LeS121_ai_36	10	CONFIDENCE	428
LeS11_GA_205_2	76	LeS121_ai_37	2		
LeS11_GA_205_3	68	LeS121_ai_40	1		
LeS11_GA_205_4	64	LeS121_ai_41	25		
LeS11_GA_205_5	59	LeS121_ai_42	16		
LeS11_GA_251_1	67	LeS121_ai_44	33		
LeS11_GA_251_2	55	LeS121_ai_48	1		
LeS11_GA_252	47	LeS121_ai_52	8		
LeS11_GA_253	44	LeS121_ai_53	1		
LeS11_GA_254_1	39	LeS121_ai_54	1		
LeS11_GA_254_2	35	LeS121_ai_56	33		
LeS11_GA_254_3	33	LeS121_ai_59	10		
LeS11_GA_254_4	30	LeS121_ai_60	4		
LeS11_GA_301	15	LeS121_ai_61	20		
LeS11_GA_302	11	LeS121_ai_62	39		

Language Trap Adaptive Element Usage

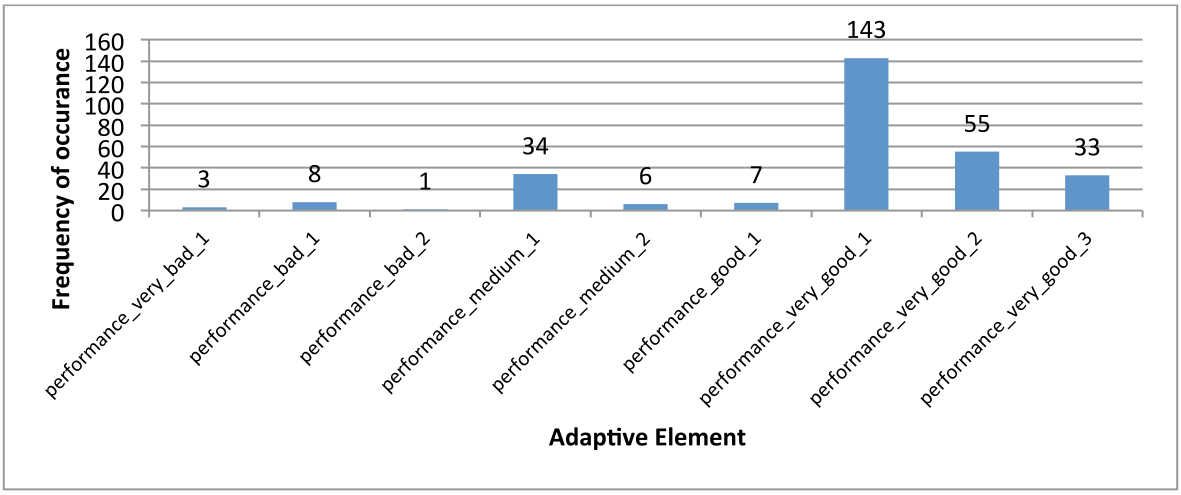


Figure 133. Language Trap performance feedback Adaptive Element frequency

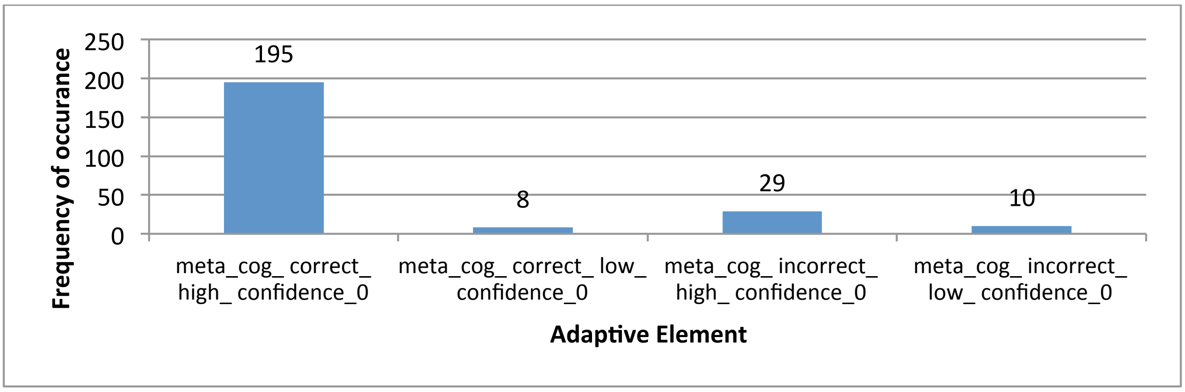


Figure 134. Language Trap meta-cognitive feedback Adaptive Element frequency

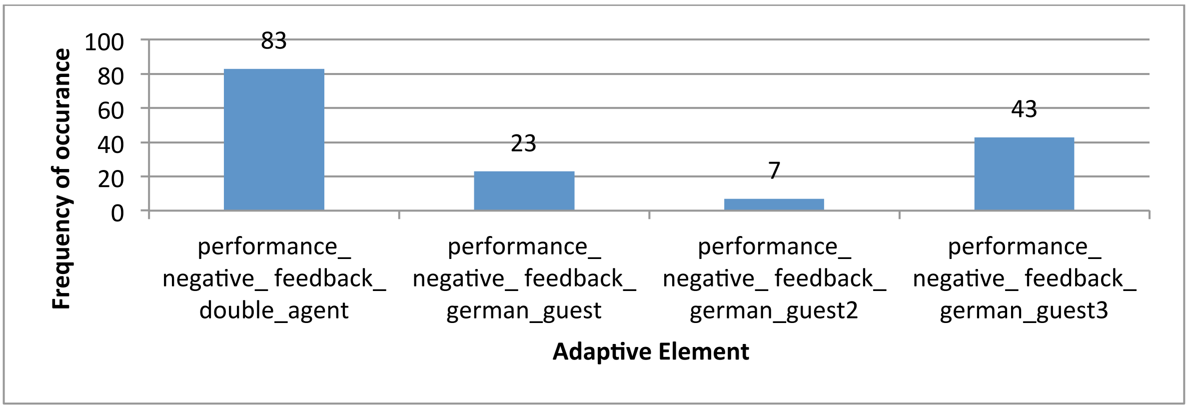


Figure 135. Language Trap character performance feedback Adaptive Element frequency

Appendix E – Codified Requirements

Table 30. ALIGN Design Requirements

Code	Requirement
R1	The prioritisation of the gaming experience over educational personalisation is necessary where these objectives conflict as this ensures the intrinsically motivating immersive gameplay is maintained.
R2	It is necessary to ensure that any adaptations are performed in a manner consistent with the player's understanding of the game world including the game's rules, storyline, and character consistency.
R3	Inference techniques should be employed to deal with learner evidence that is application specific or too granular for the purposes of personalisation.
R4	The learner should be able to influence and dictate their learning direction to enable self-directed learning and to increase their sense of ownership of the experience.
R5	Learner skills and motivation should not be modelled as continually progressive processes and the non-linear progression of skills should be considered.
R6	There is a need for both non-invasive user modelling and non-invasive adaptations in order to achieve non-invasive personalisation.
R7	The responsiveness of any personalisation performed must be sufficiently fast so as not to impact the highly interactive nature of the game-based learning and detrimentally affect the immersive and engaging nature of the gaming environment.
R8	There is a need for greater content reuse through techniques such as micro-adaptation wherein content can be used more extensively and tweaked for each individual learner.
R9	The independent authoring and reuse of adaptation logic across multiple games should be enabled through the separation of game logic from educational adaptation.

Table 31. Adaptive Educational Game Design Requirements

Code	Requirement
G1	Adaptation to the learner's abilities enables the presentation of a personalised challenge.
G2	Adaptive game characters can be used to promote social interactions yet must act in accordance with, and considerate of the game narrative.
G3	Learning content must be matched with appropriate game genres; further to this the game genres must be appropriate for the intended audience.
G4	The game design should reflect the move towards more learner controlled, self-directed, learner-centric, constructivist approaches, and a move away from behaviourist approaches.
G5	The context[43] where the gaming and learning occurs is significant and approaches should cater for both formal and informal learning contexts.
G6	There is a need to provide highly interactive experiences to learners who are increasingly accustomed to personalised experiences.

[43] The physical setting where the game is played, be it a formal classroom or an informal home location.

Table 32. Language Trap Game Design Requirements

Code	Requirement
LT1	The game should adopt a different game style to that of the ELEKTRA game to show the generality of ALIGN across game styles e.g. 3D, isometric style, 2D platformer, etc.
LT2	The learning content addressed should be significantly different to the ELEKTRA game to determine generality across learning content.
LT3	The game should apply best practices in educational game design.
LT4	In line with the action research methodology the game should meet the needs of the end users and address a real world problem.

Appendix F – Introduction to Rules Engines and Drools

A rule engine consists of two key concepts, that of *facts* which are the discrete inputs of data into the rule engine, and *rules* that consist of patterns that match against the *facts*. A rule consists of a left-hand side (LHS) that is the pattern of facts required to execute the rule, and a right-hand side (RHS) which is the logic to perform when the pattern is matched. The three basic operations of a rule engine consist of *insertion* (adding a fact to the rule engine), *update* (informing the rule engine that a fact has changed), and *retraction* (the removal of a fact). Any one of these operations can cause a rule to execute depending on the current rules and facts within the rule engine. A key benefit of a rule based approach is that the personalisation is clearly declarative, i.e. the rule author dictates what to do and when to do it.

The Drools Rule Engine

Within the ALIGN system the Java based Drools rule engine (JBoss, n.d.) is used as a forward-chaining state-ful rule engine. The Drools engine was selected for its high performance, scalability, rich feature set, and clear declarative rule format. The Drools rule pattern format is used on the LHS where each line represents an implied logical AND. The RHS is written in Java with additional methods to insert, update, and retract facts. An example of a simple rule written in the Drools rule format is given below in Figure 136. Within the Drools rule engine all facts are represented as Java objects. In order for rules patterns to match particular facts, attributes of the classes are exposed through appropriate getter methods. This is demonstrated in Figure 136 with the *name* attribute of the *ExampleFact* class. In this example the rule can be explained as:

if(there is a Fact named "windy" ***AND*** *a Fact named "raining") {*
remove both of these facts
add a new Fact called "stormy"
}

```
rule "example Drools rule"
```

```
        when
                $windyFact: Fact(name == "windy")
                $rainingFact: Fact(name == "raining")
        then
                retract($windyFact);
                retract($rainingFact);
                insert(new Fact("stormy"));
end
```

```
// A Simple Java Fact Class
public class Fact {
        private String name;

        public Fact(String name){
                this.name = name;
        }

        public String getName(){
                return name;
        }
}
```

Figure 136. Example Drools Rule and Java Fact Class

Within the Drools rule engine the concept of a Working Memory is used and this is where all of the facts inserted into the rule engine reside. A rulebase, which is a collection of all the rules that will act on the facts, is attached to a Working Memory so that the rules may execute. A Drools Working Memory can operate in a stateless or a stateful mode. In a stateless mode all of the facts are inserted once and then all of the rules that can execute do so. In the stateful mode all of the rules are initially present in the Working Memory and will fire as facts are progressively added to the working memory. The stateful mode is used within ALIGN as it allows evidence to be accumulated over time.

The use of the Drools rule engine within ALIGN allows for the efficient execution of declarative logic irrespective of the ordering of the input facts. This approach not only can provide timely adaptations to a game but also the flexibility to personalise to patterns of learner evidence as opposed to exact evidence.

In addition to executing rules the Drools rule engine can execute queries to retrieve facts that match a specific pattern. In effect these rules are equivalent to the LHS of a rule as is evident in the query shown below in Figure 137 where all of the Facts with a given name are returned.

Further documentation about the Drools rule format and feature set can be found at: http://www.jboss.org/drools/documentation

```
query "get facts by name" (String desiredName)
        $desiredFact: Fact(name == desiredName)
end
```

Figure 137. An example Drools query