Integrated intelligent LEARNing environment for Reading and Writing

D4.1 – User modelling for users with dyslexia and dysorthographia

Document identifier	**D4.1_ILearnRW_User_Modelling_final.docx**
Date	**2013-09-29**
WP	**WP4**
Partners	**DOLPHIN, NTUA, UoM, IoE, DYSACT, EPIRUS, LBUS**
WP Lead Partner	**IoE**
Document status	**Final**

Deliverable Number	D4.1
Deliverable Title	User modelling for users with dyslexia and dysorthographia
Deliverable version number	V3.0
Work package	WP4
Task	Task D4.1 User modelling for users with dyslexia and dysorthographia
Nature of the deliverable	**Report (R)**
Dissemination level	**Public (PU)**
Date of Version	2013-09-08

Author(s)	Daniel Gooch
Contributor(s)	M.Vasalou, D. Lukes, J. Flowers, L. Benton
Reviewer(s)	Rilla Khaled, Victoria Zakopoulou
Abstract	This deliverable details the User Modelling development of the iLearnRW project. The deliverable briefly discusses what User Modelling is and how it is commonly used within Intelligent Tutoring Systems. It goes on to present the User Model that will be used within the project for both English and Greek before considering how the project could use a visualisation of the model as a menu system for accessing the game activities.
Keywords	User Modelling, Dyslexia

Document Status Sheet

Issue	Date	Comment	Author
V1	2013-09-01	Issued for discussion amongst authors	Daniel Gooch
V2	2013-09-08	Issued for Internal Review	Daniel Gooch, Mina Vasalou, Laura Benton, Maria Mastorpavlou
V3	2013-09-29	Final document including comments and suggests by A. Symvonis, M. Mastropavlou and R. Khaled	Daniel Gooch

Project information

Project acronym:	**ILearnRW**
Project full title:	**Integrated Intelligent Learning Environment for Reading and Writing**
Proposal/Contract no.:	**318803**

Project Officer: Krister Olson

Address:	L-2920 Luxembourg, Luxembourg
Phone:	+35 2430 134 332
E-mail:	krister.olson@ec.europa.eu

Project Co-ordinator: Noel Duffy

Address:	Dolphin Computer Access Ltd. Technology House, Blackpole Estate West, Worcester, UK. WR3 8TJ
Phone:	+01 905 754 577
Fax:	+01 905 754 559
E-mail:	noel.duffy@yourdolphin.com

Table of Contents

1. Introduction

This deliverable details the User Modelling development of the iLearnRW project. It needs to be made clear from the beginning that within this document, the User Model refers predominantly to modelling the linguistic skills of an individual child. It will be necessary to model other attributes that relate to the serious game but until the details of the game are fixed, it is impossible to determine or discuss what the game user model will look like.

As a vocabulary issue; within this document the "game" refers to the Adventure mode in its entirety whereas an "activity" refers to a specific learning activity such as pelmanism or whackamole. A complete list of activities can be found in the User Requirements deliverable (see Deliverable D3.5). The activities are used within both the Play and the Adventure mode.

The deliverable breaks down into nine main Sections. **The first** Section discusses the definition of dyslexia and why User Modelling is necessary for any software tutor for students with dyslexia. **The second** Section moves on to discuss what User Modelling is, the form it takes and why it is important. **The third** Section covers the history of User Modelling in Intelligent Tutoring Systems, highlighting that many of these systems focus on modelling a students abilities within a given curriculum.

The fourth, fifth and sixth sections present details on the iLearnRW User Model. **The fourth** discuss the attributes covered by the model, focussing particularly on the linguistic difficulties a child may experience. **The fifth** Section presents a number of statistical techniques for user modelling which are deemed as being inappropriate for various reasons. It concludes with why we selected a rule based approach. **The sixth** Section discusses how the data stored within the user model is initialised and updated.

The seventh Section briefly outlines how the user model is used by other components of the iLearnRW project. More details on this can be found in the User Requirements deliverable (see Deliverable D3.1).

The penultimate Section focuses on how the User Model should be presented to a child, granting them ownership over their own learning and a visual representation of their own abilities.

Finally we outline what future work is necessary in the context of the project, focussing particularly on evaluating the User Model and the generation of content.

2. Why Is Profiling Necessary For Teaching Children with Dyslexia?

It is necessary for us to restate the definition and properties of Dyslexia, as used within the iLearnRW project, as some of these properties have a direct impact on how the User Model is developed. Developmental dyslexia, or specific reading disability, is defined as "an unexpected, specific, and persistent failure to acquire efficient reading skills despite conventional instruction, adequate intelligence, and sociocultural opportunity" [Demonet et al., 2004]. Although exact definitions vary (see [Tønnessen, 1997]), this definition is accepted by the diagnostic and statistical manual of mental disorders [APA, 1994] and the international classification of disorders, classification of mental and behavioural disorders [WHO, 1993]. Within the UK, a government report into teaching literacy to children with dyslexia uses a similar definition, highlighting difficulties in phonological awareness, verbal memory and verbal processing speed [Rose, 2009]. Further details on the definition of dyslexia, and the motivation for the project, can be found in the State of the Art User Requirements Analysis Report (Deliverable D3.1) and the User Requirements Deliverable (D3.5).

Dyslexia occurs across the range of intellectual abilities and it is important to note that dyslexia is considered to be a continuum rather than a distinct category [Snowling, 2008] [Goswami, 2008]. People with dyslexia may have other special learning needs such as ADHD or autism [Dyslexia Action, 2013]. Individuals will likely have a sub-set of all of the issues associated with dyslexia. For this reason, the Rose Report also highlights the importance of each child having an individual learning plan [Rose, 2009].

The personalised approach to teaching children with dyslexia has also been applied within computer-based tutoring systems. "ICT approaches work best when they are precisely targeted… the mediation of a skilled adult is essential to ensure technologically-driven schemes meet children's needs. Time needs to be allocated effectively so that the diagnostic tools of programmes can be used for each child appropriately" [Brooks, 2007, p. 31]

The continuum nature of dyslexia is the main reason that the iLearnRW software needs a User Modelling component. By tracking the specific individual difficulties a given child has, we can provide appropriate targeted support. Ideally, this is what teachers would like to do within their classrooms. However, the time necessary to manually develop a User Model for each child in a class, and subsequently produce an individual teaching plan appropriate for that child's specific difficulties and skills for each lesson, is beyond the time resources of nearly all teachers. However, this is something well within the abilities of a tutor using a User Modelling component.

3. What is User Modelling?

> "User modelling is nothing more than a fancy term for automated personalisation. Humans model each other all the time. I am modelling *you* as I write; my topics, presentation, and language are all aimed at a hypothetical, average reader of this journal. If I have guessed well, you will enjoy this essay. If not, you will skip to the next one. That is what user modelling systems do – they make guesses, and hopefully educated ones, about their users" [Orwant, 1996, p. 398]

User Modelling, although complicated to design and develop, is based on a tremendously simple idea. This idea is that by having information about a specific individual a given computer system can make decisions which are best suited to that individual. In other words, "user models are defined as models that systems have of users that reside inside a computational environment" [Fischer, 2001, p. 70]. Any computer system that behaves differently for different users employs a user model. The user models themselves can be big or small, complex or simple, rich or sparse [Orwant, 1996, p. 399]. "Individual items of information, or a collection of these, do not constitute a model. The presumption in talking of user models is that items of information about a user may be related to one another, or to other (typically general) knowledge stored in the system, in a manner which supports predictions that can stimulate further system actions" [Sparck Jones, 1989, p. 342].

In essence then, any user model consists of three components; the data being stored about attributes of a user, the algorithms which process this data to affect change on the computational environment and the method by which the data is obtained and updated. This follows the Sparck Jones framework, which includes "the nature of the information in model, the function of a model, and the means by which the information for a model can be obtained," [Sparck Jones, 1989, p. 341].

An excellent metaphor of user modelling is the service provided by a librarian [Rich, 1979, p. 333]. If a librarian already knows the person borrowing a book, she will be able to provide some suggestions right away. Alternatively, if the librarian doesn't know the person borrowing books, she will first size him up quickly to make some assumptions about what types of books they might like. If this is not enough information, or she wants to support her assumptions with more information, she will have to ask the borrower a few questions. Based on this metaphor, the librarian's model of the borrower allows them to select more appropriate books.

A user model can be thought of in terms of the interaction between private and shared information between a user and the machine [Kay, 1997]. Figure 1, proposed by Kay and building upon [Suchman, 1987], delimits the interactions between these components.

On the far left is the user's private information, data which the machine can't access. The shared area represents the information which is known about the user by the machine. The shared area also represents the information the user gathers from the machine's human interface. The bulk of the user modelling occurs in the machine's private space. Within this space lie three separate sets of knowledge. The first is **M(domain),** knowledge the machine has of the domain, codified from both domain experts and other knowledge sources. As we will explain in detail later, within the ILearnRW project, this information has come from the project's dyslexia experts, verified and extended with user research. The next set is **M(users.domain)** which represents knowledge about typical users within this domain. This information has come from the dyslexia experts within the project. Finally we have the information about a specific user with **M(individual)**. This is the information that will be used to customise the ILearnRW software for a specific user and is the focus of this deliverable.

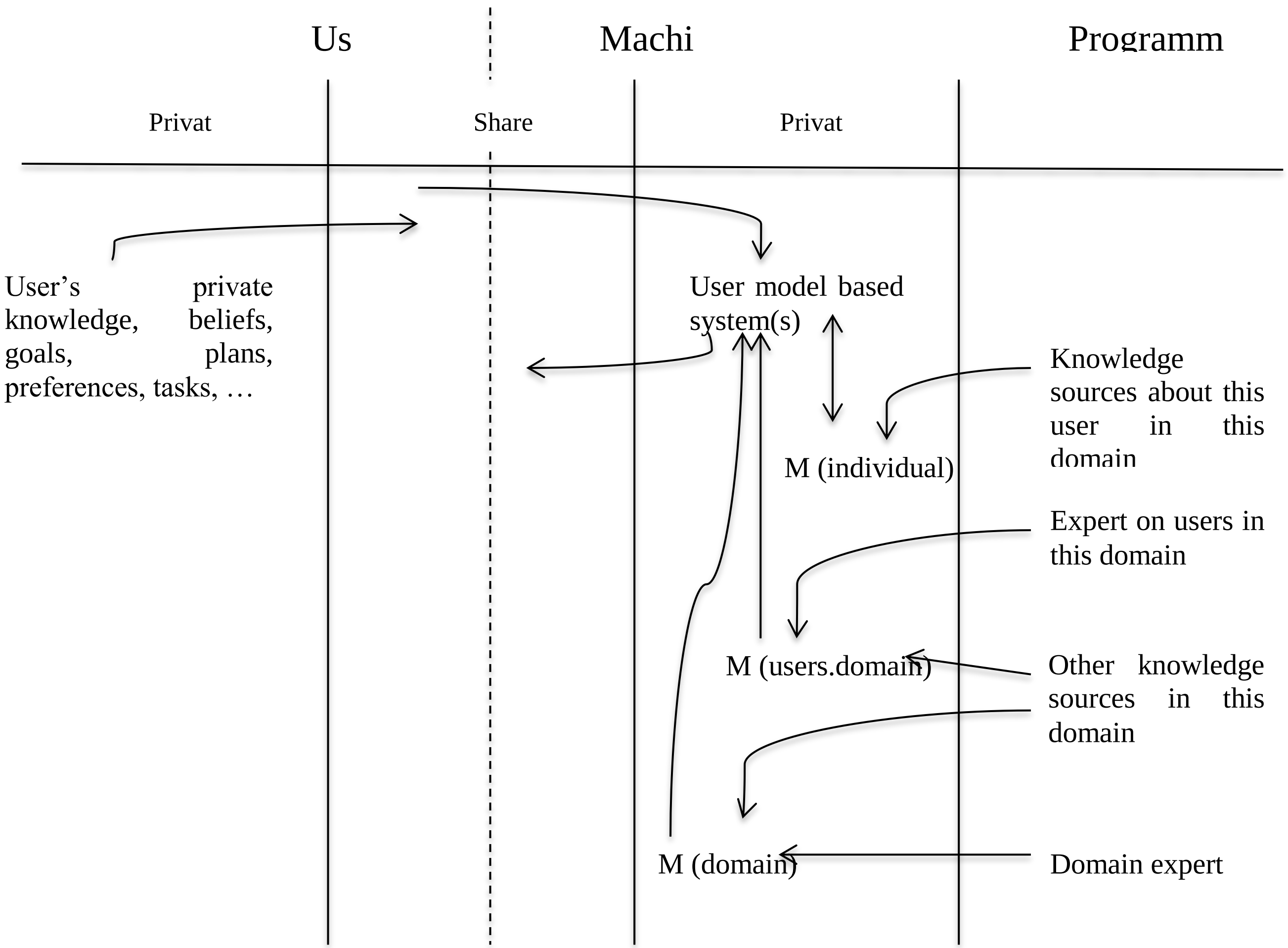

Figure 1: The [Kay, 1997] model defining the interaction between users and machines in a user model

We are focussing less on attempting to emulate human behaviour through the User Model to a more complementary approach where the computer is used in ways which plays to it's strength [Fischer, 2001]. With reference to learning systems, Kay notes: "We believe that the goal of modelling the student at the level that an excellent teacher can do is an unnecessarily difficult goal. Computer-based teachers are fundamentally different from human teachers" [Kay, 1997b, p. 18]. To a certain extent, this scopes the user modelling aspect of this project. Although we want to learn from the decisions that teachers make when adapting their lessons to fulfil the needs of an individual student, attempting to replicate those decisions are likely to fail. For example, teachers can comprehend student's pronunciation without any difficulties. Computationally this is a challenging task. Instead, we need to focus on tasks which are computationally straightforward but still educationally valuable, relying on teachers to teach the students the skills that humans are more suited to providing.

This corresponds with the derided assumption "that the more user model the better" [Sparck Jones, 1989, p. 341]. This assumption has gradually changed over time. The current consensus view, which we concur with, is that it is better to provide a smaller user model, which is well targeted to respond to specific needs. Such a model is part of a more refined system, indicating that the model should aim to achieve very specific goals.

Within the iLearnRW project, the user model underpins the three key components of the software, namely the game, the learning activities and the reader. The model is intended to provide individualised teaching through holding information about a given student's linguistic abilities and weaknesses, allowing the game, the learning activities and the reader to focus on teaching those skills and abilities which the student does not currently possess.

Having discussed the general rationale and justified the scope of application of User Models, we deepen our analysis in order to delimit our scope. Rich [1979] argues that any User Model sits within three main dimensions that can be probed with the following questions:

1. Are they models of a canonical user or are they models of individual users?
2. Are they constructed explicitly by the user himself or are they abstracted by the system on the basis of the user's behaviour?
3. Do they contain short-term, highly specific information or longer-term, more general information?

Clarifying these three dimensions from the start is crucial when designing a user model. The first dimension refers to the nature of who is being modelled; individuals or a group of users, idealised in some form. For example, are we profiling Fred as a specific child or are we profiling sub-groups of children with dyslexia together. Individual models provide more personalisation than canonical models but at the cost of increased uncertainty and complexity. Canonical models are related to the technique of using modelling 'Stereotypes', which we will go on to discuss in Section 6.6. Within the context of the iLearnRW project, we have decided to **focus on modelling individual children**. There currently exists no understanding of how to model children with dyslexia into a series of stereotypical user groups as a result of the challenges we discussed in Section 2: dyslexia is defined as consisting of a continuum of difficulties rather than existing as a distinct category. This has led us to model an individual rather than a canonical user in order to ensure that a student's personal weaknesses and needs are being addressed rather than some approximation of them.

The second dimension refers to where the data within the model comes from. The first option is to get the user to explicitly construct the model, most commonly by questioning them. Questioning users poses at least two limitations. Firstly, it might take a lot of questions to accumulate all the knowledge the system needs before constructing an accurate User Model. This can be a distraction when the user simply wants to pick-up and use the software system. Secondly, and more importantly from a modelling perspective, people may not always be able to provide accurate answers about themselves. This is particularly the case within an educational context where a student may not be aware of their own difficulties. Even more, this is true within the age range of the iLearnRW project where the students are unlikely to have developed the self-reflection skills to a degree that they can provide detailed information about their specific difficulties. Although "people are not reliable sources of information about themselves" [Rich, 1979, p. 330], a compromise is for a student to perform a series of activities. Although this seeds the model from behaviour undertaken within these activities, this data is not collected over time but upon the user's first interaction with the software. Although this compromise may improve the accuracy of the data, it imposes a task on the user that is outside the primary use of the software.

With these considerations in mind, within the iLearnRW project, the primary source of data about a student's educational abilities will be abstracted from their ongoing behaviour, particularly from within the activities. We concur with the argument that "implicitly constructed models were used because of the inherent inaccuracy and the annoyance of requiring users to construct their own models of themselves" [Rich, 1979, p. 330]. The educational activities will be developed to derive expertise about a given skill or difficulty based upon the score and time achieved in completing activities with specific content. This data can be supplemented with information provided by a special education needs teacher, if the student received such support. Section 7 details how data for the iLearnRW User Model will be initialised and updated.

The third dimension refers to the nature of the information being held within the model; does it contain short-term, highly specific information or longer-term, more general information? The problem being addressed by the iLearnRW project constrains this decision. Although it is necessary to use strong short-term teaching strategies which aim to strengthen the ability of short-term memory to code highly specific information correctly, it is necessary that the information can be decoded and recalled from long-term memory. Focussing as we are on linguistic abilities, the nature of the information is both highly specific and long-term. For example, a student's ability to deal with words which include the "ing" suffix is a piece of information which is highly specific but is unlikely to change rapidly and indeed may take a long time to develop.

To summarise our discussion of this section, we began with a brief explanation of user modelling, what a user model consists of and why it is of use within the iLearnRW project. We have detailed how this deliverable focuses on the user model of a student's educational abilities and where our user model will address three key questions:

1. The iLearnRW project will focus on individual users
2. The iLearnRW User Model is abstracted by the system on the basis of the user's behaviour?
3. The iLearnRW User Model will contain short-term, highly specific information

In the next section we move on from the general approach of designing user models to discuss how user modelling has been previously applied within Intelligent Tutoring Systems (ITS), particularly ITS whose focus has been on dyslexia.

4. History Of User Modelling On Intelligent Tutoring Systems

It has long been recognised that individualised learning is more effective than classroom learning. By classroom learning we refer to an entire class being set individual work rather than collaborative activities which social constructionists would argue are extremely important. [Bloom, 1984] argued that an average student who received one-to-one tutoring from an expert tutor scored two standard deviations higher than an average student taught in a traditional group-based instructional setting. [Cohen et al., 1982] found a similar result though not to the same effect size, based on a meta-analysis of tutoring in general.

Achieving a similar degree of individualisation has been key to the development of Intelligent Tutoring Systems (ITS). As Anderson argues, "The promise of computer-based tutors is that they can make the benefits of individualized instruction available to all students at affordable costs" [Anderson, 1992, p. 3]. To achieve one-to-one instruction, an understanding of students and targeted adaptation is needed.

Van Dam expresses this philosophy in saying that "IT's role is to augment (not to replace) the teacher, to provide human-centred tools that encourage and support adaptability and flexibility, and to enable appropriate modes of learning" [Van Dam et. al, 2005, p. 30]. Nonetheless, human tutors tend to offer assistance in locating an error and computer tutors tend to take on the error repair process [Merrill et al., 1992], indicating that human tutors have some significant benefits over computer-based systems. In light of this limitation the goal of ITS remains to provide the benefits of one-to-one instruction automatically and cost-effectively [Girard, 2012]. In other words, whilst having a human tutor for each individual child would be the ideal case, ITS is better than the status quo.

As detailed in [Corbett et. al, 1990] and presented in [Girard, 2012] any ITS is composed of four different components, namely: (1) Task Environment (2) Domain knowledge (3) Student Model (4) Pedagogical module. In other words, user modelling provides most of the "intelligent" aspect of any Intelligent Tutoring System. The focus of this deliverable is 2 and 3: we discuss the dyslexia knowledge that guides our tutoring system and how this is modelled for each individual student.

There are a number of areas of research in ITS which we are not focussing within the iLearnRW project. We are not considering how to prevent students from gaming the system [Baker, 2007] [Baker et al., 2006] [Baker et al., 2005] [Baker et al., 2004] [Baker et al., 2004b]. Similarly, we are not considering using teachable agents [Ogan et al., 2012] [Biswas et al., 2005], nor how our tutor would operate outside of Greece or the UK [Ogan et al., 2012b]. Although the mobile nature of the iLearnRW software has implications for other parts of the project, we do not concentrate, as some have on how mobility affects the user modelling aspect of the iLearnRW project [Ghadirli and Rastgarpour, 2012]. We are also not concerned with lifelong learner modelling as has been proposed by some researchers [Kay, 2008]. The scope of any ITS project is potentially huge. These aspects are specifically listed as being beyond the scope of the iLearnRW project as they are considerations that were potentially significant given the nature of the project.

Two main areas of development in ITS are Cognitive Tutors (CT) [Koedinger et al., 1997] [Corbett and Anderson, 1995] and Constraint-Based Modelling (CBM) [Mitrovic, 2012]. Cognitive tutors represent knowledge as being procedural, mapping it onto student actions. CBM tutors represent declarative knowledge as constraints over student answers [Desmarais and Baker, 2012]. In spite of their differences, CT and CBM tutors can achieve similar results [Mitrovic et al., 2003]. These tutors rely on the ability to provide remedial help just-in-time, based on the current problem.

Within the iLearnRW project we are focussing on a different form of tutor, namely a content sequencing tutor [Desmarais and Baker, 2012]. This family of tutors guide students through a set of learner material. The most widely used tutor is reportedly ALEKS (www.aleks.com) [Desmarais and Baker, 2012]. The approach taken by ALEKS is known as curriculum sequencing, a concept traceable back to [McCalla et al., 1982] and [Peachey and McCalla, 1986] and consists of defining learning paths in a space of learning objectives. "Whereas CT and CBM aim to provide specific remedial content based on a detailed analysis of the student's problem solving steps or answers, curriculum sequencing aims to make broader skills assessment to adapt the learning content in general" [Desmarais and Baker, 2012, p. 14]. Such an approach is taken by many of the teacher-led intervention programmes for dyslexia, including DILP [Walker et al., 2008], Units of Sound 1, 2 and 3 [Bramley, 2004] and Alpha to Omega [Hornsby et. al, 1999].

Many Intelligent Tutoring Systems base their personalisation on pre-existing curriculum. For example, [Anderson, 1992] presents a High School Mathematics tutor based on the US mathematics curriculum, using production rules on problem solving skills and including a set of common bugs and errors. [Anderson et. al, 1990] present a tutor based on teaching proof skills in geometry and [Corbett and Anderson, 1991] present a Lisp tutor, both of which are based on pre-existing curricula. [Lesta and Yacef, 2002] present a logic tutoring system where teachers manually set out the curriculum students will follow. [Suraweera and Mitrovic, 2002] discuss a tutor which helped students understand database design.

Some systems are not based on curriculum per se but the personalisation is still driven by content and an understanding of the level of difficulty of particular problems. For example, [Radlinkski and McKendree, 1992] present a COBOL tutor which focuses on a production system model of an "ideal student", suggesting what code errors a student has made and what type of code should follow what they have written. [VanLehn et al., 2002] present a tutor based on qualitative physics, the ANDES system [Gertner and VanLehn, 2000] [VanLehn et al., 2002] [Albacete and VanLehn, 2000], based on introductory college physics, which models beliefs, goals and knowledge about specific problems. Although the second language tutor presented by [Trust and Truong, 2011] doesn't currently personalise the content, content selection is highlighted as an element of further work.

Many of these content-based ITS have demonstrated evaluative success. The ANDES system has been deployed in two different studies which provided some indication that the ITS increased exam scores [Gertner and VanLehn, 2000] [VanLehn et al., 2002]. There is some indication that the maths tutor from [Lesta and Yacef, 2002] helped improve homework and exam scores. The database tutor from [Suraweera and Mitrovic, 2002] showed a successful increase in test scores compared to a control group.

Much of the work around software to support dyslexia is based on developing assistive readers which change the presentation of text [Kanvinde et. al, 2012], modifying the text-to speech element of talking books [Sampath et. al, 2009], controlling the movement of text in a software reader through tracking a user's gaze [Schneider et. al, 2011] and comparing a "phonic-based talking book" to paper versions of the same book [Wood, 2005]. Wood demonstrated that phonic-based software showed equivalent gains to those children given one-to-one adult tutoring with paper versions of the same books.

A variety of dyslexia-focussed tutoring systems have been developed which do not include a personalisation aspect. [Pandey and Srivastava, 2011] present a tangible spelling aid for children with dyslexia though the paper focuses on the development of a hardware system rather than focussing on use cases. [Rello et al., 2012] presents a dyslexia app where the personalisation element is limited to selecting a skill level of easy, medium and hard. [de Haan and Oppenhuizen, 1994] discuss a tutoring program to improve spelling skills. [Ndombo et al., 2013] present a comprehensive review of intelligent tutors for dyslexia. [Di Mascio et al., 2012] focus on story telling and other reading difficulties at a different level to the phonological difficulties we are focussing on.

Attempts have been made to create ITS based on trying to personalise reading support for children with dyslexia, notably in the AGENT-DYSL project. One of the focuses of the AGENT-DYSL project was personalising the system based on interpreting the child's voice, head pose and eye gaze [Tzouveli et al., 2008] [Athanaselis et al., 2012] [Asteriadis, 2009]. Interpreting speech and vision is not something computers are suited to, particularly in situations where the wrong interpretation could be extremely damaging, as is the case in sensitive educational contexts. We are thus advocating an alternative approach whereby we personalise the system based on things we already know a computer system can process accurately, namely grapheme processing, leaving speech development to human-to-human interaction.

Based on the literature we have reviewed around ITS and dyslexia, there appears to be a research gap which the iLearnRW program fulfils. This gap is based around having a tutoring system which is customised to best support an individual student's difficulties.

Our review of ITS more generally, and ITS for dyslexia, evidences that the focus of adaptation within this field has been on content. Although this is clearly necessary, there are a variety of other attributes which researchers have considered modelling in order to better personalise their learning experience. Learners' affective state has been one of them with Desmarais and Baker going so far as to argue that "Affect has perhaps been the area which has received the greatest interest within learner modelling" [Desmarais and Baker, 2012, p. 28]. For example, Conati worked on detecting affect in educational software, using a combination of physical sensors and aspects of log files to detect student's emotions when playing an educational game [Conati et al., 2003] [Conati and Maclaren, 2009]. [Mota and Picard, 2003] developed a model that could infer, from posture, a student's interest. [Chaouachi and Frasson, 2010] use affect detection based on EEG sensors to study student attention when interacting with educational software. [Chaffar and Frasson, 2004] created an affect architecture that provided the means through which to predict – and induce - an 'optimal' emotional state. [Baschera et al., 2011] presented a model of engagement dynamics in learning spelling. A comprehensive review of this work is provided by [Desmarais and Baker, 2012].Motivation has also received some attention from the user modelling community. [de Vincente and Pain, 2002] developed a model to detect several aspects of motivation, Conati and Maclaren (2009) modelled learner goals. Rebolledo-Mendez et al. (2006) modelled effort, confidence and independence within an intelligent tutor. [Costagliola et al., 2010] detailed a method for modelling attention based on body posture in front of a monitor. Unfortunately, one shortcoming of this work is its lack of evidence in terms of improving the student's educational performance.

A third and final attribute, which has been considered in the area of user modelling is learning style, particularly the distinction between verbal and visual learning styles. In evaluating the impact of this approach, several studies have demonstrated no statistical difference between students matched to their learning style and those who were unmatched, even if student's qualitative reports indicated that they preferred being matched [Brown and Brailsford 2004] [Brown et al., 2006] [Brown et al., 2006b]. Although learning styles have been discussed within the context of dyslexia, we do not consider them given their elusive and dynamic nature.

To summarise this section, we have seen how user modelling is one of the main techniques of providing the "intelligent" aspect of Intelligent Tutoring Systems. Having analysed those tutoring systems based around dyslexia, we can conclude that the combination of the reading and game components of the software, both personalised to a student's individual educational needs is novel within the field of developing an ITS for dyslexia. We moved on to note that the majority of ITS base their personalisation around the selection of content and that, when evaluated, such systems improve student's exam scores. We then considered what other attributes, beyond content, have been modelled within ITS, noting that affect and motivation have both received considerable attention though it is less clear how successfully such models improve student's educational abilities. In having presented the need for, and applications of user modelling, the remainder of this document considers what attributes we model for the iLearnRW project.

5. Designing the attributes of the iLearnRW User Model

As we stated when discussing what a user model consists of, in essence any user model consists of three components; the data being stored about attributes of a user, the algorithms which process this data to affect change on the computational environment and the method by which the data is obtained and updated. The following three Sections will consider each of these components in turn, with this Section focussed on what user attributes the model will include.

Selecting what user attributes to model can be viewed as a design exercise. There are various ways of conceptualising the process of design. These processes are important to recognise given that the method of carrying out design has a direct impact on the resulting 'artefact', in our case, a user model. Given that we apply a design lens on user modelling, it is necessary to explain what we mean by 'design'. [Fallman, 2003] describes three different philosophies to design: the *conservative*, the *romantic* and the *pragmatic*.

According to the *conservative* account of design, "the design process is supposed to progress gradually from the abstract (requirements specifications) to the concrete (resulting artefacts). Progress is achieved through following a series of well-described, discrete, rational, and structured methodological steps" [Fallman, 2003, p. 226]. [Simon, 1996] was the main proponent of design as a rational process (also known as being reason-centric). This process characterises design as a search process, in which designs are selected based on how well they fulfil the needs of a set of fixed requirements and constraints.

The *romantic* account highlights the role of the designer, focussing on their ability to be creative and thus construct designs in a black-box manner. This perspective expresses the ways in which design might be approached within the art or drama. We do not utilise that approach within the iLearnRW project.

The *pragmatic* approach "takes the form of a hermeneutic process of interpretation and creation of meaning, where designers iteratively interpret the effects of their designs on the situation at hand. It is a reflective conversation with the materials of the design situation" [Fallman, 2003, p.227]. The pragmatic approach has gained popularity due to the recognition that a reason-centric process is not an accurate reflection as to how designers actually work. Additionally, the process assumes that requirements and constraints are well-known and fixed [Ralph, 2010]. Schon [1983] elaborates on this view to define design as a 'reflective conversation with the situation'. Problems are framed by designers (where goals are identified), who then take actions (or make 'moves'), which are then reflected upon as to whether the new design has improved. It has been argued that reflection-in-action is better suited for conceptual problems with no clear strategy to success [Dorst and Dijkhuis, 1995].

Within the iLearnRW project, we have followed a process that integrates many of these processes together. Sections 5.1 and 5.2 describe the process of creating the User Model for English. The structure of the model and the initial version of the English model were passed to the project's Greek dyslexia partners (EPIRUS) who used the structure to create the Greek version of the User Model, as detailed in Section 5.3.

5.1. Conservative Approach

5.1.1. Aims and methods

The first stage of selecting the attributes to be modelled followed a conservative design approach. This entailed considering what aspects are currently modelled during tutoring sessions with dyslexia-specialist teachers. We note that this approach follows the process undertaken by many ITS designers (see Section 4). Based on a 1-day workshop with 5 Dyslexia Action (DA) teachers (and 1 Dyslexia Action teacher trainer), we identified that the main student attributes which teachers focused on were their linguistic abilities. We expanded this to a list of 9 linguistic difficulties of high priority which students typically encounter (see Figure 2a).

(1) Syllable division refers to the difficulty some children have in dividing longer words into smaller chunks (i.e. syllables) which are more manageable. **(2) Vowel sounds** refers to the challenge that in English there are many vowel sounds which share the same latters (e.g. "i" in did vs. "i" in ivy). **(3) Suffixing** and **(4) Prefixing** are both skills which some children with dyslexia struggle with. **(5) Grapheme/phoneme correspondence** is similar to vowel sounds but with consonants (e.g. the phoneme /sh/ appears as "sh" in shop and "s" in sure). **(6) Letter patterns** refers to the difficulty that some letter patterns have (e.g. "mb" in bomb). **(7) Letter names** refers to a student needing to learn that names of the letters in the alphabet. **(8) Irregular/sight words** covers those words which do not follow any of the patterns within English (e.g. sword). **(9) Confusing letter shapes** refers to the fact that some graphemes are visually similar (e.g. "b" and "d") which can be challenging for children with dyslexia.

Some of these difficulties may contain a series of specific cases, which need to be learnt to master the higher-level difficulty. To ensure the inclusion of these sub-cases, we conducted a comprehensive review on several literacy programmes starting with the Dyslexia Institute Literacy Program (DILP) [Walker et al., 2008], which is the literacy program most commonly used within Dyslexia Action Centres. These difficulties were supplemented with information from Units of Sound 1, 2 and 3 [Bramley, 2004] and Alpha to Omega [Hornsby et. al, 1999], which are two other well-known, respected and used literacy programs. We also consulted an assessment pack, the Dyslexia Portfolio [Turner, 2008]. Association between phoneme and graphemes is based on the IPA as presented by [Adonis and Hughes, 2007]

Before we can explain how this workshop informed the structure of the user model (Figure 2), it is necessary for us to briefly consider the structural nature of English. "The character structure of words in alphabetical languages like English... represents the sound structure of these words... People at different levels of spelling expertise seem to use different strategies that make a different use of the structural relations between sounds and signs of words. Experienced spellers write familiar words as a unit, while less experienced spellers attempt to convert phoneme chunks successively into character chunks. At the lowest level, single phonemes are transformed into characters" [de Haan and Oppenhuizen, 1994, p. 25]. The problem in converting sound by sound is that in most languages there are many alternative ways to write a particular sound. For example, the sound /k/ in cat can be spelt as k, c, ch or ck. Capturing this was a consideration in developing the iLearnRW user model.

5.1.2. Structure and Properties of User model

The User Model is characterised by a series of superordinate difficulties. Six out of these difficulties, contain a series of subordinate exact cases.

Figure 2a represents the final set of high level difficulties that students with dyslexia can experience. The list contains the 9 key superordinate difficulties identified during our workshop by the dyslexia teachers. The first 6 of those difficulties are associated with an index. Each superordinate difficulty includes a range of cases whose complexity, and thus difficulty, increases. The index represents the position within the set of subordinate specific cases of that superordinate difficulty that a given child is currently working on. An index of 0 indicates that a given child has no problems with that difficulty.

The user model expressed in Figure 2a demonstrates that the child has no difficulty with Syllable Division, Vowel Sounds, Prefixing or Letter patterns.

When the index is more than 0, it links to a position in a second array, which holds details on the specific subordinate sub-difficulties within the superordinate difficulty. In Figure 2b, the suffixing superordinate difficulty has an index of 3, which indicates that the specific cases in indices 1 and 2 (-s and -ed) have been dealt with and that the suffix -es is currently being worked on. Within Figure 2c, an index of 2 for the grapheme/phoneme correspondence superordinate difficulty indicates that the phoneme /p/ is currently being worked on, with index 1, the phoneme /t/, having been dealt with.

2a: Nine linguistic areas of difficulty

Difficulty	Index
(1) Syllable Division	0
(2) Vowel Sounds	0
(3) Suffixing	3
(4) Prefixing	0
(5) Grapheme/ Phoneme Correspondence	2
(6) Letter patterns	0
(7) Letter names	Exception
(8) Irregular/sight words	Exception
(9) Confusing letter shapes	Exception

2b: Breaking down Suffixing

Index	1	2	3	4	5	6
Specific Case	-s	-ed	-es	-en	-ish	Doubling rule
Expanded Case	(s), (z)		-less, -ness	-ing, -ful		-ing, -ed, -en, -ish
Teaching Point	6	18	22	33	38	45
Severity	1	1	3	1	2	3
Example Word	snips, pins	ended	passes, endless, sadness	dampen, camping, cupful	blackish	grabbing, padded, sadden, thuggish

2c: Breaking down Grapheme/Phoneme Correspondence

Index		1	2	3
Specific Case	Phoneme	/t/ (t)	/p/ (p)	/n/ (n)
	Grapheme	t	p	n
Expanded Case		tt, -ed	pp	nn
Teaching Point		1	3	4
Severity		1	3	3
Example Word		tap, butter, jumped	pen, happy	net, funny

Figure 2: The Structure of the iLearnRW User Model.

Appendix A contains a series of tables detailing each difficulty and the specific cases it contains.

So far, we have described which difficulty areas we are focusing on and how these areas link to specific cases within the superordinate difficulty. The difficulties *vowel sounds* and *grapheme/phoneme correspondence* are different from the other difficulties in that both difficulties have a split between phonemes and graphemes within the specific cases of that difficulty. Each specific case of a difficulty has additional information associated with it. The expanded case provides a detailed set of difficulties for each point. For example for the suffix -es (index 3, Figure 2b), it is also necessary to cover the suffixes -less and -ness.

The teaching point associated with each specific case is an index into DILP, the Dyslexia Action curriculum. This will not be implemented within the User Model but is a reference point for the project to access the information and word lists associated with that teaching point within the DILP teaching materials.

The severity level associates each specific case of a difficulty (such as the suffix -es, Figure 2b) as to whether it always occurs (level 3), sometimes occurs (level 2) or never occurs (level 1). We will discuss the meaning and use of this assessment of severity in Section 7 when discussing how the attribute data is gathered and updated.

The final piece of data associated with each specific case of a difficulty is an example word which illustrates the difficulty under consideration. This is particularly useful when considering subordinate difficulties involving graphemes and phonemes. For example, to take the grapheme “ea”, unless you understand IPA symbols, it is impossible to know whether it refers to the phoneme in “sea” or the phoneme in “bread” without an example word.

5.1.3. Exceptions

Figure 2 described the structure for holding information on 6 of the 9 main difficulties and recognised three exceptions which we now detail.

Letter names follows the same indexed structure as the difficulties in Figure 2 but only holds the index, name of the letter, teaching point and severity level.

Irregular/sight words are also associated with an index into 6 categories. The categories are informed by the DILP Key Word to Literacy lists and similar lists included within the Alpha to Omega teaching program. In essence each category is based on the frequency with which a particular word is used. The “master” list of irregular words is thus segmented into the following categories:

1. The first 12 words
2. The next 20 words
3. The next 68 words
4. The remaining 265 words
5. Words with silent letters
6. Any word from the 500 most frequent words

Word lists for the first 5 of these categories can be found in Appendix C.

The Confusing Letter Shapes difficulty is the biggest exception as it does not refer to an indexed list. Instead, each pair of confusing letters is stored within the User Model (see Table 1). Each pair of confusing letters is associated with a binary variable which indicates whether a student does (mark 1) or does not (mark 0) experience that difficulty.

a/o
b/d
b/q
b/g
d/q
d/g
q/g
m/n
m/h
n/h
r/t
r/f
t/f
k/x
l/r

Table 1: The confusing letter shapes used within the iLearnRW project

Understanding words from context is an important linguistic skill which is related to skills of inference.

This can be a difficulty for students that have limited knowledge of the word or understanding of specific language use like metaphor and idioms which can result from limited exposure to language. Up to the age of about 8 most language is learnt though conversation and after that through reading. As many students with dyslexia do not read this can be limited. This can also be a strategy for students who have a good understanding of language but have difficulty with phonemic decoding. Because their understanding of language in context is very good they can make an educated guess at a word they cannot decode.

Modeling such a skill is difficult. However, within the confines of the iLearnRW project, we do not need to model a student's ability to understand words from context. Instead we present two complementary techniques for selecting words which are appropriate to test in context.

(1) Select any words which the student has highlighted as being difficult in their "tricky words" list. These would need to be seen in a sentence or a few sentences at least so that the student could then try and guess the meaning of difficult word.

(2) Select exercises where the words are selected based on the child's position within the syllable division, vowel sounds, suffixing, letter similarity and grapheme/phoneme correspondence superordinate difficulties.

5.1.4. Dysorthographia

It may appear that the focus of this model is on dyslexia and reading rather than dysorthographia and writing. Many of the superordinate difficulties which we have listed have demonstrable relevance for improving writing skills. Our Dyslexia Action experts made clear that one way of assisting children with dysorthographia is to practice deconstructing words into their component parts. This is equally true for Greek as it is for English. By understanding how words are formed from smaller units, a child's ability to construct words (i.e. writing) is improved. Thus those superordinate difficulties which focus on the deconstruction of words (namely syllable division, suffixing, prefixing, letter patterns and confusing letter shapes) are equally useful for children with dysorthographia as they are for children with dyslexia. We have also described a writing-focussed learning activity (the train dispatcher activity) in the User Requirements deliverable (see Deliverable D3.5).

Focussing on the curriculum-based approach has been noted to be difficult, despite being the approach taken by most designers of ITS. "This is very much like expert system development where the educators serve as the experts and we as the knowledge engineers trying to codify their expertise... it can be a struggle to extract them from the rules" [Anderson, 1992, p. 5].

5.2. Pragmatic Approach

5.2.1. Aims and Methods

The pragmatic approach to design is similar to the process of user-centred design (UCD), focussing as it does on a designer making decisions and seeing how they change the applicability of the design to the given design scenario. The pragmatic approach highlights the reflective process of design which is utilised in many UCD approaches.

Although UCD methods have been applied to the design of Interactive Learning Environments (e.g. [Rau et al., 2013] [Soloway et al., 1996] [Jackson et al., 1998]), little has been done in demonstrating how UCD techniques can be used to determine what attributes should be contained within User Models.

Given UCD's ability to explore ill-defined design problems and its focus on the experience of the designer we undertook a series of user-centered design activities to better understand how dyslexia specialist teachers currently personalise their teaching sessions for the individual needs of a specific child.

As designers, without undertaking a series of UCD activities, we would feel like the creation of the User Model was an automatic approach. We would have had no control/expertise over the development of the UM as we are not experts in dyslexia. Additionally the UCD activities open up the potential scope of the User Model to areas of interest that the conservative curriculum based approach would not consider and explore attributes that aren't typically accounted for in conventional uses of UM.

We spent a day observing specialist Dyslexia Action teachers (both with over 15 years of experience in teaching children with dyslexia) [DA1 and DA2] in intervention sessions, in addition to interviewing them. We additionally interviewed the head of a Dyslexia Action centre [HDA]. The observation sessions lasted approximately 5 hours and were not recorded. Observers kept detailed notes of their own observations and the teacher's responses to direct questions. The interview with [HDA] lasted for around 30 minutes, was not recorded but detailed notes were kept. We also interviewed mainstream teachers: a year 6 teacher [Y6T], a year 1 teacher [Y1T], a year 4 teacher [Y4T], and two SEN teachers [SEN1] and [SEN2]. The schools these teachers work at varied in terms of their socio-economic status. Each of the interviews lasted for an hour. The interviews with [Y6T] and [SEN1] were audio recorded and later transcribed. The other teachers were not comfortable being recorded so detailed notes were kept instead.

There is a limitation in the observation/interview methodology we have used. In interviewing teachers we are gathering a portrayal of the more general attributes they look for. Returning to our initial definition of UM, asking teachers about general attributes makes sense since it is more likely to trigger recall about relational attributes, rather than standalone facts. However, this is qualitatively different than asking them about one student at a time. While it is more powerful in the sense that the most salient characteristics will emerge, this approach might miss some of the detail about specific children.

In the interest of wanting to consider the broadest range of attributes a student with dyslexia might have, we decided to ask some DA teachers about one of their student's specific difficulties. As part of their training, the DA teachers are accustomed to reflecting upon their teaching sessions and identifying how they changed their teaching approach based on how a particular child was reacting. Three DA teachers provided information on a specific teaching session with a different child with dyslexia. In total we received reports on 5 different children ([HW], [SG], [LMS], [HR] and [OM].

Data from the observations, the interviews and the teaching probes was analysed using the thematic analysis technique [Braun and Clarke, 2006]. The following three sub-sections presents the results of these UCD activities. The next sub-section covers those attributes which have been identified by these UCD activities and included in the final User Model. The sub-section after that discussed those identified attributes which are accounted for by other aspects of the design. A third and final sub-section discusses those attributes which the UCD activities identify but which we are not utilising within the iLearnRW User Model.

5.2.2. Key findings

We will now discuss those attributes that the observations and interviews revealed as being significant and useable within the iLearnRW User Model. We will also indicate which teachers indicated that such attributes would be useful to model when considering how to best tailor tutoring support.

We should first note that the first aspect teachers were interested in modelling was the learning level [HDA] and using content specific for each child [HDA]. We have already described how the iLearnRW project models the difficulties each child needs to work on.

There was also the suggestion to "store a word bank personalised to the child" [HDA]. This was also something which our dyslexia experts had suggested. Within the project the word bank has been termed the "tricky words list". For further details on how the tricky words are used within the project, refer to the User Requirements deliverable (see Deliverable D3.5).

Likewise, a number of teachers also suggested that it was necessary to "assess the strategies they are using" [HDA] as lessons were "partly to do with showing them that there are support strategies that they can use themselves" [SEN1]. Although based around an individuals abilities, monitoring a student's skills is an alternative approach to modelling a student's ability with regards to a given difficulty (e.g. the student knows how to suffix using the doubling rule rather than the student knows how to suffix using "ing").

The second attribute our interviews revealed was the necessity to consider a pupil's interests [DA1]. Using "something the children can relate to… what interests the children" [Y6T] and "tailoring the sessions to the children's interests" [SEN2] increases a child's motivation. Many teachers suggested "having a conversation with the child about their interests and make game linked in with that e.g. ghosts, that can be used for multiple purposes" [SEN2].

Ideally these interests could be utilised to customise the gamified learning activities. Unfortunately, we do not have the resources to customise the games in such a way that they are skinned based on a child's interests, particularly when those interests could be extremely specific (e.g. dinosaurs or cars).

However, within the project we are utilising a child's interests through the content classification system. This system is used to select books for the reader which are appropriate for a given child. Such a selection can go beyond the child's linguistic skills and include a selection based on interest. We thus created a classification of fiction books based on the classification of fiction books from amazon.co.uk[1] and the Book Industry Communication (BIC) UK Standard Library Classification of Children's and Teenage Fiction – Genre Classification[2].

- Adventure Fiction
- Biographies
- Classics
- Thrillers
- Crime/mystery
- Animal Stories
- Classics
- Family Stories
- Film/TV connection
- Fantasy/Magic
- Fantasy Romance
- General Fiction
- Historical Fiction
- Horror
- Humorous Stories
- Medical
- Poetry and Drama
- Religious/Inspirational
- Romance
- School Stories
- Science Fiction
- Short stories
- Sport Stories
- War
- Westerns/cowboys
- Traditional Tales/Fairy/Folk tales/myths and legends

While this approach doesn't provide the degree of granularity of customisation that teachers envisioned (i.e. customisation based on very specific interests such as "dinosaurs" or "castles"), it provides what is currently possible within the constraints of the project.

---

[1] http://www.amazon.co.uk/Fiction-Books/b/ref=amb_link_162814547_12?ie=UTF8&node=62&pf_rd_m=A3P5ROKL5A1OLE&pf_rd_s=left-1&pf_rd_r=0GXVP7235G7MA8KMEBWH&pf_rd_t=101&pf_rd_p=361137207&pf_rd_i=266239
[2] http://www.bic.org.uk/files/pdfs/UKSLC_FINAL_101212.pdf

5.2.3. Attributes utilised in broad design strategies

There are five attributes the teaching sessions raised which we are not modelling per se but which are accounted for through other aspects of the software. These attributes were not modelled as to do so would be too complex; however they are integrated into the iLearnRW project through broader design strategies.

The first attribute is how independently a child can work: “Activities are very carefully selected as he is unable to work independently” [OM], “responds to challenging work” [HR]. This is accounted for by allowing a child to select which game they want to play from a limited selection based on their current abilities (see Section 9 on how the User Model is presented to the child).

Related to this is the second attribute which is dealing with failure. “A lot of the children have got a big problem with [overcoming failure]” [SEN1]. [Y6T] also discussed how what is motivating to a low ability class (particularly around giving out merits) is not at all motivating for higher ability groups. This indicates that we could model a child’s ability to deal with failure/willingness to be challenged in addition to what motivates them. In both cases, it is relatively clear how the program would change it’s behaviour (particularly around the selection of content and awarding “badges”) – it is less clear how such data could be gathered and handled in a reliable manner. We have accounted for this attribute by allowing the student to select which game they want to play from a limited selection based on their current abilities (see Section 9 on how the User Model is presented to the child). Dealing with failure has also been a design consideration within the creation of the learning activities.

The third attribute is any co-occurring difficulty the child may have. ADD [LMS], Dyspraxia [HW] and ADHD [HR] were each mentioned from our teaching session probes. While the range of co-occurring difficulties is broad, focussing on ADD and ADHD, these are addressed by “more frequent changes of activity” [LMS]. This is again dealt with by allowing a child to select which game they want to play.

When talking to teachers about what, beyond linguistic improvements, they would like their students to get out of their teaching sessions, three main aspects came up. These were subsumed into the attribute of non-linguistic difficulties. The first attribute was an improvement in memory [SEN2], the second was wanting to build self confidence and self esteem within lessons [DA1] [DA2]. These are legitimate concerns which are currently covered within the activities undertaken within Dyslexia Action intervention sessions. We are likewise attempting to improve memory skills, self-esteem and self-confidence through the learning activities used within the iLearnRW software. For example, the Pelmanism activity helps to improve a student’s memory skills.

The fifth and final attribute is the difficulty in reading moving text. [SG] “finds it hard to read moving text such as that on destination boards at a train station or airport”. Instead of modelling a child’s ability to deal with moving text, to maintain simplicity we have used this as a design guideline and avoided moving text in all proposed activities and reader functionalities.

5.2.4. Attributes which are not being used within the User Model

In addition to those attributes we are modelling and those which are covered by broader design guidelines, there are a number of attributes we found to be important but which go beyond the scope of the iLearnRW project. However, it is important to note what these attributes are as they could be of interest to other researchers. Additionally, they demonstrate that the UCD activities covered the broadest scope of possible User Model attributes.

Learning style was raised by two of our interviewees as teaching sessions should be tailored to use the “best way the child learns and adapt accordingly e.g. through muscle memory or visuals” [SEN2]

[HDA]. However, we've previously noted that tutoring systems which have attempted to model a student's learning style have not been successful. As such we are not considering learning style within the User Modelling aspect of this project. We have to be careful with learning styles, as when working with children with dyslexia, one of the main targets is not to change their own learning styles but to help them to adopt new ones. The teaching strategies are particularly associated with learning styles within the learning activities (see Learning Strategy Deliverable D3.5).

The second attribute was generating a self-understanding of what a particular child's aims were through "talking with the children about what they want to be able to do" [SEN2]. [DA2] mentioned something similar when discussing a particular student who really wanted to be able to read some of Jacqueline Wilson's books. This recognises that not all children will be able to overcome all of their dyslexia difficulties but teaching could be tailored towards helping a child to achieve their own goals. Such a model would be extremely rich but it is difficult to conceive of how a ITS could make use of such information.

The final aspect which our interviews raised was a child's behaviour during a session: "you might have someone who is being naughty or not trying and then I would say you need to concentrate" [SEN1] or the child might have "an attitude problem, them not applying themselves then we work very closely with the child… basically if it is a behaviour thing and we have a lot of strategies to bring that round" [Y6T]. Although behaviour has a clear impact on the way a teaching session runs, it is beyond the scope of this project to consider how we would change the program behaviour based on this. Tiredness was a particular issue which, although a behavioural aspect, we had not discussed before. "This session was good as the boys were less excitable than is often the case" [OM], "tired today close to end of term, feeling unwell" [LMS].

For all of the attributes thus far which we have chosen not to model, Sparck Jones presents a very concise argument as to why not: "we should restrict modelling to the user properties we have a chance of getting good information about... In general, the more indirect clues are the less helpful they are" [Sparck Jones, 1989, p. 357]. We are confident that we can gather, update and use valid information about a child's linguistic difficulties. We are less confident that the other attributes fulfil these criteria are pursuing them could be detrimental to the success of the rest of the project.

A final point to consider is that any Intelligent Tutoring System fits into a broader context. Some activities are best run in collaboration with parents at home. However, parents are not all the same – they have different technological skills ("the parents that were doing it [online secondary school selection] had a good level of literacy but as soon as you transfer it onto the computer they were completely thrown" [Y6T]) and different literacy skills ("will send a bank of questions home at parents evening, but the lower ability parents can really struggle as they may not have very good literacy skills themselves" [Y1T]) – which could necessitate the ITS changing its behaviour. Although such information doesn't directly relate to an individual, and thus would not normally be considered within the realms of a user model, it would directly impact upon a student's use of the technology. Although beyond the scope of the current project, this issue is something which we will need to consider and account for in the evaluation of the iLearnRW software project.

This far we have been focussing on a child's linguistic ability and what attributes are modelled during a teaching session. We should make clear that there may be a separate User Model which focuses on game components. For example, we may need to model the *type* of games that the child enjoys (puzzles, platform, rpg, sim, racing etc.). Such considerations are beyond the remit of this deliverable.

5.3. The Development of the Greek Profile

The Greek User Model was designed based on the initial version created for English. The same format was used, while the language areas selected include those that pose the greatest difficulties to Greek students with dyslexia. In creating the Greek User Model, the linguistic differences between English and Greek were taken into consideration, as these lead to different difficulties encountered by students with dyslexia. Two major difficulties that lead to differential patterns in dyslexic performance involve the transparency of orthography and grammar. Specifically, Greek is considered to have a highly transparent orthographical representation, with a relatively close grapheme-to-phoneme correspondence. English orthography, on the other hand, is considered non-transparent, while the graphemic representation of English phonology includes numerous non-systematic patterns, which require that English students employ rote learning and lexical memory to a much greater extent that Greek students do. As a result, English students with dyslexia encounter greater difficulties with English vowels, a problem that is non-existent in Greek, apart from few instances of spelling exceptions (see Table B.**3** in Appendix B.3). On the other hand, consonants with phonetic (or acoustic) similarity are a greater problem for Greek students with dyslexia, so the language area of Phonemes had to place greater emphasis on the acoustic similarities of consonants (Table B.**2** in Appendix B.2).

A second difference between English and Greek that leads to differential performance by students with dyslexia involves the transparency of grammar in the morphophonology of the language. Greek is an inflectional language, whereby grammatical relations are explicitly marked on almost all grammatical categories (i.e. articles, nouns, adjectives, verbs). Therefore, spelling is very highly correlated with grammatical and morphological awareness, an area that is often affected in dyslexia. Enhancing grammatical awareness is thus a useful strategy in improving spelling skills in Greek. As a result of the inflectional character of Greek, the Greek User Model was designed to include a category of difficulties with Inflectional/Grammatical suffixes (Table B.**5** in Appendix B.5), while function words like determiners, which also mark grammatical features (e.g. gender, number, case) also constitute an area of difficulty in dyslexia and were also included in the User Model (Table B.**8** in Appendix B.8).

As already mentioned, the Greek User Model was designed in the same format and based on the same rationale as the English User Model. Ten language areas were included (Figure 3), 8 of which include levels associated with an index. For example, the Syllable Division category (Category 1) includes 20 levels, each associated with an index number. The levels correspond to a specific instance (or environment) of the difficulty and they have been positioned in the scale in terms of learning complexity. This means that if a student is given the index 6, then he/she has already worked on levels 1-5 (or has acquired to a satisfactory degree) and is currently working on the specific instance illustrated in 6, that is, CVC-CV(C) syllabic structures. Two of the language areas included in the User Model are marked as binary, meaning that each student is characterized as either having difficulty in that area or not.

Difficulty	Index
(1) Syllable Division	0
(2) Phonemes: Consonants	0
(3) Phonemes: Vowels	2
(4) Suffixing: Derivational	2
(5) Suffixing: Inflectional / Grammatical	0
(6) Prefixing	0
(7) Grapheme-Phoneme Correspondence	0
(8) Grammar: function words	0
(9) Word Recognition: Sight/irregular words	Binary
(10) Letter visual similarity	Binary

Figure 3: Structure for linguistic difficulties

5.4. Language Difficulties not covered by the iLearnRW project

We fully acknowledge that there are a host of language skills which are not covered by our software and yet which are both important and difficult for children with dyslexia. Within any project it is necessary to scope certain aspects as being beyond the interest of the project. Within the iLearnRW project we have decided to focus on those difficulties which our dyslexia experts (both on the project and other dyslexia teachers) thought were important. Therefore we will not be considering aspects such as:

- Days of the week
- Months of the year
- Teaching the time
- Story writing
- Similes
- Punctuation skills
- How to use a dictionary
- Common French words used in English
- Analogies
- Proverbs

Which Alpha to Omega [Hornsby et. al, 1999] includes as important language skills. The Dyslexia Portfolio [Turner, 2008] also includes tests for non-word reading and reciting combinations of digits forward and backwards.

These are skills with language which go beyond the linguistic difficulties focussed on within the User Model and the iLearnRW project more generally. The reason for this is that these are skills which are harder to tutor through a machine, especially as they require a level of comprehension from the tutor (either man or machine). Additionally, these are not skills which integrate well into a structured intervention program as they are stand alone difficulties or difficulties which focus on very specific needs. For these reasons these difficulties are not currently covered by the iLearnRW software.

5.5. Summary

This Section has discussed those attributes which will be modelled within the iLearnRW software suite. After describing the general structure the User Model will have, we presented the linguistic elements which will be modelled. Full details can be found in Appendix A. Moving on from the linguistic difficulties, we presented a variety of user-centred activities to explore what other attributes we could model. We decided to include a child’s interest as an aspect of the User Model while accounting for a child’s ability to deal with failure through other means. We then discussed how the Greek User Model was developed. Finally we made clear that while this User Model remains focussed on a child’s linguistic abilities, there may be a separate User Model which accounts for game-only attributes.

6. Techniques for User Modelling

Having presented the data being stored about attributes of each user, we now move on to discuss the algorithms which process this data to affect change on the computational environment. We will begin by discussing the various statistical techniques which have been used within user modelling before concluding that they are overly complex for what we are attempting to achieve. We then move on to discuss rule-based modelling as the modelling technique we will be using within the iLearnRW project.

"Statistical models are concerned with the use of observed sample results (which are observed values of random variables) in making statements about an unknown, dependent partner. In predictive statistical models for user modelling, this parameter represents an aspect of a user's future behaviour, such as his/her goals, preferences, and forthcoming actions or locations" [Zukerman and Albrecht, 2001, p. 6].

Two main approaches are taken within the statistical modelling world; content-based and collaborative. The former suggests that "each user exhibits a particular behaviour under a given set of circumstances, and that this behaviour is repeated under similar circumstances. The latter is based on the tenet that people within a particular group tend to behave similarly under a given set of circumstances" [Zukerman and Albrecht, 2001, p. 6]. In our project, a user's behaviour is predicted from their past behaviour, arguing for a content-based approach. This is supported by our dyslexia experts' view on the expected behaviour of a user with their particular User Model. "Content-based learning is used when a user's past behaviour is a reliable indicator of his/her future behaviour" [Zukerman and Albrecht, 2001, p. 7]. Such a distinction has little impact on the statistical techniques which can be used.

6.1. Linear Modelling

Linear Modelling is a technique which takes the weighted sum of known values and predicts the value of an unknown quantity. Linear modelling is a very inexpensive technique which is easily learnable, extended and generalised [Orwant, 1996] [Zukerman and Albrecht, 2001]. As a straightforward example, one might take height and waist size as known values and then predict someone's weight. In the context of the iLearnRW project, linear modelling is too prescriptive for our needs. There is not a strong enough connection between a student suffering with any given linguist difficulty and a student having a verifiable issue with another given difficulty for linear modelling to be useful to us.

6.2. Beta Distribution

The Beta Distribution requires only two numbers in order to make predictions; the number of correct predictions and the number of incorrect predictions. From these it can generate both an estimate and a confidence level [Orwant, 1996].

To take an example from [Orwant, 1994], let us consider personalising a newspaper. All the UM has to collect is information of whether an article (which can be coded into belonging to an ontology of topics) was liked or not. Over time, as the number of "likes" and "dislikes" are collected, it becomes possible to answer questions such as "what is the user's preference for the Olympics topic" which can then be answered in terms of an estimate and the system's confidence of that estimate, both based on the Beta distribution.

Although such techniques could be suitable for other aspects of the project (for example, the content classification system), there is no conceivable single bit of data which could be used to provide useful information to the other components of the system (such as which exercise to play next, which difficulties a child needs supporting in the reader, classifying which text to read next or how to change the game).

6.3. Markov Models

A Markov model consists of a set of states, a set of probabilities which determine the likelihood of transition between these states and, for each state, a set of observation/probability pairs [Orwant, 1994]. At each time tick, the system may change. In other terms, “given a number of observed events, the next event is predicted from the probability distribution of the events which have followed these observed events in the past” [Zukerman and Albrecht, 2001, p. 9].

Markov models are particularly useful for certain behaviours such as website navigation [Zukerman and Albrecht, 2001] and physical location/activity within the workplace [Orwant 1994] where past actions are a good indicator of future behaviour. This is not necessarily the case with the iLearnRW project as the selection of activities is not only dependent on prior activities and the score within those activities but on other teaching principles (such as overlearning which dictates that content and skills need to be consistently practiced over time to ensure that the child’s potential memory shortcomings are overcome). However, of the statistical techniques we have discussed thus far, Markov Models are perhaps the most appropriate for this project.

6.4. Bayesian Networks

A Bayesian network is a directed acyclic graph where nodes denote variables and the arcs connecting nodes represent causal links from parent nodes to child nodes. Each node is associated with a conditional probability distribution which “assigns a probability to each possible value of this node for each combination of the values of its parent nodes” [Zukerman and Albrecht, 2001, p. 11].

As an example, let us consider the association between wet grass, a sprinkler system and rain. Figure 4 shows the connection between the two parent nodes (sprinkler and rain) and the child node (grass wet) alongside the conditional probabilities which determine the connection between the states. A model such as then allows us to ask questions such as “what is the probability that it is raining, given the grass is wet?”. If we change the nodes to represent dyslexia difficulties and their related exercises, it becomes clear why such a technique is of interest to us.

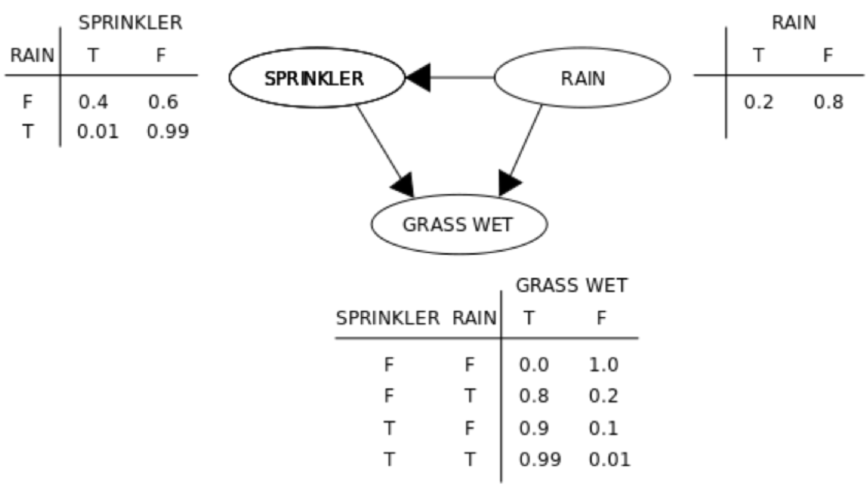

Figure 4: An Example Bayesian Network (from http://en.wikipedia.org/wiki/Bayesian_network)

This technique has a number of advantages including the ability to handle missing data (the model accounts for dependencies between all variables), its ability to deal with noise and the inherent flexibility of the model.

However, the technique has a number of disadvantages that prevent us from using this technique. Firstly, all branches must be calculated in order to calculate the probability of any one branch. The calculation of the network is NP-hard so can be costly [Hebert et al., 2006].

Of more concern is uncertainty over where the data comes from. The data can be either from a human expert or from data. [Lozano-Pérez and Kaelbling, 2002] [Conati and Maclaren, 2009]. We have no pre-existing data regarding these connections and it is beyond the resources of the iLearnRW project to collect such data, especially considering the restraints around privacy/confidentiality of children's information.

We are left then with getting our dyslexia experts to generate the probabilities to move between the various states. Unfortunately humans do not tend to think in probabilistic forms and it is difficult to provide validation as to whether the values they generate are correct [Lozano-Pérez and Kaelbling, 2002] [Conati and Maclaren, 2009]. Due to the difficulty in generating suitable probability values, we have decided not to use a Bayesian network.

6.5. Other techniques

There are a lot of other statistical techniques (such as TFIDF-Based Models, Classification, Cluster Mining, Rule Induction) which are not suitable for the iLearnRW project as they are designed for tasks which are too distinct from our learning context (for example, recommending films or documents) [Orwant, 1996] [Zukerman and Albrecht, 2001].

6.6. Stereotypes

Having discussed the main statistical techniques commonly used within user modelling, we move on to consider one of the main non-statistical approaches: stereotypes.

Stereotypes are used all the time in day-to-day life. "People use stereotypes as a means for dealing with the fact that the world is far more complex than they can deal with without some form of simplification and categorisation" [Rich, 1979, p. 331]. Common examples of people using stereotypes include credit agencies considering who is a poor risk, newspaper editors who consider what news people would like and advertising managers who base their campaigns on what appeals to various targeted populations.

Stereotypes are essentially "collections of facet-value combinations that describe groups of system users" [Rich, 1979, p. 331]. They "capture default information about groups of people" [Kay, 1994, p. 1] in the form of clusters of characteristics. For example, "stereotype a" might indicate that if a student has difficulties with the suffix "ing" they would also have difficulties with the prefix "un" and the vowel sound "/a/ (æ)". Alternatively "stereotype b" might indicate that if a student has no difficulty with the syllable pattern "vc/cv" then they have no difficulty with the suffix "able" but will have a difficulty with the vowel sound "/igh/ (aɪ)".

Stereotypes are particularly "useful mechanisms for building models of individual users on the basis of a small amount of information about them" [Rich, 1979, p. 329]. We have seriously considered using stereotypes as the means of initialising the user model as they give an opportunity to extract a rough approximation of the user model based on very little data, meaning that the user would not be particularly distracted from their main task when providing the data to form the stereotype.

Unfortunately our dyslexia experts argued that we currently do not have a clear enough understanding of the connections between the various linguistic difficulties we are storing data on to create a series of initial stereotypes. Instead, we hope that we will be able to extract these connections, and thus a series of stereotypes, at the end of the evaluation period of the iLearnRW project based on the User Models created and used during the evaluation stage.

6.7. Rule Based Modeling

"The terms "modelling" often implies a certain level of computational complexity. That is not always necessary – useful personalisation can often be achieved by making the right data streams accessible" [Orwant, 1996]. The statistical approaches we have listed here are relatively heavyweight, generally necessitating the creation of data which does not currently exist (e.g. the probabilities of transferring between states for the Bayesian network). However, "there is little to be gained if expensive mechanisms are used to achieve minimal improvements in usability and usefulness" [Fischer, 2001, p. 79]. We have thus settled on using a non-statistical, lightweight approach to performing the modelling algorithms; rule based modelling.

Rule based modelling is akin to the way that early user modelling systems depended on expert-crafted knowledge bases to make inferences about users. This was particularly true within plan recognition systems [Carberry, 2001].

As a technique, it is still widely used, particularly within knowledge tracing systems. Such systems attempt to provide assistance to a given problem using an ideal solution. In this case, the rules are a series of if…then… rules which model a student's current abilities [Corbett et al., 2008]. These rules can be applied against an "ideal mode" of how a particular task can be completed to determine which rules are known and which are not.

We are not generating the rules from user behaviour as some have suggested [Adomavicius and Tuzhilin, 2001]. Instead we are proposing the use of a series of if...then... rules, created in consultation with our dyslexia partners, which dictate the selection of which linguistic difficulty to work on, using what activity and with what content. These rules will be based on information stored within the User Model and the "logger" (the component of the system which stores the history of user actions with the software). Within this deliverable we will not be detailing the exact rules that will control the iLearnRW software. As the game and activities have yet to be fully specified, it is not possible for us to detail the exact rules. Instead, in the next section we discuss the broad principles and decisions which will be used within the iLearnRW software.

The rule-based modelling approach has a substantial advantage over the statistical approaches we have discussed in that we do not need to generate a substantial amount of data in order for it to work. Given the large range and number of dyslexia difficulties, a huge number of children would be needed to generate this data. Using a rule based approach we only need to rely on our dyslexia experts and information about current teaching practices.

7. How is the User Model data collected?

As we discussed in Section 5, the third aspect of any User Model is the method by which the data is obtained and updated. There are generally two methods to collecting data for a User Model [Tsiriga and Virvou, 2004]: (1) initialising the student model when a learner logs on for the first time (2) updating the model based on interactions with the system. We will discuss each of these aspects in turn and explore their suitability and application to iLearnRW.

7.1. How is the User Model initialised?

"Initializing a student model for individualized tutoring in educational applications is a difficult task, since very little is known about a new student… the process of the initialization has often been neglected or it has been dealt with using trivial techniques" [Tsiriga and Virvou, 2004, p. 290].

In general a User Model needs to be initialised as "an ITS runs the risk of losing its credibility and be considered as irritating and worthless to use by a student, if it fails to make plausible hypotheses about a student, before the student loses her/his patience with the system" [Tsiriga and Virvou, 2004, p. 291].

[Aïmeur et. al, 2002] distinguishes three distinct approaches used to initialize a student model:

1. The ITS can assume the student knows nothing and subsequently infer information from user actions (e.g. usage data [Hill et al., 1992])
2. The student can perform a pre-test
3. The system may use patterns among students in order to group similar students together [da Costa Pereira and Tettamanzi, 2006] [Milne et al., 1996]

Beyond the three approaches [Aïmeur et. al, 2002] laid out, there are some alternative approaches. [Guo and Greer, 2006] have also presented an alternative, namely to

4. analyse a portfolio of work

[Fischer, 2001, p. 69] reports that there are three main sources of user data, one of which is distinct from Aïmeur's approach:

5. communicating information from external events ([Harper et al., 1992])

We will take each of these alternative approaches in turn, discussing their relevance before selecting the approach which will be utilised within the iLearnRW project.

[Weber and Brusilovsky, 2001] demonstrate a system which takes the first approach, relying on in-use data to personalise the learning environment. Such an approach is relatively limited as the customisation of the iLearnRW software could only occur gradually as more and more data about a given student is collected. However, the form the User Model has taken ensures that if no other data is held about a student then they receive a comprehensive teaching program. This is targeted to the extent that content is provided based on their expertise. However it does mean that it takes some time for a given child to work through the skills they already have developed. Based on the principle of overlearning (see Learning Strategy Deliverable D3.2) this is no bad thing. The level of difficulty increases at a rate commensurate with the child's abilities. If the child is working on content which is too easy, the difficulty level increases quickly as the child is achieving scores in the learning activities (see Section 7.2) appropriate to increasing the difficulty of the activities. However, if the child is working on content which they find challenging, the difficulty level stops increasing.

The second approach is the simplest and using exhaustive pre-tests can produce answers to questions related to every aspect of the model. “This approach may be applicable in cases where the domain of interest is rather restricted” [Tsiriga and Virvou, 2004, p. 292]. In essence the advantage of this technique is that you can craft the pre-test such that it produces the exact data the User Model needs. Unfortunately this approach is somewhat error-prone as students are often not aware of their own capabilities [Hothi and Hall, 1998]. Additionally this technique has a shortcoming in that it forces users to undertake tasks unrelated to what they actually want to achieve. In the context of this project, a pre-test prevents a student from getting on and reading text or playing their educational games. “Users may be annoyed by being required to interact with a system and providing information without being aware of the use of this information” [Tsiriga and Virvou, 2004, p. 292]. There is a further weakness in that completing the pre-test prevents them from using the tutoring system in a way which is meaningful to them [Schwab and Kobsa, 2002].

One way of shortening the period of pre-testing is to use an adaptive approach that provides a dynamically generated individual test based on previous answers [Guzman and Conejo, 2002]. Others have described techniques to deal with the uncertainty factors in using pre-test data, including incomplete data and unsolicited behaviour such as skipping questions or guessing at answers [Sonamthiang et. al, 2006]. [Aïmeur et. al, 2002] provides a variation where a pre-test associates students with a stereotype.

We do not believe that this technique is suitable for the iLearnRW project. The reason for having a game component to the project is that it is inherently fun and motivating. Any pre-test system would interfere with that motivation. In addition, we do not have the resources to construct a rigorous assessment system to gather data to seed the model.

We have already discussed how the third option, utilising stereotypes, is not suitable for the iLearnRW project. This includes other approaches which result in a student being placed within a stereotype. For example, [Tsiriga and Virvou, 2004, p. 292] present an approach for seeding the UM by combining a series of pre-test questions which lead to a student being categorised into a stereotype group. The model is further refined by using a nearest-neighbour approach to refine the individual UM based on the values of other students within that stereotype group. As we have already argued, stereotypes are not an appropriate means of modelling our student group.

A fourth approach has been proposed by [Guo and Greer, 2006]. This involves using a constructed portfolio of work in digital form (an e-portfolio). The authors envisage a situation in which each student has a body of work in digital form which represents their formal learning to date. They go on to discuss how this information could be used to initialise a personalised tutoring system. This is, in many ways, an extended form of the pre-test option. Although this is theoretically the best option for modelling a student with dyslexia, due to the variety of difficulties a given child may have, the natural language processing necessary to make accurate assessments of a child’s skills and weaknesses makes such an option untenable.

Finally we have the fifth option of using information from some outside source. The most obvious source within the context of this project is from a child’s specialist dyslexia teacher. Based on the expert opinion of our Dyslexia Action partners, parents, mainstream teachers and SEN teachers do not have the expert knowledge to inform the initialisation of the User Model.

Based on an analysis of the various options we have thus determined how the User Model will be initialised. This is based on the first and fifth approaches we have discussed.

1. By default, all specific difficulties are marked as being needed
2. If a specialist teacher has information, we can turn difficulties off as the child does not need to practice that skill

If a teacher marks a difficulty as being unnecessary for a specific child, the child will automatically play one activity utilising that difficulty to provide additional evidence that it does not need supporting.

If we consider what this means most broadly, it is likely that any given child begins with experiencing content which is too easy and that they do not have a difficulty with. Although this means that the system is not personalised to a given child from the beginning (unless the teacher has done so) we do not consider this to be a bad thing. Firstly, it fits with the principle of overlearning, of teaching skills again and again to overcome the memory deficit that many children with dyslexia have (see the Learn Strategies Deliverable D3.2). Secondly, it allows users to become acquainted with the software before experiencing difficult content meaning that the child is not attempting to master the software **and** the linguistic difficulty at the same time. Finally we anticipate that such a structure will assist with the self-motivation/esteem aspects of the software. In addition to the activities being designed around it being OK to fail, the User Model passport also provides facilities for improving self-esteem/motivation.

7.2. How is the User Model updated?

Given the structured nature of the User Model we have presented, updating the User Model is relatively straightforward. We have decided to mimic the structured form of progression which is present in DILP [Walker et al., 2008], Units of Sound [Bramley, 2004] and Alpha to Omega [Hornsby et. al, 1999].

As a brief reprise of the structure of the English profile; there is a set of 9 key superordinate difficulties identified during our workshop by the dyslexia teachers. The first 6 of those difficulties are associated with an index. Each superordinate difficulty includes a range of cases whose complexity, and thus difficulty, increases. The index represents the position within the set of subordinate specific cases of that superordinate difficulty that a given child is currently working on. The Greek profile follows a similar structure with 10 key superordinate difficulties, 8 of which are associated with an index into a series of subordinate difficulties.

Based on the opinions of our Dyslexia Action experts, the severity level of a subordinate difficulty is improved after the child completes three distinct activities (if three distinct activities for that difficulty exist), using three distinct sets of words (if three distinct sets exist) one after the other and achieves a given score.

To improve a severity score from 3 to 2, the necessary score is 65%. In order to improve a severity score to 1 a score of 80% is necessary. However, not all activities are associated with a score; for example pelmanism always results in a score of 100%. In those cases, the time taken to complete the activity is comparable to the score. Those time limits cannot be set until the activities have been fully specified.

Once all of the sub-difficulties associated with a difficulty have a severity level of 1, the User Model indicates that the child no longer needs assistance with that specific linguistic difficulty.

As we discussed in Section 5, two difficulties do not follow the same strategy as the other difficulties in the User Model. Irregular/sight words are associated with an index into 6 categories like the other difficulties. As a reminder, the categories are:

1. The first 12 words
2. The next 20 words
3. The next 68 words
4. The remaining 265 words
5. Words with silent letters
6. Any word from the 500 most frequent words

In order to progress from one list to the next list, a child must complete sufficient activities such that each word within that list is marked as being correct three times in a row. This does not mean that the same set of words are used in the same activity three times in a row, but that words can be drawn from the entire list until all words in the last have been marked correct three times in a row. With the exception of the silent letters list, in each activity one word from every previous list is included to ensure it is not forgotten – for example, if a child is working on list 4, one word from list 1, list 2 and list 3 is included within the activity.

The Confusing Letter Shapes difficulty is the biggest exception to the standard structure as it does not refer to an indexed list. Instead, each pair of confusing letters is stored within the User Model (see table R). Each pair of confusing letters is associated with a binary variable which indicates whether a student does (mark 1) or does not (mark 0) experience that difficulty. In order to progress from a mark of 1 to a mark of 0, a student has to complete three distinct activities (if three distinct games for that difficulty exist), using three distinct sets of words (if three distinct sets exist) one after the other and achieves a score of 80%.

8. How Does The User Model Change The Behaviour Of The Software?

Strictly speaking, this is the purview of the User Requirements Deliverable (D3.1) and the work packages for each adapted component. Within this Section we will briefly mention how the User Model will be used by the other components of the iLearnRW software. We will then outline the principles as to how algorithmic decisions can be made based on the data held within the user model.

8.1. Play and Adventure Modes

The User Model only has one function with regards to customising the play and adventure modes. This is selecting activities which are appropriate for a given child to complete given their current set of linguistic skills.

Within the play mode, this is achieved by only unlocking certain badges/achievements when a linguistic standard has been met and subsequently limiting what activities can be played and what difficulties can be practiced.

Within the adventure mode the intention is to select a series of activities (~12) based on a child's User Model at that moment in time. Once all of these activities have been played, the next set of activities is determined.

Selecting the activities in this fashion ensures that we are providing a structured intervention program which is based on the Learning Strategies specification (see Deliverable D3.2).

Unfortunately, as the exact nature of the activities is yet to be determined, it is not possible to produce the algorithm which will dictate the selection of activities. However, we can state that the selection of the target difficulty is based on a selection algorithm which utilises three key pieces of data:

1. Which superordinate difficulty is currently ranked as being the weakest
2. The specific teaching method (visual etc.) utilised within each activity
3. The skills involved in each activity (e.g. pelmanism is an easier activity than whackamole)

These three pieces of data were selected in consultation with the dyslexia experts within the project. Additional information, such as the last games played or the content last used within a given activity, is also likely to be used within the algorithm.

8.2. Reader

The personalisation aspect of the reader is threefold – selecting appropriate content through the content classification system (which will be presented in Deliverable D4.4), customising the presentation of text and providing scaffolding of the text being read based on a child's linguistic difficulties.

In terms of content classification, the User Model needs to provide no information beyond the data we hold about a child's difficulties. Based on this data, texts can be classified on the basis of the number of words within it containing a difficulty (such as the –ing suffix) and thus rate how difficult it will be to read.

Secondly, the UM will hold data on a child's preferences with regard to the presentation of text. The details of these properties are discussed in the User Requirements Deliverable D3.5.

Finally we have the scaffolding elements, primarily delivered through highlighting those words which the child may find difficult. This again requires no further processing of the data within the User Model. Instead, the logger is checked for the last five distinct difficulties which have been worked on (in either the play or adventure mode) and these are selected as optional "skins" for the child to turn on and off. As a "skin" is turned on, it highlights all the words within the text which are associated with that difficulty.

9. How should the User Model be presented to the child?

Thus far in this deliverable we have described the way in which the iLearnRW user model fulfils the three main aspects of any user model, namely the data being stored about attributes of a user, the algorithms which process this data to affect change on the computational environment and the method by which the data is obtained and updated. We have also briefly discussed in broad terms the main ways in which the User Model is used to adapt the iLearnRW game, learning activities and reader components. We now move on to discuss a question which, although strictly speaking not essential to creating a user model, is important to achieving our educational aims - how should the User Model be presented to the child?

This Section is not intended to commit the project to delivering the visualisation of the User Model as detailed here. Any such visualisation must be considered to be an additional component, of lower priority than any of the core components. However, given that it will be necessary to have some method of accessing the activities we believe that the visualisation we are about to present allows the activities to be accessed through a system which is also educationally meaningful.

9.1. Open Learner Models

Making the User Model accessible to the student is not a new idea. Open Learner Models (OLM) are models of the user that are available for viewing by the learner. The main reason for considering OLMs is that they have been found to help in improving the learner's performance [Baker et. al, 2004] [Luckin and Hammerton, 2002] [Bull and Broady, 1997] as well as promoting reflection and planning, a view taken by many from a philosophical point of view (e.g. [Self, 1990] [Bull and Kay, 2008] [Bull et al., 1995] [Bull and Pain, 1995] [Zapata-Reviera, 2003]). It is common practice in many specialist sessions to show a student their progress in a given exercise over a period of time. This could be considered to be a form of OLM. These considerations go beyond the philosophical questions of whether it is morally right to allow the student to see the data being held about them, encouraging a transparent approach to education.

In addition to the educational factors, there are a number of additional elements which feed into the desire to open up the user model to scrutiny, namely "the right to access information about themselves, the accountability it enforces on the programmer creating and using the user model and the benefit of having the user verify or correct the information in the user model" [Cook and Kay, 1994, p. 1]. "If the learner is expected to take responsibility for their own learning, it seems inconsistent to expect them to tolerate an incomprehensible, inscrutable system which manages their learning. Ultimate control over adaptation requires that the user be able to see aspects of the current student model" [Kay, 2001, p. 118].

It is necessary to consider against whom we are comparing a given student against; the "average" student, a top student, a particular expert, a teacher, the threshold for an exam have all been proposed as possible benchmarks to compare against [Kay, 1997b]. Within the iLearnRW project we will base the comparison on a teacher's expertise as the data on the student's attributes are also based on intervention programmes and our dyslexia expert's knowledge.

On a theoretical level it has been argued that "some representations are better for supporting student reflection than others" [Kay, 1997b, p. 22]. However, while Bull and Kay [Bull and Kay, 2007] [Bull and Pain, 1995] [Bull and Kay, 2005] [Bull et. al, 2005] have proposed a framework to describe, compare and analyse different OLM systems, it does not take into account the visual form the model is associated with. Visualisations are important as they are the means through which the openness is achieved. If a student cannot understand the visualisation, how can they understand the model? If the student does not like the representation, why would they visit it?

Early approaches visualised the model in a form that easily matched with the machine representation of the data rather than considering how to present the model in a form that is meaningful in terms of the user's educational aims. Displaying the model as a tree, Cook and Kay have argued that it is important to include three other functions, that the model needs to "justify the value of the component; alter the truth value of the component and explain the meaning and purpose of this part of the model" [Cook and Kay, 1994]. Although "users found it [the tree representation] easy to use and intuitive" [p. 6], there is no evidence that it makes an educational impact. Within the iLearnRW project we will only be using the first of these functions. Altering the user model is not necessarily a function which children have the ability to use responsibly. What's more, it is not clear whether a child has the necessary ability to self-reflect and update the user model. With regards to the third function, the meaning and purpose of the model is consistent across all elements and does not need to be embedded into the visualisation of the model.

A variety of different visualisations have been used. The most commonly used is skillometers. These represent a student's ability in a given skill as progress along a bar (see Figures 8 through 13). Skillometers provide a "good first step… [as they] help the learner appreciate the current learning goals" [Kay, 2001, p. 118] although skillometers have had little evaluation in terms of the educational benefits they provide [Weber, 1999], [Koedinger, 1999] [Corbett et al., 2008]. Other representations have been used including illustrating the extent of knowledge above the neutral line and areas of difficulty below the line [Bull and Nghiem, 2002], a hierarchical tree structure [Kay, 1997b], a conceptual graph [Dimitrova, 2003], textual descriptions of knowledge [Bull and Pain, 1995], concept-maps [Cimolino et al., 2003] (see Figure 7) and textual explanations of a fuzzy logic model [Mohanarajah et al., 2005]. Bayesian graphs (see Figure 5) and haptic representations (where known concepts feel hard, difficulties are soft and misconceptions are soft and sticky, see Figure 6) have also been used. Finally, some have considered Embodied Pedagogical Agents [Girard, 2012] where support is provided through an anthropomorphic character.

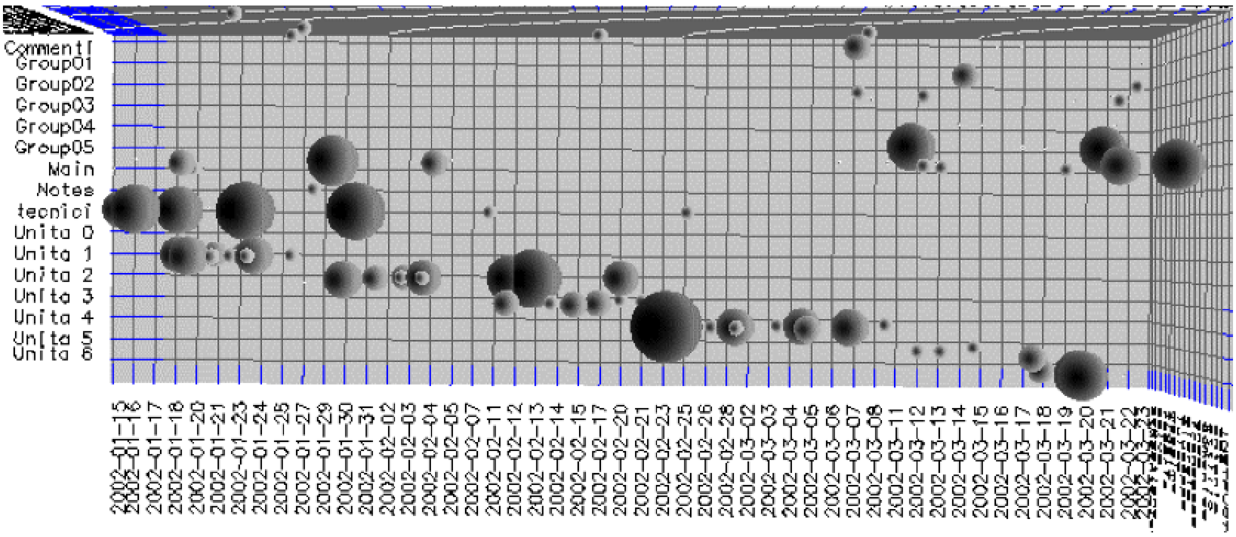

Figure 5: A Bayesian representation of a user model. From [Mazza and Dimitrova, 2004].

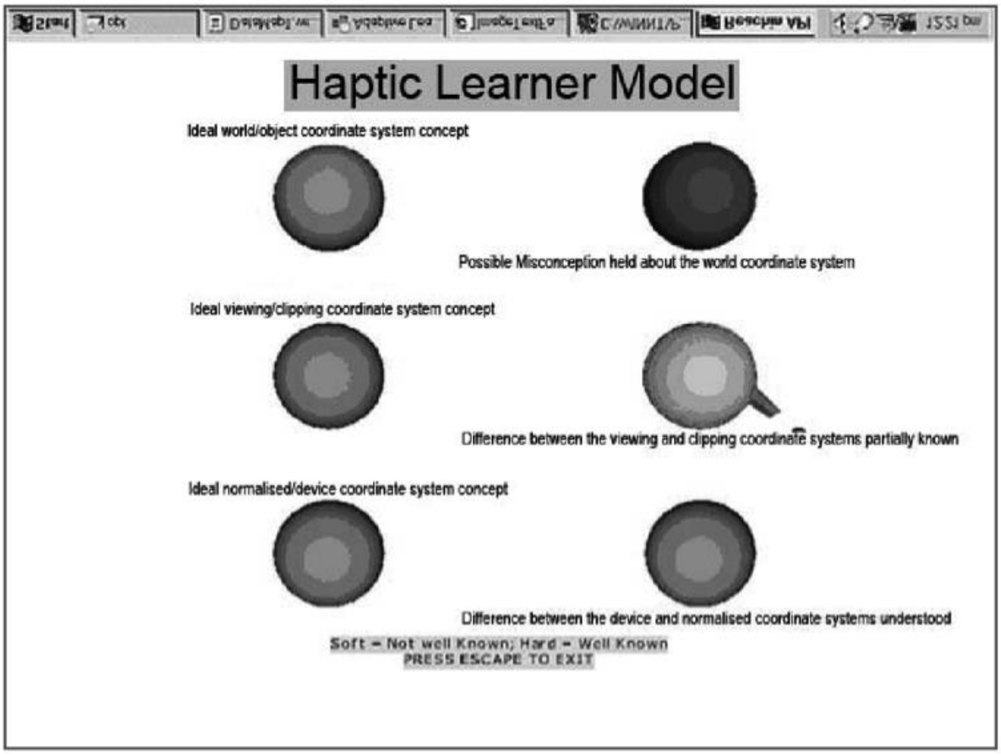

Figure 6: A Haptic Representation of a user model. From [Lloyd and Bull, 2006].

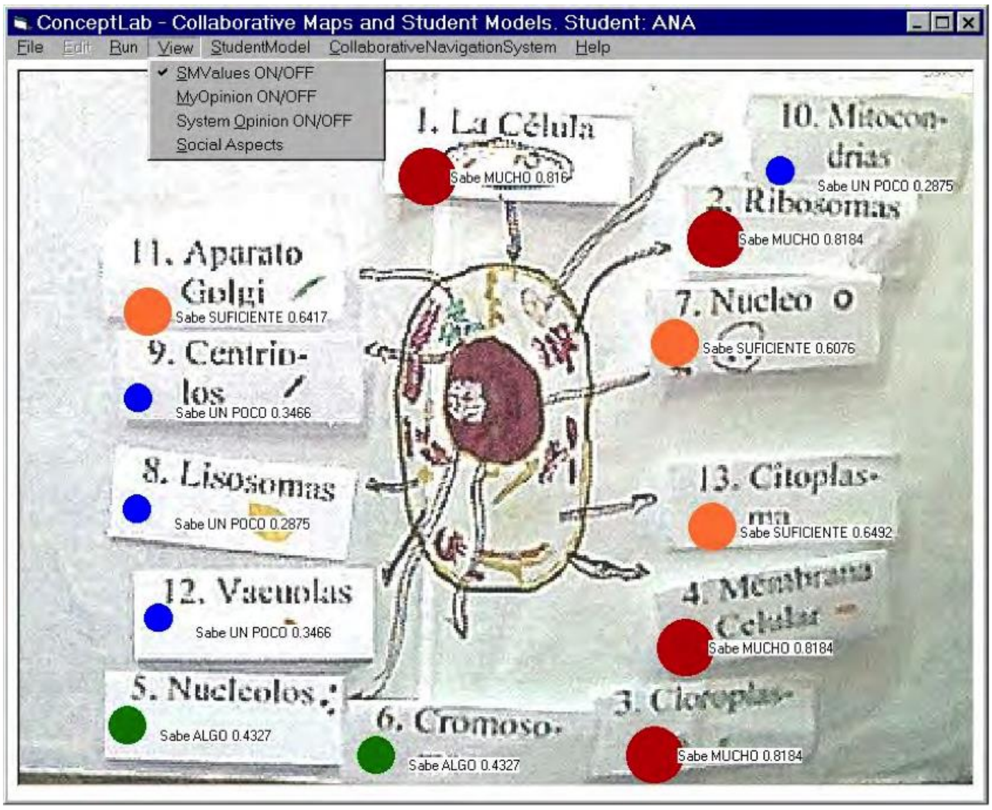

Figure 7: A concept map of a user model. From [Zapata-Rivera, 2003].

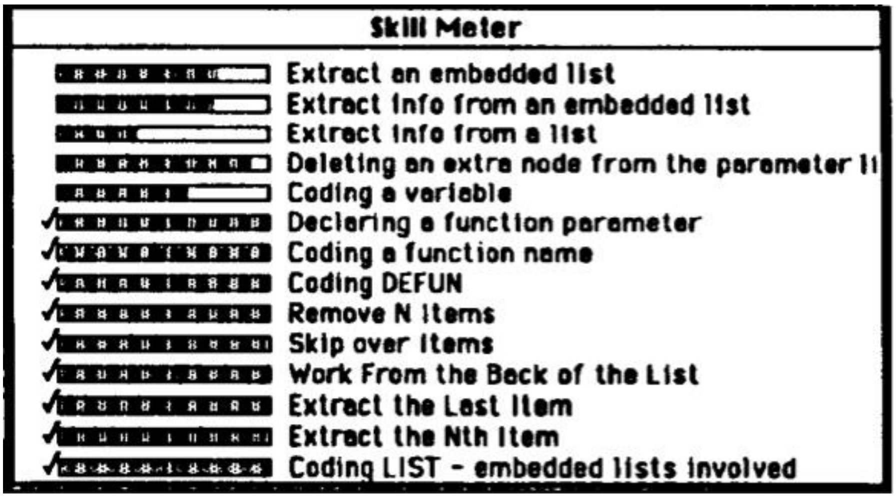

Figure 8: The skillometer from [Corbett and Anderson, 1995]

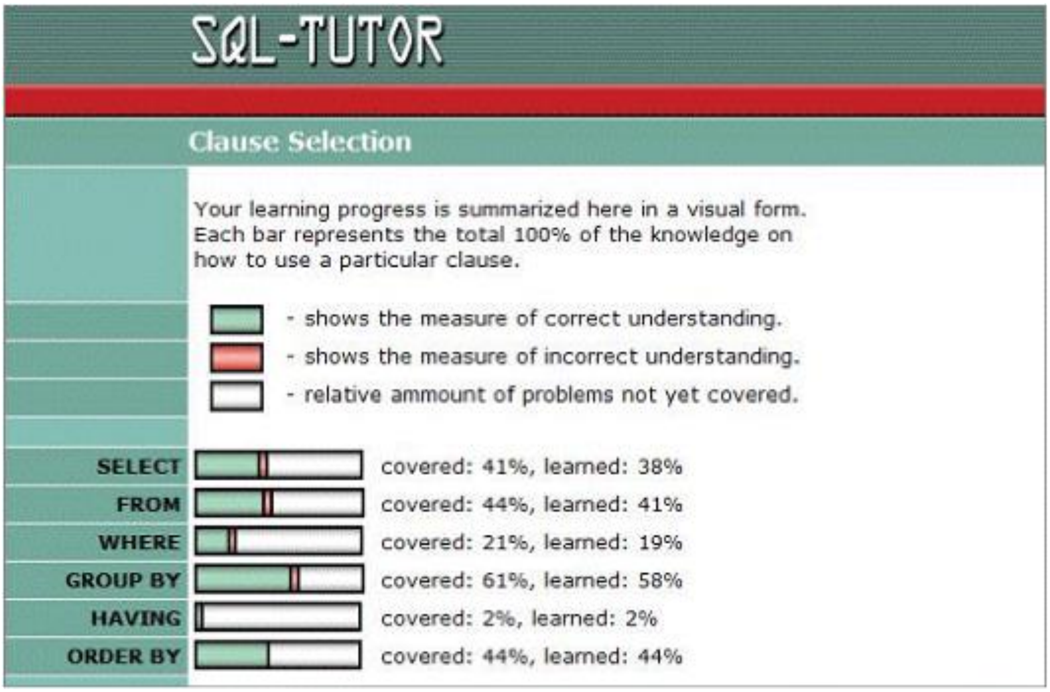

Figure 9: A skillometer representation of a user model. From [Mitrovic and Martin, 2007].

"In most of the studies performed on OLM, the targeted users are adults, from university students to elders, who can be expected to understand the role of reflection in learning. The educational and developmental benefits of using OLM with child users to improve reflective processes has yet to be clearly defined, and to date, mixed results have been found as to the willingness of children to use the learner model information, and how they use it. While Zapata-Riviera and Greer (2004) argue that children aged ten to thirteen can perform self-assessment and undertake reflection on their knowledge in association with an OLM, Barnard and Sandberg's study found that secondary school children did not look at their learner model when it was available to them for voluntary use (1996)" [Girard, 2012, p. 58].

One possible reason for these mixed results would be the visualisation technique used. [Bull and Mabbott, 2006] presented a study on students' preferences in representations. They highlighted skillometers as the most commonly used tool in OLM systems. There has been some consideration of how to present skillometers in a manner appropriate for children, representing knowledge level as coloured magic wands for 7-8 years old [Bull et. al, 2005] (see Figure 10), smiling faces to represent the different levels of knowledge for 8-9 years old [Bull and McKay, 2004] (see Figure 11) or as trees [Lee and Bull, 2008] (see Figure 12).

Figure 10: The Magic Wand representation of a user model. From [Bull et. al, 2005].

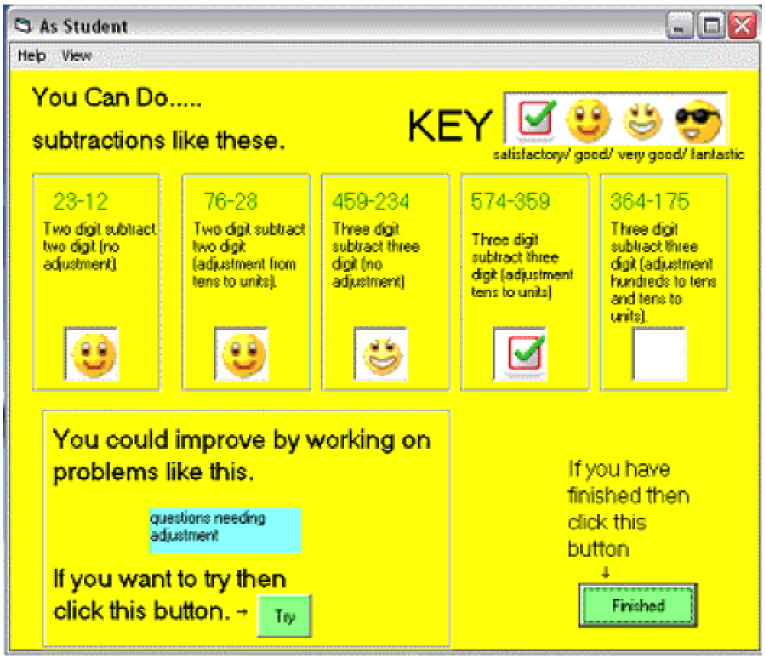

Figure 11: The Smiling Faces representation of a user model. From [Bull and McKay, 2004].

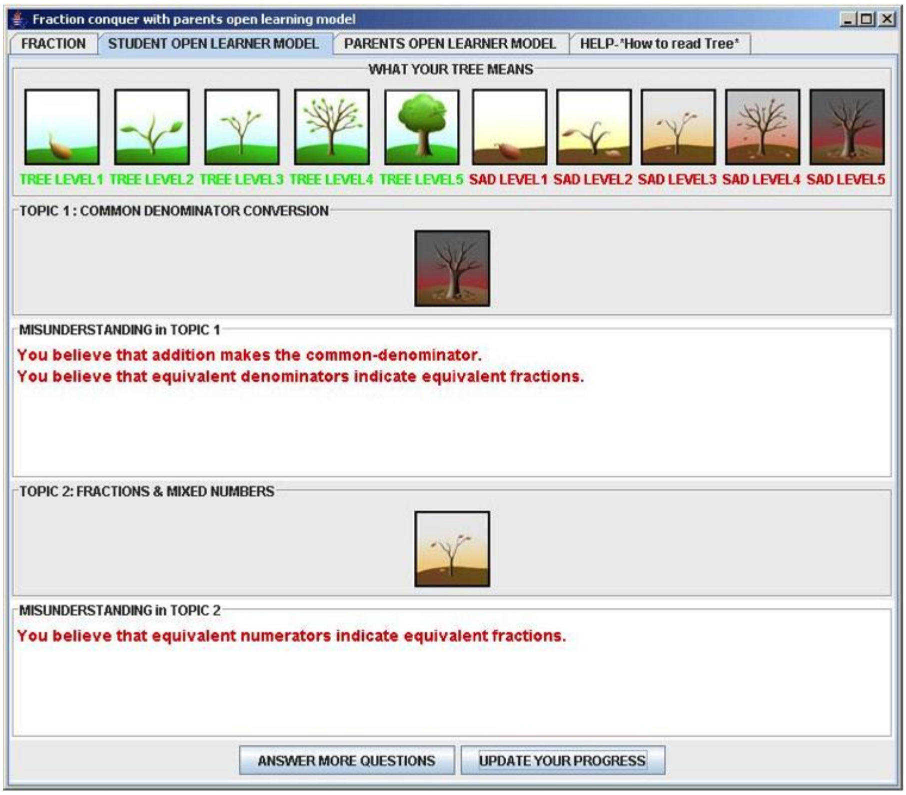

Figure 12: The Tree version of the skillometer. From [Lee and Bull, 2008]

Some dyslexia learning platforms (such as Units of Sound, Figure 13) also visualise a user's User Model using a skillometer-type view.

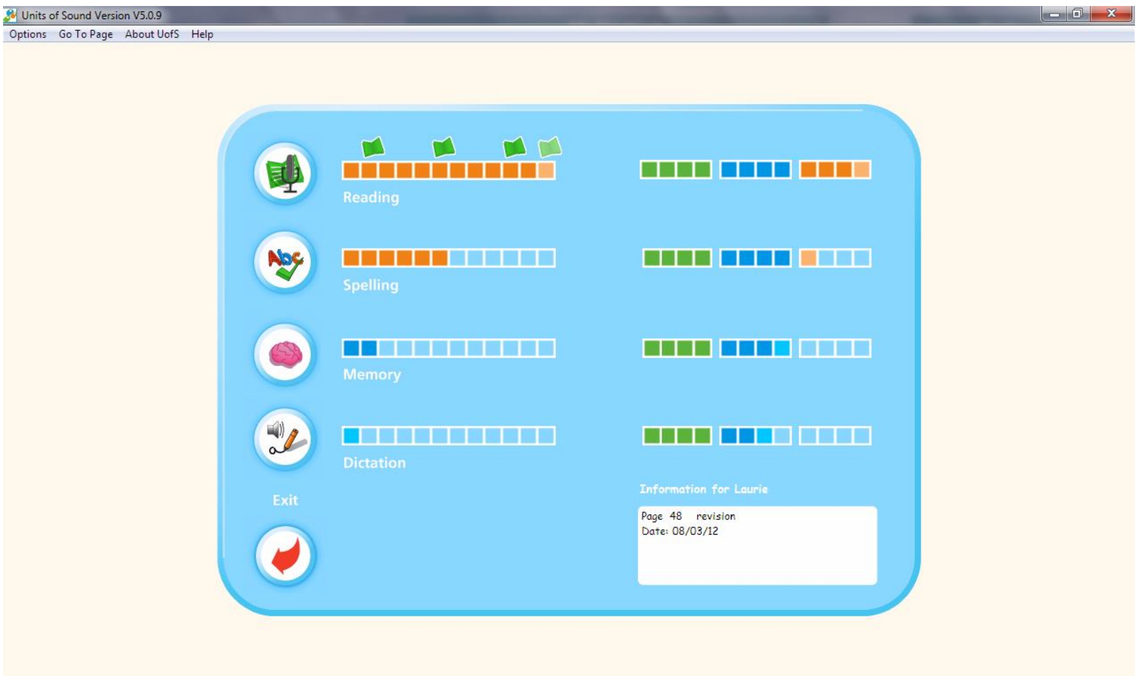

Figure 13: Units of Sound User Model visualisation [Bramley, 2004].

However, these representations are somewhat plain and un-engaging. In many areas there has been an interest in borrowing elements from gaming research in order to increase a user's motivation. The concept of using game mechanisms within other user interfaces is not a new idea. Malone wrote seminal papers deriving heuristics for designing enjoyable user interfaces in the early 1980s [Malone, 1981]. This interest in using game elements in non-game contexts is known as gamification.

9.2. Gamification

Deterding et al. present a discussion of the concept of gamification, its historical perspective and what it actually means [Deterding et al., 2011]. They define gamification as "the use of game design elements in non-game contexts" [Deterding et al., 2011, p. 10]. "Gamification uses elements of games for purposes other than their normal expected use as part of an entertainment game" [Deterding et al., 2011, p. 12].

Gamification has been applied to systems in many different contexts including crowdsourcing, technology to encourage users to change their lifestyle patterns to do more eco-friendly activities [Liu et. al, 2011], teaching game principles [O'Donovan, 2012], University orientation [Fitz-Walter, 2011], or assisting dementia sufferers [McCallum, 2012].

One of the more common aspects of gamification is the achievement system [Hamari and Eranti, 2011]. "The video game achievement system is a concept that has evolved over the last decade to become a very popular way to add extra challenges and play time to video games with little expense. Video game achievements are task-reward systems that usually reward the player with points, unlock bonus in-game material or simply exist as status symbols" [Fitz-Walter et. al, 2011, p. 122].

Considering the "Ten Ingredients of Great Games" identified by Reeves and Read, reputations, ranks and levels were identified as being an important element of games [Reeves and Read, 2009]. The Game Design Patterns derived by [Björk and Holopainen, 2004] identified rewards as a key component of games:

"Rewards are the positive effects that players hope to get by completing goals. The Rewards may be changes to the game state or other game-related effects that make other goals easier to complete, or may be effects outside the game... Rewards are one of the main ways game designers have to encourage players to do certain actions in a game. However, the players must be aware of the Rewards for the Rewards to be able to influence them, and players must feel that the Reward is purposeful either to advance their chances in the game or give enjoyable Extra Game Consequences" [Björk and Holopainen, 2004, p. 184]

"Representing achievements as badges or trophies is a standard practice in online gaming" [Antin and Churchill, 2011]. Badges and achievements have a history long before online gaming, having their roots in the medals of ancient Rome or the badges awarded within the Scout movement. One of the first large-scale implementations of badges in online games was in 2002 when Microsoft started the Xbox Live Service (Figure 14). Other online systems such as Steam also include badge and achievement systems (Figure 15). OpenFeint was a similar social gaming platform for mobile games (Figure 16). Many android game apps include similar achievement systems including Tap the Frog (Figure 17), Plants vs Zombies (Figure 18) and Cut the Rope (Figure 19).

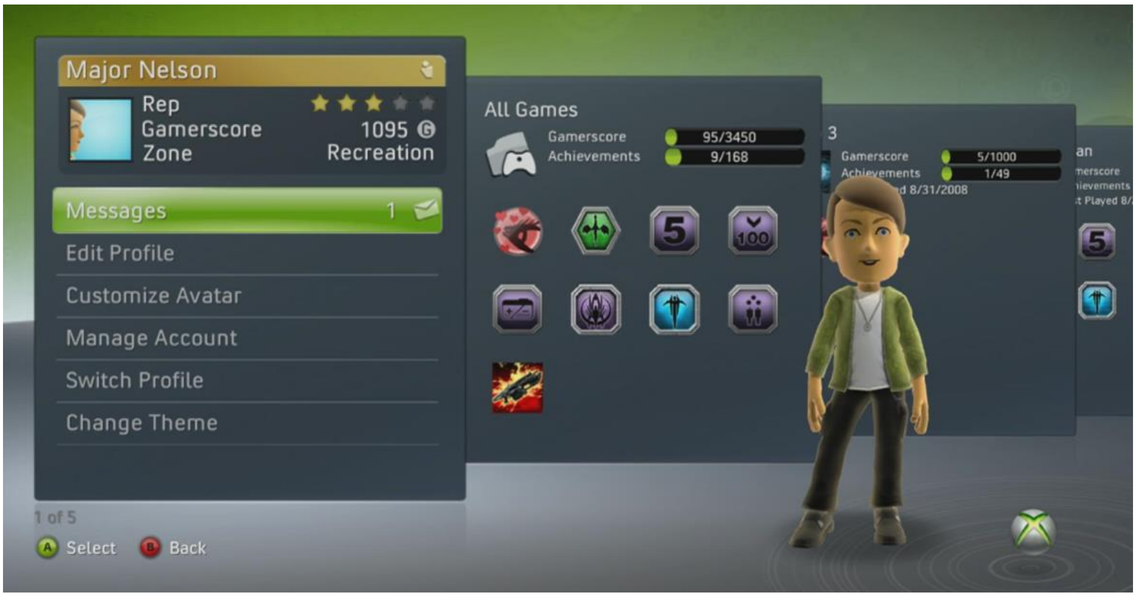

Figure 14: The Xbox Live Achievement system. (Image sourced from http://www.digitaltrends.com/wp-content/uploads/2012/09/nxexboxlive.jpg)

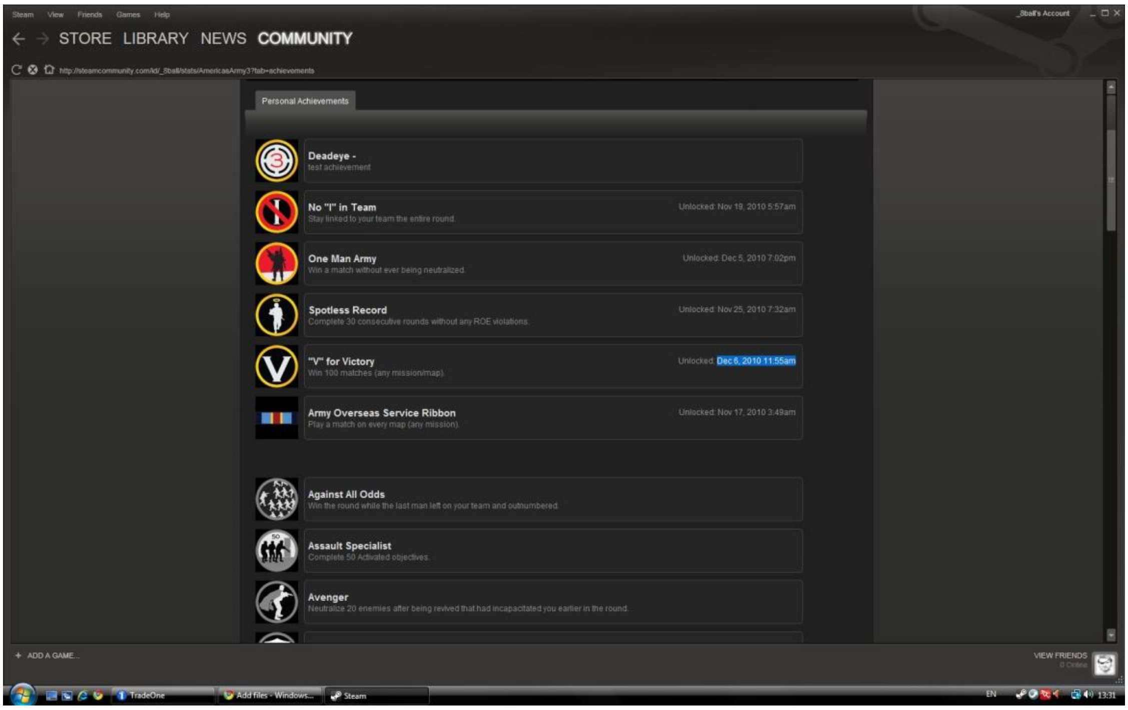

Figure 15: The Steam achievement system. (Image sourced from http://public.dm1.livefilestore.com/y2pbWKCr-Dv98y4q2zeXldfaASCt5aHlEX8ztMBnCRIxPQsk9Esiu8iHL0z2FQUh7tseOnVjignpivvp5mIZyhEg_MnEJRORQprxPtIP9UWz7Q/Achievemens.jpg?psid=1&rdrts=49718139)

Figure 16: The OpenFeint gaming platform. (Image sourced from http://www.insidesocialgames.com/wp-content/uploads/2009/10/OFFP2.jpg)

Figure 17: Tap the Frog achievement system. (Image sourced from http://main.makeuseoflimited.netdna-cdn.com/wp-content/uploads/2012/06/tap-the-frog-2-2.jpg)

Figure 18: Plants vs Zombies achievement system. (Image sourced from http://images2.wikia.nocookie.net/__cb20120205052229/plantsvszombies/images/4/4c/Achievement.png)

Figure 19: Cut the Rope achievement system. (Image sourced from http://www.mactricksandtips.com/wp-content/uploads/2012/02/cut-the-rope-achievements.png)

When considering the social psychological functions for badges in social media, [Antin and Churchill, 2011] establish four functions for badges which apply to learning technologies, namely:

- goal setting
- instruction
- reputation
- status/affirmation

In terms of setting goals, badges challenge users to meet the mark that is set for them. Setting goals is known to be motivating, particularly when those goals are just out of reach [Ling et. al, 2005]. Goal setting is particularly effective when users can see their progress, possibly because people can escalate their efforts when they know they are close to their goals [Fox and Hoffman, 2002].

Badges can also provide instruction through indicating the types of activities and interactions that are valued by the system [Kriplean et. al, 2008]

Badges are a valuable encapsulation of a user's interests, expertise and past interactions, and can thus substitute for direct experience [Kollock, 1999]. They can also provide information about a user's skill-set and expertise.

Badges can be motivating as status symbols. The power of status symbols stems from the expectation that other people will view you more favourably if you hold the badge [Berger et. al, 1972]. "Badges also provide personal affirmation in that they serve as reminders of past achievements much like trophies on a mantelpiece" [Antin and Churchill, 2011].

We should note that although "badges can be fun and interesting, these qualities do not inherently produce social engagement or enhance motivation" [Antin and Churchill, 2011]. In reality, "gamification typically uses only the least interesting part of a game - the scoring system" [Nicholson, 2012, p. 1]. We do need to note that "adding points to an activity does not make it a game. The derogatory term coined by Margaret Robertson for this reductionist approach to games is pointsification" [McCallum, 2012, p. 92]. Although we concur with this assessment, the Play mode of the iLearnRW project allows us to frame the passport visualisation in a gamified manner without it appearing arbitrary. Additionally, we are not trying to motivate use of the system through this gamified visualisation system. Our perspective is that users are motivated to play the game through the motivation built into the Adventure mode. The notion of rewards in games is pretty flexible: it's not just more points or badges. Rewards can be unlocking new content or gaining new abilities; a meaningful reward is one that enhances the player's abilities to do something either in the game world or outside of it. The Adventure mode of the project will focus on delivering such rewards; the badge/achievement style of the visualisation simply provides a supplementary form of motivation.

Some have noted that badges can be counter-productive as game mechanics [Hecker, 2010] and the "corruption effects of extrinsic incentives" [Deci, 1971] could make some badges harmful to intrinsic motivation. Game designers have expressed doubts as to whether achievements may obscure the core game experience shifting motives towards simply hunting achievements [Carvalho, 2009] [Hecker, 2010]. The "underlying message of these criticisms of gamification is that there are more effective ways than a scoring system to engage users" [Nicholson, 2012, p. 1]. A meta-analysis by [Deci et. al, 2001] of 128 studies that examined motivation in education settings found that almost all forms of rewards reduced internal motivation. However, they found that if the task was already uninteresting, as internal motivation was already low, reward systems did not reduce internal motivation. The implication of these findings is that if the external motivation is ever removed, the user's motivation will decrease. This is not an insoluble issue as it is difficult to conceive of the iLearnRW system removing the achievement system. However, if we are considering the broader context of learning, these issues are less contentious, particularly as some would argue that the education system has an achievement system of it's own: grades.

Within the iLearnRW project then, the visualisation of the user model is achieved through the gamification system of badges and achievements. This will also be the mechanism through which the activities are directly accessed through the menu system in the Play mode (refer to the User Requirements Deliverable D3.5 for details and visual mock-ups). Figures 20 and 21 show one design of what the iLearnRW visualisation might look like.

There remain elements of the achievement system which need to be clarified. The first is what does an achievement actually consist of? "Each achievement had a title and clue, accompanied by an image and text that were revealed when the achievement was completed" [Fitz-Walter et. al, 2011, p. 123]. [Hamari and Eranti, 2011] made a similar observation, arguing that each achievement needs a name, an icon/badge, a description of what the player has to do and an indication of what she will receive in return.

When considering the economic approach to the award of game badges, Easley and Ghosh distinguish between "some sites such as StackOverflow [which] award badges for meeting fixed levels of contribution, while others like Amazon and Y! Answers reward users for being amongst some top set of contributors on the site, corresponding to a competitive standard of performance [Easley and Ghosh, 2003, p. 359]. Within an educational context we would argue that it is necessary to award badges and achievements based on fixed levels of achievement. This models most school curricula where grades are based on fixed score levels. Additionally, if we are considering these badges as a motivational tool and a historical record of a student's progress it is more important to track progress on fixed levels rather than rank students against one another which could be un-motivating to a given child even if they are making progress.

In terms of progressing between the different badges that are available, "when an achievement was unlocked then immediate feedback was provided via a pop-up message. To make it challenging achievements became progressively harder to complete" [Fitz-Walter et. al, 2011, p. 124]. The progression between achievements will be selected using the rule-based methodology we introduced in Section 6 when discussing the various techniques which can be used within user modelling. As we stated there, the exact rules are not included within this deliverable as the exact nature of the game and the activities has yet to be determined. Instead, in Section 8 we outlined the principles which will guide the creation of these rules.

Without the exact details of the achievements it is impossible to design the visual appearance of the badges. When the rules have been completely established, we intend to use a user-centred approach to create designs which are visually appealing to children. A similar approach has been suggested by others (e.g. [Nicholson, 2012, p. 5]). The User Requirements deliverable D3.5 includes screen mock-ups of how the visualisation might look.

We should also consider that learner models can be opened up to people other than the learner [Hansen and McCalla, 2003] [Kay, 1997b]. Models open to teachers can allow them to follow a student's progress [Rueda et al., 2003], help teachers personalise their teaching towards individuals [Grigoriadou et al., 2001] [Zapata-Rivera and Greer, 2001] [Yacef, 2005], help teachers organise learning groups [Muhlenbrock et al., 1998] or allow the teacher to combine the information with data they hold from outside the system [Jean-Daubias and Eyssautier-Bavay, 2005]. Within the iLearnRW project we do not intend to allow teachers or parents direct access the user model through a visualisation. As we have previously discussed, specialist teachers will have the ability to edit and update User Models through an online form (see Section 7). Mainstream teachers will be able to produce forms which detail a child's progress (for details, see the User Requirements deliverable D3.5).

Figure 20: One potential design of the iLearnRW User Model visualisation

Figure 21: A potential design of how the activities might be accessed from the User Model visualisation

10. Next Steps

There are four main areas of future work with regards to the iLearnRW User Model. The first we have already discussed in Section 7; although we have laid out the principles of selecting activities and updating the User Model, until the activities have been fully specified we cannot produce the necessary algorithms. The other three areas are discussed within this Section. The first discusses how the User Model can be used to adapt the other components of the iLearnRW project. The second covers how we are testing the User Model, and finally the third sub-section refers to generating content for the project.

10.1. Adapting the iLearnRW Software

In terms of ensuring that the model adapts the software in a suitable fashion, we should not forget that "user models cannot and should not be separated from the software systems that use them. After all, what good is a user model if it will not be used for anything?" [Chin, 2001, p. 183].

It has not yet been determined how the different components of the iLearnRW project will be adapted based on the User Model presented within this deliverable. Although we have briefly outlined the principles of adaptation in Section 8, we will continue to work with the designers of each component to ensure that the User Model integrates with the software in a suitable manner.

10.2. Testing the User Model

"Contrary to machine learning evaluations, at present, there is no generally accepted methodology for the evaluation of systems which employ a user model" [Zukerman and Albrecht, 2001, p. 7]. Early user models were tested in terms of machine learning, whereby a training set of data is used to learn the model and a subsequent test set is used to evaluate the model's performance [Zukerman and Albrecht, 2001, p. 6].

What we must query is what it means to evaluate a model's performance. There are two distinct aspects of this - evaluating the model for correctness and evaluating the model for utility. In other words, ensuring the model is an accurate reflection of a student's ability and secondly, ensuring that the model is used to adapt the iLearnRW software in a suitable fashion.

Let us first consider evaluating the user model for correctness. It is generally agreed that "user modelling is an inexact discipline; assertions about user preferences and cognitive state are bound to be wrong much of the time" [Orwant, 1996, p. 1996]. Previous approaches have included theorising a series of Bayesian Networks, running data through them and comparing the results to see which BN produced the "best" result [Yudelson, 2008]. Such an approach will not work within the iLearnRW project as we are not applying a statistical approach.

"Another approach to validation is to validate assessments with external measures, such as post-tests of knowledge" [Desmarais and Baker, 2012, p. 27]. Such an approach will fit within the evaluation framework we have previously laid out (see Deliverable D3.4). The User Model has been structured in a conservative fashion such that if the data we receive is poor, or the User Model does not work as anticipated, every student still receives an appropriate program of teaching. Thus we will evaluate the correctness of the User Model in conjunction with the software as a whole; eventually comparing a student's User Model with their specialist teacher's assessment of their skills.

What we actually require is a nuanced approach whereby the UM is tested for accuracy independent of the system but evaluation must occur in conjunction with the software as a whole.

10.3. Generation of Content

Although not part of the User Modelling deliverable, we need to reflect on the process necessary to generate the content which will be used within the iLearnRW project. Although we have presented the word lists for Irregular/sight words in Appendix C, the project will need a lot more content.

Although procedural task learning (such as solving algebra problems) have had problems automatically generated [Andersen et al., 2013], our educational context necessitates the creation of a dictionary where words are tagged with the properties outlined in the User Model we have described. We will additionally need content in a longer form than individual words, namely sentences, paragraphs and short stories, such that students can practice their newly learnt linguistic skills in a more realistic setting.

We raise this as an issue as it is connected to the format the User Model has taken; the content within the iLearnRW system needs to be tagged in such a form that it can be sorted based on the linguistic difficulties highlighted within an individual's User Model.

APPENDIX A: Detailed English User Model

Before presenting the details of the English User Model, let us briefly reprise the structure of the User Model. See Section 5 for the full description. The User Model is characterised by a series of superordinate difficulties, namely:

1. Syllable division
2. Vowel sounds
3. Suffixing
4. Prefixing
5. Grapheme/phoneme correspondence
6. Letter patterns
7. Letter names
8. Irregular/sight words
9. Confusing letter shapes

The first six out of these difficulties, contain a series of subordinate exact cases. An index is stored for each of these superordinate difficulties, referring to the exact case a student is working on. This Appendix contains the detailed information of what each of those superordinate difficulties are.

Each of the tables in this Appendix follow the same structure. The "Index" represents the position that subordinate difficulty has within the general teaching program. The "specific difficulty" details what is being worked on (e.g. the suffix "ing"). The difficulties *vowel sounds* and *grapheme/phoneme correspondence* are different from the other difficulties in that both difficulties have a split between phonemes and graphemes within the specific cases of that difficulty.

The "expanded difficulty" provides a detailed set of difficulties for each point. For example for the suffix -es, it is also necessary to cover the suffixes -less and -ness.

The teaching point associated with each specific case is an index into DILP, the Dyslexia Action curriculum. This will not be implemented within the User Model but is a reference point for the project to access the information and word lists associated with that teaching point within the DILP teaching materials.

The severity level associates each specific case of a difficulty as to whether it always occurs (level 3), sometimes occurs (level 2) or never occurs (level 1).

The final piece of data associated with each specific case of a difficulty is an example word which illustrates the difficulty under consideration. This is particularly useful when considering subordinate difficulties involving graphemes and phonemes. For example, to take the grapheme "ea", unless you understand IPA symbols, it is impossible to know whether it refers to the phoneme in "sea" or the phoneme in "bread" without an example word

Superordinate difficulties 7 (Letter Names), 8 (Irregular/Sight words) and 9 (Confusing letter shapes) do not follow this exact structure.

Letter names follows the same indexed structure as the other superordinate difficulties but only holds the index, name of the letter, teaching point and severity level.

Irregular/sight words and Confusing Letter Shapes are not discussed in this Appendix as the full details for those difficulties are discussed in Section 5.

A.1. Syllable division

Index	1	2	3	4	5	6
Specific Difficulty	Closed and Open syllables	vc/cv	v/cv	v/v	vc/v	qu as vc/cv, v/cv and v/v
Expanded Difficulty						*squ, squa*
Teaching Point	*12*	*16*	*24*	*27*	*41*	*42*
Severity						
Example Word	pistol (closed), silent (open)	addict, connect, rotten	basic, defend, spiral	diet, bias, poet	banish, comic, level	banquet, equip, quiet, squirrel

Table A.1a

Index	7	8	9	10	11	12
Specific Difficulty	-ture	-tion	-consonant le	-sion	-cian	3 syllables or higher
Expanded Difficulty	*vc/cv, v/cv and vc/v*	*ation, otion, ition, ution, action, ection, iction, uction, ention*	*ble, fle, ple, tle, dle, kle, cle, gle, zle, stle. Both as open and closed*	asion, usion, usion, ision, ision, osion, mission, ession, ussion, version, ulsion, ssion		
Teaching Point	*68*	*70*	*73*	*96*	*102*	
Severity						
Example Word	capture, future, mature	creation, emotion, addition, evolution, action, collection, fiction, introduction, attention	bible, ramble, rifle, raffle, maple, sample, title, battle, cradle, saddle, pickle, bugle, angle, dazzle, castle	invasion, fusion, illusion, visio, decision, corrosion, admission, expression, concussion, conversion, compulsion, suspension	magician, politician, optician	Potato

Table A.1b

Table A.1: The subordinate exact cases for syllable division

A.2. Vowel Sounds

Index	1	2	3	4	5	6
Specific Difficulty (phoneme)	/i/ (ɪ)	/a/ (æ)	/o/ (ɒ)	/igh/ (aɪ)	/e/ (e)	/u/ (ʌ)
Specific Difficulty (grapheme)	i	a	o	i	e	u
Expanded Difficulty (grapheme)	*it*	*an, ap, at, ant*	*ot, od, op, ond, ost*		*ed, em, en, et, ep, end, ent, est*	*ub, ud, ug, ull, um, ump, un, unt, up, uss, ust, ut*
Teaching Point	*2*	*7*	*11*	*12*	*15*	*26*
Severity						
Example Word	did	bad	hop	ivy	bed	up

Table A.2a

Index	7	8	9	10	11	12
Specific Difficulty (phoneme)	/ar/ (ɒ:)	/ee/ (i:)	/or/ (ɔ:)	/i/ (ɪ)	/igh/ (aɪ)	/igh/ (aɪ)
Specific Difficulty (grapheme)	vowel-r (ar)	ee	or	y	y	ie
Expanded Difficulty (grapheme)	*ar, ard, ark, arm, arp, art, arve, a, as, ath*	*eech, eed, eel, eem, een, eep, eet, eeze, eer, e*	*orch, ord, ork, orm, orn, ort, ore, wor*	*i*		
Teaching Point	*47*	*49*	*50*	*51*	*51*	
Severity						
Example Word	car	free	or	carry	by	tie

Table A.2b

Index	13	14	15	16	17	18
Specific Difficulty (phoneme)	/igh/ (aɪ)	/ai/ (eɪ)	/ai/ (eɪ)	/ur/ (ɜː)	/oo/ (uː)	/oo/ (ʊ)
Specific Difficulty (grapheme)	i-e	a-e	ay	er	oo	oo
Expanded Difficulty (grapheme)	*ibe, ide, ife, ike, ile, ime, ine, ipe, ise, ite, ive, ize, ire*	*ade, ake, ale, ame, ane, ape, ase, aste, ate, ave, aze, are*			*ood, oof, ool, oom, oon, oop, oot, ooth, oor*	*ood, ook, oot, u*
Teaching Point	*53*	*54*	*55*	*59*	*62*	*62*
Severity						
Example Word	pipe	ate	day	her	food	good

Table A.2c

Index	19	20	21	22	23	24
Specific Difficulty (phoneme)	/oa/ (oʊ/əʊ)	/oo/ (uː)	/ee/ (iː)	/e/ (e)	/ow/ (aʊ)	/igh/ (aɪ)
Specific Difficulty (grapheme)	o-e	u-e	ea	ea	ou	igh
Expanded Difficulty (grapheme)	*obe, ode, oke, ole, ome, one, ope, ose, ote, ove*	*ube, ude, uge, uke, ume, une, use, ute, ure*	*each, eak, eal, eam, ean, eap, ease, eat, eave, ear*		*oud, out, ound, ounce, ount, ouse, our, ought*	
Teaching Point	*66*	*67*	*69*		*72*	*74*
Severity						
Example Word	code	cube	sea	bread	loud	bright

Table A.2d

Index	25	26	27	28	29	30
Specific Difficulty (phoneme)	/u/ (ʌ)	/i/ (ɪ)	/ai/ (eɪ)	/oa/ (oʊ/əʊ)	/ow/ (aʊ)	/oa/ (oʊ/əʊ)
Specific Difficulty (grapheme)	o	ice	ai	ow	ow	oa
Expanded Difficulty (grapheme)	*ove, on, one, ome, o-e*		*aid, ail, aim, ain, ait, air*	*owl, own*		*oach, oad, oaf, oak, oal, oat, oast, oax*
Teaching Point	*75*	*77*	*80*	*81*		*83*
Severity						
Example Word	son	hospice	brain	bow	bow	oat

Table A.2e

Index	31	32	33	34	35	36
Specific Difficulty (phoneme)	/oa/ (oʊ/əʊ)	/ee/ (iː)	/ur/ (ɜː)	/ur/ (ɜː)	/ur/ (ɜː)	/oi/ (oː)
Specific Difficulty (grapheme)	o	e-e	ir	ur	wor	oi
Expanded Difficulty (grapheme)		*ede, ene, eme, ere, ese, eve*	*ird, irk, irl, irm, irst, irt, irth*			*oid, oil, oin, oint, oit, oice*
Teaching Point		*84*	*85*	*87*		*88*
Severity						
Example Word	go	cede	fir	fur	work	oil

Table A.2f

Index	37	38	39	40	41	42
Specific Difficulty (phoneme)	/oi/ (oː)	/ee/ (iː)	/or/ (ɔː)	/or/ (ɔː)	/or/ (ɔː)	/oo/ (uː)
Specific Difficulty (grapheme)	oy	ie	au	aw	ore	ew
Expanded Difficulty (grapheme)		*ief, ieves, ield, iece, ierce*	*aunt, ause, aught, aunch*	*awk, awn, awl*	*our, ought, al*	
Teaching Point	*89*	*90*	*92*	*94*		*95*
Severity						
Example Word	boy	thief	cause	claw	four	new

Table A.2g

Index	43	44	45	46	47	48
Specific Difficulty (phoneme)	/oo/ (uː)	/ur/ (ɜː)	/i/ (ɪ)	/igh/ (aɪ)	/ow/ (aʊ)	/ee/ (iː)
Specific Difficulty (grapheme)	ue	ear	y	y-e	ou	ei
Expanded Difficulty (grapheme)						
Teaching Point	*97*	*98*	*104*	*104a*	*105*	*106*
Severity						
Example Word	blue	earn	crypt	dyke	bound	receive

Table A.2h

Index	49	50	51	52	53	54
Specific Difficulty (phoneme)	/ai/ (eɪ)	/ai/ (eɪ)	/er/ (ə)	/er/ (ə)	/oo/ (uː)	/i/ (ɪ)
Specific Difficulty (grapheme)	ei	eigh	our	ar	ui	ui
Expanded Difficulty (grapheme)						
Teaching Point		*107*	*108*	*109*	*110*	
Severity						
Example Word	eight	weigh	odour	altar	juice	build

Table A.2i

Index	55	56	57	58	59	60
Specific Difficulty (phoneme)	/ee/ (iː)	/ai/ (eɪ)	/oa/ (oʊ/əʊ)	/oo/ (uː)	/ure/ (ʊə)	/igh/ (aɪ)
Specific Difficulty (grapheme)	ey	ey	oe	eu	eur	ine
Expanded Difficulty (grapheme)						
Teaching Point	*111*		*112*	*113*		*114*
Severity						
Example Word	key	grey	toe	deuce	chauffeur	dine

Table A.2j

Index	61	62	63	64	65	66
Specific Difficulty (phoneme)	/i/ (ɪ)	/ee/ (iː)	/air/ (eə)	/air/ (eə)	/air/ (eə)	/ear/ (ɪə)
Specific Difficulty (grapheme)	ine	ine	air	are	ear	ear
Expanded Difficulty (grapheme)			*ah*			
Teaching Point						
Severity						
Example Word	engine	morphine	air	bare	bear	ear

Table A.2k

Index	67	68	69	70	71	72
Specific Difficulty (phoneme)	/ear/ (ɪə)	/ear/ (ɪə)	/ere/ (ʊə)	/ere/ (ʊə)	/ere/ (ʊə)	/o/ (ɒ)
Specific Difficulty (grapheme)	eer	ere	ure	oor	our	a
Expanded Difficulty (grapheme)						
Teaching Point						
Severity						
Example Word	deer	here	sure	poor	tour	was

Table A.2l

Table A.2: The subordinate exact cases for vowel sounds

A.3. Suffixing

Index	1	2	3	4	5	6
Specific Difficulty	-s	ed	-es,	-en	-ish	doubling rule
Expanded Difficulty	*(s) and (z)*		*-less and -ness*	*-ing and -ful*	*ist*	*-ing, -ed, -en, -ish*
Teaching Point	*6*	*18*	*22*	*33*	*38*	*45*
Severity						
Example Word	snips, pins	ended	passes, endless, sadness	dampen, camping, cupful	blackish	grabbing, padded, sadden, thuggish

Table A.3a

Index	7	8	9	10	11	12
Specific Difficulty	-y	drop rule	-er	-ed(d) and -ed(t) [add, drop and double]	-est [add, drop, double]	-al
Expanded Difficulty	*-ly, -ity*	*-ing, -ed, -y, -en*				
Teaching Point	*52*	*56*	*59*	*60*	*61*	*71*
Severity						
Example Word	bumpy, badly, reality	fading, faded, flaky, bribing, sided, spiky, driven	breeder	banged, bored, banned, asked, baked, capped	deepest, closest, biggest	comical

Table A.3b

Index	13	14	15	16	17	18
Specific Difficulty	change rule	doubling if syllable before suffix stressed AND add if first syllable stressed AND double l AND add k	add, drop and change,	-or, add and drop, -rror	able	ment
Expanded Difficulty			*-tious, -cious, -ious, -uous*			
Teaching Point	*82*	*91*	*101*	*103*		
Severity						
Example Word	berries, spied, bodily, emptiness, beautiful, merciless, emptier, funniest	forgetting, visiting, controlled, picnicking	dangerous, continuous, furious, ambitious, anxious, ambiguous	actor, inspector, commentator, operator	kissable	payment

Table A.3c

Index	19
Specific Difficulty	ive
Expanded Difficulty	
Teaching Point	
Severity	
Example Word	decorative

Table A.3d

Table A.3: The subordinate exact cases for suffixing

A.4. Prefixing

Index	1	2	3
Specific Difficulty	un-	under-	change rule,
Expanded Difficulty	*in-, mis-*	*over-*	*ad-, con-, in-, sub-, dis-, ob-, ex-*
Teaching Point	*26*	*63*	*100*
Severity			
Example Word	*unbolt, inland, misled*	*underestimate, oversleep*	*adventure, congenial, inactive, subtitle, disappear, obtuse, exception*

Table A.4a

Table A.4: The subordinate exact cases for prefixing

A.5. Grapheme phoneme correspondence

Index	1	2	3	4	5	6
Specific Difficulty (phoneme)	/t/ (t)	/p/ (p)	/n/ (n)	/s/ (s)	/d/ (d)	/h/ (h)
Specific Difficulty (grapheme)	t	p	n	s	d	h
Expanded Difficulty (grapheme)	tt, -ed	pp	nn	ss, c	dd, -ed	
Teaching Point	1	3	4	5	8	10
Severity						
Example Word	tap, butter, jumped	pen, happy	net, funny	sun, miss, cell	dog, muddy, pulled	hen

Table A.5a

Index	7	8	9	10	11	12
Specific Difficulty (phoneme)	/r/ (r)	/m/ (m)	/b/ (b)	/l/ (l)	/f/ (f)	/g/ (g)
Specific Difficulty (grapheme)	r	m	b	l	f	g
Expanded Difficulty (grapheme)	rr	mm	bb	ll	ff, ph	gg
Teaching Point	13	14	17	19	23	25/79
Severity						
Example Word	rat, carrot	map, hammer	bat, rabbit	leg, bell	fan, puff, photo	go, bigger

Table A.5b

Index	13	14	15	16	17	18
Specific Difficulty (phoneme)	/k/ (k)	/ng/ (ŋ)	/th/ (θ)	/v/ (v)	/w/ (w)	/sh/ (ʃ)
Specific Difficulty (grapheme)	k	ng	th	v	w	sh
Expanded Difficulty (grapheme)	c, ck	nk				s, ss, tion, tial
Teaching Point	28	29	31	34	35	37
Severity						
Example Word	cat, kit, duck	ring, pink	thin	van	wig	shop, sure, mission, mention, partial

Table A.5c

Index	19	20	21	22	23	24
Specific Difficulty (phoneme)	/y/ (j)	/j/ (dʒ)	/k/ (k)	/z/ (z)	/ch/ (tʃ)	/zh/ (ʒ)
Specific Difficulty (grapheme)	y	j	qu	z	ch	zh
Expanded Difficulty (grapheme)		g, dg		zz, s, se, ze	tch	sion, sure
Teaching Point	39	40	42	44	48	
Severity						
Example Word	yes	jet, giant, badge	queen	zip, buzz, is, please, breeze	chip, catch	vision, measure

Table A.5d

Index	25	26	27
Specific Difficulty (phoneme)	/th/ (ð)	/g/ /z/ (g z)	/k/ /s/ (k s)
Specific Difficulty (grapheme)	th	x (gz)	x (ks)
Expanded Difficulty (grapheme)			
Teaching Point		43	43
Severity			
Example Word	then	exist	extra

Table A.5e

Table A.5: The subordinate exact cases for grapheme phoneme correspondence

A.6. Letter word / patterns

Index	1	2	3	4	5	6
Specific Difficulty	ip	in	s	d	c	r
Expanded Difficulty			*st, sp, sn, sm, se*	*ad, and, de*	*act, sc, cc*	*cr, dr, pr, tr, str, spr, scr*
Teaching Point	3	4	5	8	9	13
Severity						
Example Word	*pip*	*tin*	*sin, is, stint, spin, snip, smile, seal*	*did, pad, sand, debt*	*cap, pact, scan*	*rat, crisp, drop, print, trap, strip, sprint, scrap*

Table A.6a

Index	7	8	9	10	11	12
Specific Difficulty	m	b	l	ll	ss	f
Expanded Difficulty	*am, amp, im*	*ab, ib, ob, br*	*elt, ilt, bl, cl, pl, sl, spl*	*all, ell, ill, oll (doll), oll(roll), ull*	*ass, ess, iss, oss, uss*	*eft, ift, oft, elf, aft, fl, fr*
Teaching Point	14	17	19	20	21	23
Severity						
Example Word	*map, tram, cramp, trim*	*bad, crab, rib, snob, brand*	*lad, belt, hilt, blend, clan, plan, slap, split*	*all, bell, bill, doll, poll, pull*	*lass, less, hiss, boss*	*fan, left, lift, loft, self, daft, flab, from*

Table A.6b

Index	13	14	15	16	17	18
Specific Difficulty	g	k	ng	nk	thank/than	ck
Expanded Difficulty	*ag, eg, ig, og, gl, gr*	*ask, esk, isk, usk, ilk, ulk, sk*	*ang, ing, ong, ung*	*ank, ink, unk, onk*	*ath, oth, ength*	*ack, eck, ick, ock, uck, ic*
Teaching Point	25	28	29	30	31	32
Severity						
Example Word	*gift, bag, beg, big, bog, glad, grab*	*kill, task, desk, risk, dusk, milk, bulk, skid*	*bang, ping, long, flung*	*bank, pink, drunk, honk*	*thank, bath, cloth, length, than*	*back, deck, kick, dock, duck, public*

Table A.6c

Index	19	20	21	22	23	24
Specific Difficulty	ve	w	wa	sh	x	zz
Expanded Difficulty		*sw, tw, dw*	*swa*	*shr, ash, esh, ish, osh, ush*	*ax, ex, ix, ox*	
Teaching Point	34	35	36	37	43	44
Severity						
Example Word	*active*	*wall, swag, twin, dwell*	*waft, swab*	*shall, shrank, cash, mesh, dish, cosh, bush*	*fax, text, fix, box*	*jazz*

Table A.6d

Index	25	26	27	28	29	30
Specific Difficulty	ff	ch	-ce	wh	ge	dge
Expanded Difficulty	*aff, iff, off, uff*	*anch, ench, inch, unch, arch*	*ance, ence, ince, ace, ice*		*age, arge, inge, unge, erge, ange*	*adge, edge, idge, odge, udge*
Teaching Point	46	48	57	58	64	65
Severity						
Example Word	*staff, cliff, scoff, huff*	*charm, branch, bench, pinch, bunch, starch*	*dance, fence, mince, face, dice*	*whale*	*cage, barge, hinge, plunge, merge, range*	*badge, hedge, bridge, dodge, budge*

Table A.6e

Index	31	32	33	34	35	36
Specific Difficulty	c(s)	age	tch	ph	ch/sh	kn
Expanded Difficulty	*sc*	*ege*	*atch, etch, itch, otch, utch*	*pph*		
Teaching Point	76	78	86	93	99	115
Severity						
Example Word	*cease, scent*	*damage, college*	*catch, fetch, ditch, notch, hutch*	*photograph, microphone, autograph, sapphire*	*chrome, chef*	*kneel*

Table A.6f

Index	37	38	39	40	41	42
Specific Difficulty	gn	ps	rh	mb	bt	silent l
Expanded Difficulty	*gh as f, ght*		*rrh*			
Teaching Point	115	115	115	115	115	115
Severity						
Example Word	*gnat, ghost*	*psychic*	*rhyme*	*bomb*	*debt*	*calm*

Table A.6g

Index	43	44	45	46	47	48
Specific Difficulty	mn	wr	pt	st	gu	gue
Expanded Difficulty						
Teaching Point	115	115		115	115	115
Severity						
Example Word	*hymn*	*wrap*	*accept*	*listen*	*guess*	*rogue*

Table A.6h

Index	49	50	51	52	53	54
Specific Difficulty	sc	pro	que	sch	xc before I or e	ayor
Expanded Difficulty		pre				*ayer*
Teaching Point	115		115			
Severity						
Example Word	*scene*	*protect, predict*	*mosque*	*school*	*exclude, excel*	*mayor, layer*

Table A.6i

Index	55	56	57	58	59	60
Specific Difficulty	al consonant	oh	cial	cqu	ngue at word end	ol consonant
Expanded Difficulty	*alf, alk, alm, alt*	*aoh*	*tial*			*old, olk*
Teaching Point						
Severity						
Example Word	*half, balk, calm, halt*	*ohms, Pharaoh*	*special, initial*	*acquire*	*tongue*	*folded, folk,*

Table A.6j

Index	61	62	63	64	65	66
Specific Difficulty	quar consonant	end of word: consonant re	ro	sci	scle	sure
Expanded Difficulty						
Teaching Point						
Severity						
Example Word	*Quarry, quarter*	*centre, litre*	*row, roam, crow*	*science*	*muscle*	*closure*

Table A.6k

Index	67	68	69	70	71	72
Specific Difficulty	ti	zure	thr	nd	nt	nch
Expanded Difficulty	ci as /sh/					
Teaching Point						
Severity						
Example Word	*action, facial*	*azure*	*thrush*	*bend, tent*	*bent, tent*	*branch, bench*

Table A.6l

Index	73	74	75
Specific Difficulty	mp	ology	-cise
Expanded Difficulty			
Teaching Point			-dual, -tual, -sual, -tory
Severity			
Example Word	*slump, bump*	*psychology*	*exercise, gradual, eventual, visual, history*

Table A.6m

Table A.6: The subordinate exact cases for letter/word patterns

A.7. Letter names

Index	1	2	3	4	5	6
Letter name	t	i	p	n	s	a
Teaching Point	1	2	3	4	5	7
Severity						

Table A.7a

Index	7	8	9	10	11	12
Letter name	d	c	h	o	r	m
Teaching Point	8	9	10	11	13	14
Severity						

Table A.7b

Index	13	14	15	16	17	18
Letter name	e	b	l	f	g	u
Teaching Point	15	17	19	23	25	26
Severity						

Table A.7c

Index	19	20	21	22	23	24
Letter name	k	v	w	y	j	q
Teaching Point	28	34	35	39	40	42
Severity						

Table A.7d

Index	25	26
Letter name	x	z
Teaching Point	43	44
Severity		

Table A.7e

Table A.7: The subordinate exact cases for letter names

APPENDIX B: Detailed Greek User Model

B.1 Syllable Division

Index		1	2	3	4	5	6	7	8	9	10	11	12
Category N	1												
Specific case	Syllable Division	cv-cv	cv-v	v-cv	cv-vc	vc-cv(c)	cvc-cv(c)	cv-ccv(c)	ccv-cv(c)	ccvc-cv(c)	cv-cccv(c)	v-cccv(c)	ιά/ειά
Example word		*κα-λα*	*χα-ο-τικός*	*α-πο*	*χά-ος*	*ασ-βοί, ασ-βός*	*καρ-ποί, καρ-πός*	*μι-κρό(ς)*	*σκά-βει(ς)*	*σκάρ-το(ς)*	*κά-στρο*	*ά-σπρο(ς)*	*καρ-διά / για-τρει-ά*

Table B.1a

Index		13	14	15	16	17	18	19	20
Category N	1								
Specific case	Syllable Division	ιά/ία	αί/αΐ, εί/εΐ, οί/οΐ	αί/άι, οί/όι	άι, όι (diphthongs)	αι/αϊ, οι/οϊ, ει/εϊ	ου/οϋ, ού/οΰ	αυ/αϋ, αύ/αΰ	εύω
Example word		*καρ-**διά** / αρ-**γί-α***	***παί**-ζω/**πα-ΐ**-δια, προ-**τεί**-νω/πρω-**τε-ΐ**-νη, α-**θροί**-ζω/**θρο-ΐ**-ζω*	*μαί-α/μά-ι-ος, ρόλοι/ρο-λό-ι*	***γάι**-δα-ρος, κο-**ρόι**-δο*	***παι**-δί/**πα-ϊ**-δάκι, **μοί**-ρα/**προ-ϊ**-στορία,α-**στεί**-ο/α-**στε-ϊ**-σμός*	***προ-ϋ**-πόθεση, αρα-**χνο-ΰ**-φαντος*	***αυ**-λή/**α-ϋ**-πνί-α,*	*κο-ροϊ-**δεύ**-ω*

Table B.1b

Table B.1: The subordinate exact cases for syllable division

B.2 Phonemes: Consonants

Index		1	2	3	4	5	6	7
Category N	2							
Specific case	Consonants (sound similarity)	/t/-/d/, /p/-/b/	/k/-/p/, /k/-/t/	/m/-/n/	/θ/-/ð/, /f/-/v/, /χ/-/γ/	/k/-/γ/, /k/-/χ/	/s/-/z/	/l/-/r/
Example word		*/tino/-/dino/*	*/pano/-/kano/*	*/meno/-/nemo/*	*/θelo/-/ðeno/*	*/koma/-/χoma/*	*/soma/-/zoni/*	*/tino/-/dino/*

Table B.2a

Index		8	9	10	11	12
Category N	2					
Specific case	Consonants (sound similarity)	/ð/-/v/, /f/-/θ/, /f/-/v/, /θ/-/ð/	/kt/-/pt/	/ks/-/ps/, /ks/-/sk/, /ps/-/sp/	/ðr/-/θr/, /fr/-/χr/	/χθ/-/fθ/
Example word		*/ðeno/-/veno/, /fora/-/θira/, /fora/-/vera/, /θelo/-/ðeno/*	*/ktinos/-/ptino/*	*/ksino/-/psino/, /ksini/-/skini/, /pselno/-/sperno/*	*/foðra/-/voθros/, /afros/-/oχros/*	*/χθesinos/-/fθano/*

Table B.2b

Table B.2: The subordinate exact cases for phonemes: consonants

B.3 Phonemes: Vowels

Index		1	2	3	4	5	6
Category N	3						
Specific case	Vowels	εϋ: /eɪ/	oϋ: /oɪ/	αϊ: /aɪ/	αη: /aɪ/	oΰ: /oi/	αΐ: /ai/
Example Words		*Σεϋχέλλες*	*προϋπόθεση*	*παϊδάκι*	*καημένος*	*αραχνοΰφαντος*	*Μαΐου*

Table B.3a

Table B.3: The subordinate exact cases for phonemes: vowels

B.4 Suffixing: Derivational

Index		1	2	3	4	5	6
Category N	5						
Specific case	Suffixing: Derivational	NOUNS&ADJs: Diminutives: -άκι-άκης,-άκος,-ίτσα,-κας,-οπούλα,-όπουλο,-ούδι,-ούλα,-ούλης,-ούλης/α/ούλικο,-ούτσικος/η/ούτσικο	NOUNS&ADJs: Enlargement: -άκλα,-άρα,-αράς,-αρόνα,-αρος,-ούκλα	NOUNS: Profession/person: -άς,-έας,-ιάς,-δόρος,-άρης,-ιάρης,-ιέρης/-ιέρα,-ίτης,-ιώτης,-ίστας,-ιστής/-ίστρια,-της/-τής/-τρια/-τισσα,-τζής/-τζού,-τίας,-τορας	NOUNS: Place: -είο,-ιά,-ία,-ικο,-δικο	NOUNS: Instrument/means/container: -έας,-ερό,-ιέρα,-τήρας,-τήρι,-τήριο,-τρα,-της	NOUNS: State/property/quality: -άδα,-εια,-ίλα,-ιλίκι,-μάρα,-οσύνη,-ούρα,-(σ/ξ)ιά,-(ό/ύ)τητα
Example word		*αρκούδα-αρκουδάκι, Γιώργος-Γιωργάκης, δρόμος-δρομάκος, κοπέλα-κοπελίτσα, μπαμπάς-μπαμπάκας, βοσκός-βοσκοπούλα, κότα-κοτόπουλο, άγγελος-αγγελούδι, βάρκα-βαρκούλα, θεός-θεούλης, μικρούλης/α/ούλικο, μικρούτσικος/η/ούτσικο*	*κόρη-κοράκλα, κοπέλα-κοπελάρα, σπίτι-σπιταρόνα, ψάρι-ψαρούκλα*	*κλειδί-κλειδαράς, κουρεύω-κουρέας, γράφω-γραφιάς, καντάδα-κανταδόρος, βάρκα-βαρκάρης, σκουπίδι-σκουπιδιάρης, πόρτα-πορτιέρης, κάμαρα-καμαριέρα, τέχνη-τεχνίτης, ταξίδι-ταξιδιώτης, πιάνο-πιανίστας/πιανίστρια, βιολί-βιολιστής, κλέβω-κλέφτης, προπονώ-προπονητής/προπονήτρια, αγρός-αγρότης/αγρότισσα, φορτηγό-φορτηγατζής, καφές-καφετζής/καφετζού, εισπράττω-εισπράκτορας*	*φάρμακο-φαρμακείο, ποτάμι-ποταμιά, Γάλλος-Γαλλία, μπακάλης-μπακάλικο, ψαράς-ψαράδικο*	*προβάλλω-προβολέας, τσάι-τσαγερό, ζάχαρη-ζαχαριέρα, λάμπω-λαμπτήρας, ποτίζω-ποτιστήρι, πλένω-πλυντήριο, κρεμάω-κρεμάστρα, διακόπτω-διακόπτης*	*φρέσκος-φρεσκάδα, αναιδής-αναίδεια, ξινός-ξινίλα, υπουργός-υπουργιλίκι, κουτός-κουταμάρα, δίκαιος-δικαιοσύνη, θολός-θολούρα, ζεστός-ζεστασιά, μόνος-μοναξιά, ιδιαίτερος-ιδιαιτερότητα, ταχύς-ταχύτητα*

Table B.4a

Index		7	8	9	10	11	12
Category N	5						
Specific case	Suffixing: Derivational	NOUNS: Colours: -ί, Plants: -ιά	NOUNS: Activity/activity outcome: -άλα,-εία,-ειά,-εια,-(σ/ξ/ψ)η,-(σ)ία,-(σ/ψ/ξ/ματ)ιά,-(σ/ξ/ψ)ιμο,-(α/η/ω/σ/γ/)μα,-μός,-(η/α/κ/χ/φ/π)τό	ADJs: -ικός/-ική/-ικό,-σιμος/-σιμη/-σιμο,-ιάρης/-ιάρα/άρικο,-ερός/-ερή/-ερό,-τός/-τή/-τό,-άτος/-άτη/-άτο,-ινος/-ινη/-ινο,-ιακός/-ιακή/-ιακό,-ανός/-ανή/-ανό,-ούρης/-ούρα/-ούρικο	ADJs: -ίστικος/-ίστικη/-ίστικο,-ήσιος/-ήσια/-ήσιο,-λέος/-λέα/-λέο,-αίος/-αία/-αίο,-ωπός/-ωπή/-ωπό,-ένιος/α/ο,-τέος/-τέα/-τέο,-ώδης/-ώδες	VERBS: -ίζω/-άζω/-ιάζω,-αίνω,-ώνω,-ύνω,-εύω,-άρω	VERBS: lexical suffixes: -βολώ,-λογώ,-ποιώ
Example word		*κανέλα-κανελί, θάλασσα-θαλασσί, κεράσι-κερασιά*	*τρέχω-τρεχάλα, θεραπεύω-θεραπεία, δουλεύω-δουλειά, προσπαθώ-προσπάθεια, πλένω-πλύση, πλέκω-πλέξη, χωνεύω-χώνεψη, αποτυγχάνω-αποτυχία, εργάζομαι-εργασία, δάχτυλο-δαχτυλιά, κλέβω-κλεψιά, δαγκώνω-δαγκωματιά, δένω-δέσιμο, γράφω-γράψιμο, τρέχω-τρέξιμο, ζεσταίνω-ζέσταμα, βοηθώ-βοήθημα, τελειώνω-τελείωμα, βαδίζω-βάδισμα, ανοίγω-άνοιγμα, χάνω-χαμός, βογκάω-βογκητό, κατεβαίνω-κατεβατό, πλέκω-πλεκτό, γράφο-γραφτό/γραπτό*	*δήμος-δημοτικός/ή/ό, αναλύω-αναλύσιμος/η/ο, σοκολάτα-σοκολατένιος/α/ο, άρρωστος-αρρωστιάρης/α/άρικο, βροχή-βροχερός/ή/ό, φουσκώνω-φουσκωτός/ή/ό, φεύγω-φευγάτος/η/ο, ξύλο-ξύλινος/η/ο, μοναστήρι-μοναστηριακός/ή/ό, δίπλα-διπλανός/ή/ό, μουρμουράω-μουρμούρης/α/ο*	*αγόρι-αγορίστικος/η/ο, σπίτι-σπιτήσιος/α/ο, φεύγω-φευγαλέος/α/ο, μήνας-μηνιαίος/α/ο, πράσινος-πρασινωπός/ή/ό, προτιμώ-προτιμητέος/α/ο, νέφος-νεφώδης/ες*	*κακός-κακίζω, στέγη-στεγάζω, ξαφνικά-ξαφνιάζω, βάθος-βαθαίνω, δύναμη-δυναμώνω, μέγεθος-μεγεθύνω, χορός-χορεύω, πρόβα-προβάρω*	*πέτρα-πετροβολώ, κακός-κακολογώ, δράμα-δραματοποιώ*

Table B.4b

Index		13
Category N	5	
Specific case	Suffixing: Derivational	ADJs: lexical suffixes: -ειδής/-ειδές, -μελής/-μελές, -ετής/-ετές
Example word		*αράχνη-αραχνοειδής, τριμελής/πολυμελής/μονομελής..., πρωτοετής/τριετής... Κλπ*

Table B.4c

Table B.4: The subordinate exact cases for suffixing: derivational

B.5 Suffixing: Inflectional/Grammatical

Index		1	2	3	4	5	6
Category N	6						
Specific case	Suffixing: Inflectional	freq. noun classes (nom./ acc.sing): -ος/-ο, -ας/-α, -ης/-η, -α, -η, -ο	freq.noun classes (nom./acc.pl): -οι/-ους, -ες, -εις, -α.	Freq. noun classes (gen.sing&pl): -ου/-ων, -ες/-ων, -εις/-εων, -ες/-ών/-ων,-ου/-ων	less freq.noun classes (nom/acc.sing.): -ες/-ε, -άς/-ά, -ούς/-ού, -ού, -ι, -ον, -ος, -ας, -α, -υ	less freq.noun classes (nom/acc.pl): -έδες, -άδες, -ούδες, -οντα, -ά, -η, -ατα	less freq.noun classes(gen.sing&pl): -έ/-έδων, -ά/-άδων, -ού/-ούδων, -ούς/-ούδων, -ιού/-ιών, -οντος/-όντων, -ατος/-άτων
Example word		*άνθρωπος/άνθρωπο, ταμίας/ταμία, μαθητής/μαθητή, πόρτα, τάξη, δένδρο*	*άνθρωποι/ανθρώπους, ταμίες, μαθητές, πόρτες, τάξεις, δένδρα*	*ανθρώπου/ανθρώπων, ταμία/ταμίων, μαθητή/μαθητών, πόρτας/πορτών, τάξης/τάξεων, δένδρου/δένδρων*	*καναπές/καναπέ, παπάς/παπά, παππούς/παππού, αλεπού, παιδί, καθήκον, δάσος, κρέας, γράμμα, δόρυ*	*καναπέδες, παπάδες, παππούδες, αλεπούδες, παιδιά, καθήκοντα, κρέατα, γράμματα, δόρατα*	*καναπέ/καναπέδων, παπά/παπάδων, παππού/παππούδων, αλεπούς/αλεπούδων, παιδιού/παιδιών, καθήκοντος/καθηκόντων, κρέατος/κρεάτων, γράμματος/γραμμάτων, δόρατος/δοράτων*

Table B.5a

Index		7	8	9	10	11	12
Category N	6						
Specific case	Suffixing: Inflectional	freq.adjective classes (nom/acc.sing.): -ος/-η/-ο, -ος/-α/-ο, -ός/-ιά/-ό, -ης/-α/-(ικ)ο, -άς/-ού/-άδικο	less freq.adj. classes (nom/acc.sing.): -ύς/-ιά/-ύ, -ής/-ιά/-ί, -ής/-ές, πολύς/πολλή/πολύ	freq.adjective classes (nom./acc.pl.): -οι/-ες/-α, -ηδες/-ες/-ικα, -άδες/-ούδες/-άδικα	less freq.adj. classes (nom/acc.pl.): -ιοί/-ιές/-ιά, -είς/-ή, πολλοί/-ές/-ά	freq.adjective classes (gen.sing.&pl.): -ου/-ης/-ου, -ου/-ας/-ου, -ού/-ιάς/-ού, -η/-ας/-(ικ)ου, -ά/-ούς/-άδικου	less freq.adj. classes (gen.sing.&pl.): -ιού/-ιάς/-ιού/-ιών, -ούς/-ών
Example word		*μεγάλος/-η/-ο, πλούσιος/-α/-ο,κακός/-ιά/-ό,γκρινιάρης/-α/-ικο, υπναράς/-ού/-ούδικο*	*βαθύς/-ιά/-ύ, δεξής/-ιά-/ί,διεθνής/-ές,πολύς/πολλή/πολύ*	*μεγάλοι/-ες/-α, πλούσιοι/-ες/-α, κακοί/-ες/-α, γκρινιάρηδες/-ες/-ικα, υπναράδες/-ούδες/-ούδικα*	*βαθιοί/-ιές/-ιά, δεξιοί/-ιές/-ιά, διεθνείς/-ή, πολλοί/πολλές/πολλά*	*μεγάλου/-ης/-ου/-ων, πλούσιου/-ας/-ου/-ίων, κακού/-άς/-ού/-ών, γκρινιάρη/-ας/-ικου/-ηδων/-ων, υπναρά/-ούς/-ούδικου/-άδων/-ούδων/-ούδικων*	*βαθιού/-ιάς/-ιού/-ιών, δεξιού/-ιάς/-ιού/-ιών, διεθνούς/-ών*

Table B.5b

Index		13	14	15	16	17
Category N	6					
Specific case	Suffixing: Inflectional	verbs,present/active: -ω/-εις/-ει/-ουμε/-ετε/-ουν, -ώ/-άς/-ά(ει)/-άμε/-ούμε/-άτε/-ούν(ε)/-άν(ε)/-ούν, -ώ/-είς/-εί/-ούμε/-είτε/-ούν(ε)	verbs,past/active: -α/-ες/-ε/-αμε/-ατε/-αν(ε), -αγα/-αγες/-αγε/-άγαμε/-άγατε/-αγαν(ε), -ούσα/-ούσες/-ούσε/-ούσαμε/-ούσατε/-ούσαν(ε)	verbs, present&past passive: -ομαι/-εσαι/-εται/-όμαστε/-όσαστε/-εστε/-ονται, -ιέμαι/-ιέσαι/-ιέται/-ιόμαστε/-ιέστε/-ιούνται/-ιόνται, -ιούμαι/-είσαι/-είται/-ούμαστε/-είστε/-ούνται,	verbs, past simple passive: -όμουν(α)/-όσουν(α)/-όταν(ε)/-όμασταν/-όμαστε/-όσασταν/-όσαστε/-ονταν(ε)/-όντουσαν, -ούμουν(α)/-ούσουν(α)/-ούνταν/-ούμασταν/-ούμαστε/-ούσασταν/-ούσαστε/-ούνταν(ε), -ηκα/-ηκες/-ηκε/-ήκαμε/-ήκατε/-αν	adjectival participles: -ών/-ούσα/-όν, -είς/-είσα/-έν
Example word		*ντύνω/-εις/-ει/-ουμε/-ετε/-ουν, αγαπώ/-άς/-ά(ει)/-άμε/-άτε/-άν(ε)/-ούν, θεωρώ/-είς/-εί/-ούμε/-είτε/-ούν*	*έντυνα/-ες/-ε/ντύναμε/-ατε/έντυναν, έντυσα/-ες/-ε/-ντύσαμε/-ατε/-αν, αγάπαγα/-αγες/-αγε/-άγαμε/-άγατε/-αγαν, αγαπούσα/-ες/-ε/-ούσαμε/-ούσατε/-ούσαν(ε), αγάπησα/-ες/-ε/-ήσαμε/-ήσατε/αν*	*ντύνομαι/-εσαι/-εται/-όμαστε/-όσαστε/-εστε/-ονται, αγαπιέμαι/-ιέσαι/-ιέται/-ιόμαστε/-ιέστε/-ιούνται, θεωρούμαι/-είσαι/-είται/-ούμαστε/-είστε/-ούνται*	*ντυνόμουν/-όσουν/-όταν/-όμασταν(-ε)/-όσασταν(-ε)/-ντύνονταν/-όντανε/-όντουσαν, ντύθηκα/-ες/-ε/ντυθήκαμε/-ήκατε/-αν, αγαπιόμουν(α)/-ιόσουν(α)/-ιόταν(ε)/-ιόμασταν(-ιόσαστε)/-ιόσασταν(-ιόσαστε)/-ιούνταν(ε)/-ιόνταν(ε)/-ιόντουσαν, θεωρούμουν(α)/-ούσουν(α)/-ούνταν/-ούμασταν(-ούμαστε)/-ούσασταν(-ούσαστε)/-ούνταν(ε)*	*παρών/-ούσα/-όν/-όντος/-ούσας/-όντες/-όντων,προαχθείς/-είσα/-έν/-έντος/προαχθέντες/-είσες/-έντα/-έντων/-εισών*

Table B.5c

Table B.5: The subordinate exact cases for suffixing: inflectional/grammatical

B.6 Prefixing

Index		1	2	3	4	5	6
Category N	7						
Specific case	Prefixing	ADJS: Privative/Opposite/ Difficulty: α-,αντι-,δυσ-	ADJS&NOUNS:Quantity (over/under): υπερ-/υπο-, κατα-	VERBS: Quantity(over/under):	Lexical prefixes: δι-/τρι-,πρωτο-,αυτο-,πολυ-,μικρο-,ψιλο-,ημι-	VERBS: ανα-,αντι-,απο-,δια-,εισ-,εκ-/εξ-,εν-,επι-,κατα-,μετα-,παρα-,περι-,προ-,προσ-,συν-	VERBS: Lexical prefixes: ψιλο-,μισο-,κουτσο-,ψευτο-
Example Word		*συνεπής-ασυνεπής, λαϊκός-αντιλαϊκός, εύκολος-δύσκολος*	*υπεραρκετός, υπερκόπωση, υπογλυκαιμία*	*υπερβάλλω, υποτάσσω*	*δίτροχος, πρωτόγνωρος, πολυετής, μικροπρεπής, ψιλοάγουρος, ημίτρελλος*	*αναβάλλω, αποβάλλω, διαβάλλω, εισβάλλω, εκβάλλω, επιβάλλω, καταβάλλω, μεταβάλλω, παραβάλλω, περιβάλλω, προβάλλω, προσβάλλω, συμβάλλω, υπερβάλλω, υποβάλλω*	*ψιλοβλέπω, μισογεμίζω, κουτσοβλέπω, ψευτογελάω*

Table B.6a

Table B.6: The subordinate exact cases for prefixing

B.7 Grapheme/Phoneme Correspondence

Index		1	2	3	4	5	6	7
Category N	8							
Specific case	Regular: Consonant clusters	2-syll, initial: /sp/,/st/,/sk/	2-syll, initial: /pr/,/tr/,/kr/,	2-syll, initial: /gr/,/dr/,/br/	2-syll, initial: /fr/,/ðr/, /χr/,/vr/,/γr/,/θr/	2-syll, initial: /spr/,/skr/,/str/,/sfr/	3-syll, initial: /sp/,/st/,/sk/	3-syll, initial: /pr/,/tr/,/kr/
Example word		*σπίτι, στέκα, σκεπή*	*πρόκα, τρένο, κρόσι*	*γκρεμός, ντροπή, μπρίκι*	*χρυσό, βροχή, γράμμα, θράσος*	*σπρώχνω, σκράπα, στράτα, σφρίγος*	*σπιτάκι, στέκομαι, σκαλώνω*	*πράκτορας, τράβηξα, κρεβάτι*

Table B.7a

Index		8	9	10	11	12	13	14
Category N	8							
Specific case	Regular: Consonant clusters	3-syll, initial: /gr/,/dr/,/br/	3-syll, initial: /fr/,/ðr/, /χr/,/vr/,/γr/,/θr/	3-syll, initial: /spr/,/skr/,/str/,/sfr/	2-syll, internal: /sp/,/st/,/sk/	2-syll, internal: /pr/,/tr/,/kr/,	2-syll, internal: /gr/,/dr/,/br/	2-syll, internal: /fr/,/ðr/, /χr/,/vr/,/γr/,/θr/
Example word		*γκρεμίζω, ντρέπομαι, μπρατσάκι*	*φράγματα, δρομάκι, χρώματα, βραδάκι, γρανίτα,*	*σπρώξιμο, στρώματα, σφριγηλός*	*λάσπη, λίστα, ασκί*	*κίτρο, άκρη*	*άντρας, λαμπρή*	*αφρός, αδρός, ωχρός, αγρός*

Table B.7b

Index		15	16	17	18	19	20
Category N	8						
Specific case	Regular: Consonant clusters	2-syll, internal: /spr/,/skr/,/str/,/sfr/	3-syll, internal: /sp/,/st/,/sk/	3-syll, internal: /pr/,/tr/,/kr/,	3-syll, internal: /gr/,/dr/,/br/	3-syll, internal: /fr/,/ðr/, /χr/,/vr/,/γr/,/θr/	3-syll, internal: /spr/,/skr/,/str/,/sfr/
Example word		*άσπρο, άστρο*	*ασπίδα, αστακός*	*κίτρινος, ακρίδα*	*αγκράφα, αντράκι*	*αφρώδης, αδρανής, άχρηστος, αγρότης, άθροισμα*	*άσπρισε, αστράκι, όσφρηση*

Table B.7c

Index		21	22	23	24	25	26	27
Category N	8							
Specific case	Irregular	ευ:/ev-ef/	αυ:/av-af/	εϋ: /eɪ/	οϋ: /oɪ/	αϊ: /aɪ/	οΰ: /oi/	αΐ: /ai/
Example Word		*μαζεύω – ευχή*	*αυλή – αυτός*	*Σεϋχέλλες*	*προϋπόθεση*	*παϊδάκι*	*αραχνοΰφαντος*	*Μαΐου*

Table B.7d

Table B.7: The subordinate exact cases for grapheme/phoneme correspondence

B.8 Grammar/Function Words

Index		1	2	3	4	5	6	7	8	9	10
Category N	9										
Specific case		Def. article, plural, gen	Indef. article, nom	Indef. article, gen	Definite article, singular nom	Def. articles, singular, gen.	Def. article, plural nom:	Prepositions: σε	prepositions: με	prepositions: για	prepositions: από
Example word		*των*	*ένας, μία, ένα*	*ενός, μιας*	*ο / η / το*	*του / της*	*οι, τα*	*σε*	*με*	*για*	*από*

Table B.8a

Table B.8: The subordinate exact cases for grammar/function words

APPENDIX C: Irregular/Sight Word Lists

First 12	Next 20	Next 68	Final Set	Silent Letters
a	all	about	friend	gnat
and	as	an	wrong	gnaw
he	at	back	half	gnu
I	be	bee	calf	gnash
in	but	before	calm	gnome
is	are	big	large	sign
it	for	by	very	design
of	have	call	every	align
that	had	came	sword	alignment
the	him	can	snore	consign
to	his	come	horde	consignment
was	not	could	shore	calm
	on	did	store	palm
	one	do	bore	calf
	said	down	core	half
	so	first	score	folk
	they	from	tore	yolk
	we	get	wore	psalm
	with	go	swore	almond
	you	has	water	iron
		her	forwards	write
		here	upwards	writer
		if	backwards	wrought
		into	poor	wrinkle
		just	door	wring
		like	floor	wrong
		little	moor	who
		look	fault	whom
		made	palm	whose
		make	become	whole
		me	something	autumn
		more	bush	condemn
		much	push	solemn
		must	purr	column
		my	egg	exhibit
		new	odd	exhaust
		no	add	Thames
		now	too	limb
		off	England	lamb
		old	English	comb
		only	pretty	crumb
		or	knob	numb
		other	knit	thumb
		our	knock	plumber
		out	trek	tomb
		over	wreck	debt
		right	wrist	doubt
		see	wren	subtle

		she	gnat	knack
		some	any	knapsack
		their	many	knob
		them	anything	knock
		then	wrap	knot
		there	o'clock	knuckle
		this	white	sword
		two	while	answer
		up	knife	Wednesday
		want	write	often
		well	wrote	listen
		went	four	science
		were	pour	scene
		what	tour	scent
		when	does	ascend
		where	done	descend
		which	goes	indict
		who	gone	mortgage
		wil	whose	fatigue
		your	whom	intrigue
			whole	catalogue
			during	prologue
			sure	dialogue
			sugar	colleague
			mother	league
			brother	epilogue
			grandmother	whisk
			another	whiskey
			once	whirl
			tongue	whisper
			roll	whither
			lonely	Whitsun
			alone	whistle
			soldier	
			orange	
			guard	
			guardian	
			climb	
			bomb	
			lamb	
			tomb	
			sign	
			signal	
			signature	
			design	
			resign	
			ghost	
			Britain	
			straight	

			obey	
			science	
			quiet	
			weird	
			caffeine	
			protein	
			seize	
			either	
			neither	
			leisure	
			height	
			isle	
			island	
			Ireland	
			Irish	
			ocean	
			anxious	
			region	
			legion	
			religion	
			piano	
			idea	
			parliament	
			language	
			area	
			Europe	
			European	
			acre	
			neuter	
			neutral	
			iron	
			euro	
			extra	
			panda	
			llama	
			soda	
			opera	
			pyjama	
			cinema	
			china	
			banana	
			umbrella	
			camera	
			panama	
			Coca-Cola	
			brooch	
			though	
			although	
			shoe	

			canoe	
			cocoa	
			would	
			should	
			fruit	
			suit	
			juice	
			bruise	
			cruise	
			biscuit	
			build	
			building	
			built	
			through	
			truth	
			group	
			soup	
			route	
			Ruth	
			queue	
			sew	
			eye	
			buy	
			bye	
			sigh	
			high	
			thigh	
			great	
			steak	
			break	
			breakfast	
			bear	
			pear	
			wear	
			swear	
			whether	
			coupon	
			wound	
			boulder	
			shoulder	
			mouldy	
			soul	
			oar	
			roar	
			broad	
			board	
			cupboard	
			sausages	
			coarse	

			hoarse	
			because	
			aunt	
			cauliflower	
			heart	
			hearth	
			busy	
			business	
			bury	
			burial	
			beauty	
			beautiful	
			pity	
			piteous	
			miscellany	
			miscellaneous	
			lie	
			die	
			tie	
			lying	
			dying	
			tying	
			spirit	
			fury	
			guerrilla	
			worry	
			figure	
			failure	
			injure	
			treasure	
			procedure	
			pressure	
			measure	
			muscle	
			castle	
			bristle	
			thistle	
			nestle	
			whistle	
			people	
			leopard	
			double	
			trouble	
			couple	
			touch	
			nourish	
			flourish	
			young	
			youth	

			country	
			cousin	
			courage	
			court	
			mourn	
			source	
			course	
			honest	
			amateur	
			courteous	
			bough	
			plough	
			dough	
			laughter	
			draught	
			dessert	
			desert	
			Lieutenant	
			Colonel	
			Sergeant	
			clerk	

Table C.1

Bibliography

Adomavicius, G., & Tuzhilin, A., 2001. Expert-driven validation of rule-based user models in personalization applications. *Data Mining and Knowledge Discovery, 5*(1-2), 33-58.

Adonis, A. and Hughes, B., 2007. Letters and Sounds: Notes of Guidance for Practioners and Teachers, Primary National Strategy, Ref: 00282-2007BKT-EN.

Aïmeur, E., Brassard, G., Dufort, H. amd Gamps, S., 2002. CLARISSE: a machine learning tool to initialize student models. In: S A Cerri, G. Gouardéres and F. Paraguaçu (eds.), Proceedings of the Sixth International Conference on Intelligent Tutoring Systems, Lecture Notes in Computer Science, Vol. 2363. Springer-Verlag, Berlin, Heidelberg, pp. 718-728.

Albacete, P. L., & VanLehn, K., January 2000. The Conceptual Helper: An intelligent tutoring system for teaching fundamental physics concepts. In *Intelligent Tutoring Systems*, Springer Berlin Heidelberg, pp. 564-573.

Aleven, V., & Koedinger, K. R., January 2000. Limitations of student control: Do students know when they need help?. In *Intelligent Tutoring Systems,* Springer Berlin Heidelberg, pp. 292-303.

American Psychiatric Association, 1994. Diagnostic and statistical manual of mental disorders, 4th edition. Washington, DC: APA 1994.

Anderson, J. R., January 1992. Intelligent tutoring and high school mathematics. In *Intelligent tutoring systems,* Springer Berlin Heidelberg, pp. 1-10.

Anderson, J. R., Boyle, C. F., Corbett, A. T., & Lewis, M. W., 1990. Cognitive modeling and intelligent tutoring. *Artificial intelligence, 42*(1), pp. 7-49.

Anderson, J., Corbett, A., Koedinger, K. and Pelletier, R., 1995. Cognitive Tutors: Lessons Learned, The Journal of the Learning Science, 4(2), pp. 167-207.

Anderson, J. and Reiser, B., 1985. The LISP Tutor. Byte, 10(4), pp. 159-175.

Andersen, E., Gulwani, S., & Popovic, Z., April 2013. A trace-based framework for analyzing and synthesizing educational progressions. In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems* (pp. 773-782). ACM.

Antin, J., & Churchill, E. F., 2011. Badges in social media: A social psychological perspective. In *CHI 2011 Gamification Workshop Proceedings (Vancouver, BC, Canada, 2011)*.

Asteriadis, S., Tzouveli, P., Karpouzis, K., & Kollias, S., 2009. Estimation of behavioral user state based on eye gaze and head pose—application in an e-learning environment. *Multimedia Tools and Applications*, *41*(3), 469-493.

Athanaselis, T., Bakamidis, S., Dologlou, I., Argyriou, E. N., & Symvonis, A., 2012. Making assistive reading tools user friendly: a new platform for Greek dyslexic students empowered by automatic speech recognition. *Multimedia Tools and Applications*, 1-19.

Baker, R., Corbett, A.T. and Koedinger, K., 2004. 'Detecting student misuse of intelligent tutoring systems', Proceedings of the Seventh International Conference on Intelligent Tutoring Systems, pp. 531-540.

Baker, R. S., Corbett, A. T., Koedinger, K. R., & Wagner, A. Z., April 2004b. Off-task behavior in the cognitive tutor classroom: when students game the system. In *Proceedings of the SIGCHI conference on Human factors in computing systems* (pp. 383-390). ACM.

Baker, R. S., Roll, I., Corbett, A. T., & Koedinger, K. R., May 2005. Do Performance Goals Lead Students to Game the System?. In *AIED* (pp. 57-64).

Baker, R. S., Corbett, A. T., Koedinger, K. R., Evenson, S., Roll, I., Wagner, A. Z., Naim, M., Raspat, J., Baker, D.J. & Beck, J. E., January 2006. Adapting to when students game an intelligent tutoring system. In *Intelligent Tutoring Systems* (pp. 392-401). Springer Berlin Heidelberg.

Baker, R. S., 2007. Modeling and understanding students' off-task behavior in intelligent tutoring systems. In *Proceedings of the SIGCHI conference on Human factors in computing systems* (pp. 1059-1068). ACM.

Barnard, Y., and Sandberg, J., 1996. Self-explanations, Do We Get them from Our Students? Proceedings of European Conference on Artificial Intelligence in Education. Lisbon, Spain. p. 115-121.

Baschera, G. M., Busetto, A. G., Klingler, S., Buhmann, J. M., & Gross, M., January 2011. Modeling engagement dynamics in spelling learning. In *Artificial Intelligence in Education* (pp. 31-38). Springer Berlin Heidelberg.

Berger, J., Cohen, B.P. and Zelditch, M., 1972. Status Characteristics and Social Interaction. American Sociological Review 37, 3 (1972), p. 241-255.

Biswas, G., Leelawong, K., Schwartz, D., Vye, N., & The Teachable Agents Group at Vanderbilt, 2005. Learning by teaching: A new agent paradigm for educational software. *Applied Artificial Intelligence*, *19*(3-4), 363-392.

Björk, S. and Holopainen, J., 2004. Patterns in Game Design. Hingham, MA, USA: Charles River Media.

Bloom, B. S., 1984. The 2 sigma problem: The search for methods of group instruction as effective as one-to-one tutoring. *Educational Researcher*, *13*(6), 4-16.

Bramley, W., 2004. Units of Sound 1,2 and 3, Fourth Edition. The Dyslexia Institute, Surrey: UK.

Braun, V. and Clarke, V., 2006. Using thematic analysis in psychology. *Qualitative research in psychology,* 3(2), pp. 77-101.

Brooks, G., 2007. What works for pupils with literacy difficulties? London: DCSF.

Brown, E. and Brailsford, T., 2004. Integration of learning style theory in an adaptive educational hypermedia (AEH) system. Paper presented at the 11th International Conference of the Association for Learning Technology (ALT-C 2004), 14-16 Sept 2004, Exeter, UK.

Brown, E., Brailsford, T., Fisher, T., Moore, A. and H. Ashman, 2006. Reappraising cognitive styles in adaptive web applications. Proceedings of the 15th International World Wide Web Conference (WWW2006), Edinburgh, UK, 22-26 May 2006, pp. 327-335.

Brown, E., Stewart, C. & Brailsford, T., 2006b. Adapting for visual and verbal learning styles in AEH. Proceedings of the Sixth IEEE International Conference on Advanced Learning Technologies (ICALT 2006), Kerkrade, The Netherlands, 5-7 July 2006, pp. 1145-1146.

Bull, S. and Pain, H., 1995. "Did I say what I think I said, and do you agree with me?": Inspecting and Questioning the Student Model, Proceedings of World Conference on Artificial Intelligence in Education, pp. 501-508, AACE, Washington DC, USA (1995)

Bull, S., & Nghiem, T., 2002. Helping learners to understand themselves with a learner model open to students, peers and instructors. In *Proceedings of Workshop on Individual and Group Modelling Methods that Help Learners Understand Themselves, International Conference on Intelligent Tutoring Systems* (Vol. 2002, pp. 5-13).

Bull, S., Brna, P. and Pain, H., 1995. Extending the Scope of the Student Model, User Modeling and User Adapted Interaction, 5(1), p. 45-65.

Bull, S. and Broady, E., 1997. Spontaneous peer tutoring from sharing student models, Artificial Intelligence in Education, pp. 143-150, IOS Press (1997)

Bull, S. and Kay, J., 2005. A Framework for Designing and Analysing Open Learner Modelling, Proceedings of Workshop on Learner Modelling for Reflection, International Conference on Artificial Intelligence in Education, 2005, Amsterdam, pp. 81-90.

Bull, S. and Kay, J., 2008. Metacognition and Open Learner Models. In I. Roll and V. Aleven (eds.), Proceedings of Workshop on Metacognition and Self-Regulated Learning in Educational Technologies, International Conference on Intelligent Tutoring Systems.

Bull, S., & Kay, J., 2007. Student Models that Invite the Learner In: The SMIL:) Open Learner Modelling Framework. *International Journal of Artificial Intelligence in Education, 17(*2), 89-120.

Bull, S., & McKay, M., January 2004. An open learner model for children and teachers: inspecting knowledge level of individuals and peers. In *Intelligent tutoring systems* (pp. 646-655). Springer Berlin Heidelberg.

Bull, S., & Mabbott, A., 2006. *20000 Inspections of a Domain-Independent Open Learner Model*. ITS 2006, LNCS 4053, pp. 422 – 432, 2006.

Bull, S., Mangat, M., Mabbott, A., Abu Issa, A. S., & Marsh, J., 2005. Reactions to inspectable learner models: seven year olds to University students. In *Proceedings of workshop on learner modelling for reflection, international conference on artificial intelligence in education* (pp. 1-10).

Burden, R., 2005. Dyslexia and Self-Concept: seeking a dyslexic identity. London: Whurr.

Carberry, S., 2001. Techniques for Plan Recognition. User Modeling and User-Adapted Interaction, 11(1-2), p. 31-48.

Carvalho, D., 2009. What have we achieved? http://danielcarvalho.com/articles/what-have-we-achieved/

Chaffar, S., & Frasson, C., January 2004. Inducing optimal emotional state for learning in Intelligent Tutoring Systems. In *Intelligent Tutoring Systems* (pp. 45-54). Springer Berlin Heidelberg.

Chaouachi, M, and Frasson, C., 2010 "Exploring the relationship between learner EEG mental engagement and affect." *Intelligent Tutoring Systems*. Springer Berlin Heidelberg, 2010.

Chin, D., 2001. Empirical Evaluation of User Models and User-Adapted Systems. User Modeling and User-Adapted Interaction, 11, pp. 181-194.

Cimolino, L., Kay, J., & Miller, A., July 2003. Incremental student modelling and reflection by verified concept-mapping. In *Supplementary Proceedings of the AIED2003: Learner Modelling for Reflection Workshop* (pp. 219-227).

Cohen, P. A., Kulik, J. A., & Kulik, C. L. C., 1982. Educational outcomes of tutoring: A meta-analysis of findings. *American educational research journal,19*(2), 237-248.

Conati, C., and Maclaren, H., 2009. Empirically building and evaluating a probabilistic model of user affect. *User Modeling and User-Adapted Interaction*, *19*(3), 267-303.

Conati, C., Chabbal, R., & Maclaren, H., 2003. A study on using biometric sensors for monitoring user emotions in educational games. In *Workshop on Assessing and Adapting to User Attitudes and Affect: Why, When and How*.

Cook, R. and Kay, J., 1994. The justified user model: A viewable explained user model. Technical Report Number 483, Basser Department of Computer Science. University of Sydney, pp. 1-6 (1994)

Corbett, AT., Anderson, J.R. and Patterson, E.G., 1990. Student modeling and tutoring flexibility in the Lisp Intelligent Tutoring System. In C. Frasson and G. Gauthier (Eds.) Intelligent tutoring systems: At the crossroads of artificial intelligence and education. Norwood, NJ; Ablex Publishing.

Corbett, A. T., & Anderson, J. R., 1991. Feedback control and learning to program with the CMU LISP tutor. *Department of Psychology*, 28.

Corbett, A. and Anderson, J., 1995. Knowledge Tracing: Modeling the Acquisition of Procedural Knowledge. User Modeling and User-Adapted Interaction, 4, pp. 253-278 (1995).

Corbett, A., Anderson, J. and O'Brien, A., 2008. The Predictive Validity of Student Modeling in the ACT Programming Tutor, 2008, Department of Psychology, Carnegie Mellon University, Paper 80.

Costagliola, G., De Rosa, M., Fuccella, V., Capuano, N., & Ritrovato, P., October 2010. A Novel Approach for Attention Management in E-learning Systems. In *DMS* (pp. 222-227).

da Costa Pereira, C. and Tettamanzi, A.G., 2006. An ontology-based method for user model acquisition. In Soft Computing in Ontologies and Semantic Web, p. 211-229, Springer Berlin Heidelberg.

Dale, M. and Taylor, B., 2001. How Adult Learners Make Sense of Their Dyslexia. Disability and Society, 16:7, pp. 997-1008.

Deci, E., 1971. Effects of Externally Mediated Rewards on Intrinsic Motivation. Journal of Personality and Social Psychology 18, (1971), p. 101-115.

Deci, E. L., Koestner, R., & Ryan, R. M., 2001. Extrinsic rewards and intrinsic motivation in education: Reconsidered once again. *Review of Educational Research*, *71*(1), 1-27.

de Haan, A., & Oppenhuizen, T., 1994. SPELLER: A reflexive ITS to support the learning of second language spelling. *Computers in human behavior*, *10*(1), 21-31.

Demonet, J., Taylor, M. and Chaix, Y., 2004. Developmental dyslexia. Lancet, 363, pp. 1451-1460.

Desmarais, M. C., & d Baker, R. S., 2012. A review of recent advances in learner and skill modeling in intelligent learning environments. *User Modeling and User-Adapted Interaction*, *22*(1-2), 9-38.

Deterding, S., Dixon, D., Khaled, R., & Nacke, L., September 2011. From game design elements to gamefulness: defining gamification. In *Proceedings of the 15th International Academic MindTrek Conference: Envisioning Future Media Environments* (pp. 9-15). ACM.

de Vicente, A., & Pain, H., January 2002. Informing the detection of the students' motivational state: an empirical study. In *Intelligent tutoring systems*(pp. 933-943). Springer Berlin Heidelberg.

Di Mascio, T., Gennari, R., & Vittorini, P., 2010. The Design of An Intelligent Adaptive Learning System for Poor Comprehenders. *Proc. of Cognitive and Metacognitive Educational Systems*.

Dimitrova, V., 2003. STyLE-OLM: Interactive open learner modelling. *International Journal of Artificial Intelligence in Education*, *13*(1), 35-78.

Dorst, K. and Dijkhuis, J., 1995. Comparing paradigms for describing design activity. Design Studies, 16(2):261–274, 1995.

Dyslexia Action, 2013. About dyslexia. Available online at http://dyslexiaaction.org.uk/about-dyslexia

Easley, D., & Ghosh, A., June 2013. Incentives, gamification, and game theory: An economic approach to badge design. In *Proceedings of the fourteenth ACM conference on Electronic commerce* (pp. 359-376). ACM.

Fallman, D., April 2003. Design-oriented human-computer interaction. In *Proceedings of the SIGCHI conference on Human factors in computing systems* (pp. 225-232). ACM.

Fischer, G., 2001. User Modeling in Human-Computer Interaction. User Modeling and User-Adapted Interaction, 11, pp. 65-86.

Fisher, S. and DeFries, J., 2002. Developmental Dyslexia: Genetic Dissection of a Complex Cognitive Trait. Nature Reviews, Neuroscience, 3, pp. 767-782.

Fitz-Walter, Z., Tjondronegoro, D., & Wyeth, P., November 2011. Orientation passport: using gamification to engage university students. In *Proceedings of the 23rd Australian Computer-Human Interaction Conference* (pp. 122-125). ACM.

Fox, S. and Hoffman, M., 2002. Escalation Behavior as a Specific Case of Goal-Directed Activity: A Persistence Paradigm. Basic and Applied Social Psychology 24, 4 (2002), p. 273.

Gertner, A. S., & VanLehn, K., January 2000. Andes: A coached problem solving environment for physics. In *Intelligent Tutoring Systems* (pp. 133-142). Springer Berlin Heidelberg.

Ghadirli, H.M. and Rastgarpour, M., 2012. An Adaptive and Intelligent Tutor by Expert Systems for Mobile Devices, In *International Journal of Managing Public Sector Information and Communication Technologies*, 3(1), p. 21-28.

Girard, S., 2012. Traffic Lights and Smiley Faces : Do children learn mathematics better with affective Open-Learner Modelling tutors? PhD. Thesis, University of Bath, UK.

Goswami, U., 2008. Learning difficulties: Future challenges. A paper prepared as part of the Foresight Review on Mental Capital and Wellbeing, accessed from http://www.bis.gov.uk/assets/foresight/docs/mental-capital/learning_difficulties.pdf

Grigoriadou, M., Papanikolaou, K., Kornilakis, H., & Magoulas, G., July 2001. INSPIRE: an intelligent system for personalized instruction in a remote environment. In *Proceedings of 3rd Workshop on Adaptive Hypertext and Hypermedia* (pp. 13-24).

Guo, Z. and Greer, J., 2006. Electronic Portfolios as a Means for Initializing Learner Models for Adaptive Tutorials. In W. Nejdl and K. Tochtermann (eds.), EC-TEL 2006, Lecture Notes in Computer Science 4227 Springer-Verlag, p. 482-487, 2006.

Guzman, E. and Conejo, R., 2002. Simultaneous evaluation of multiple topics in SIETTE. In: S A Cerri, G. Gouardéres and F. Paraguaçu (eds.), Proceedings of the Sixth International Conference on Intelligent Tutoring Systems, Lecture Notes in Computer Science, Vol. 2363. Springer-Verlag, Berlin, Heidelberg, pp. 739-748.

Hamari, J., & Eranti, V., 2011. Framework for designing and evaluating game achievements. *Proc. DiGRA 2011: Think Design Play*, *115*, 122-134.

Hansen, C., & McCalla, G., July 2003. Active open learner modelling. In *Proceedings of Learner Modelling for Reflection Workshop International Conference on Artificial Intelligence in Education*.

Harper, R., Lamming, M. and Newman, W., 1992. Locating systems at work: implications for the development of active badge applications. *Interact. Comput.* 4, 3 (December 1992), pp. 343-363.

Hebert, S., Lee, V., Morabito, M. and Polan, J., 2006. Bayesian network theory. In the Michigan Chemical Process Dynamics and Controls Open Text Book, https://controls.engin.umich.edu/wiki/index.php/Bayesian_network_theory.

Hecker, C. 2010. Achievements Considered Harmful? 2010.

Hill, W., Hollan, J., Wroblewski, D. and McCandless, T., 1992. Edit wear and read wear. In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems* (CHI '92), Bauersfeld, P., Bennett, J. and Lynch, G. (Eds.). ACM, New York, NY, USA, pp. 3-9.

Hornsby, B., Shear, F., & Pool, J., 1999. *Alpha to Omega: The AZ of teaching reading, writing and spelling, Fifth Edition*. Heinemann.

Hothi, J. and Hall, W., 1998. An evaluation of adaptive hypermedia techniques using static user modelling. In P. Brusilovsky and P. De Bra (eds.), Proceedings of the Second Workshop on Adaptive Hypertext and Hypermedia, p. 45-55.

Jackson, S. L., Krajcik, J., & Soloway, E., January 1998. The design of guided learner-adaptable scaffolding in interactive learning environments. In *Proceedings of the SIGCHI conference on Human factors in computing systems* (pp. 187-194). ACM Press/Addison-Wesley Publishing Co..

Jean-Daubias, S., & Eyssautier, C., 2005. An environment helping teachers to track students' competencies. In *Proceedings of the 12th International Conference on Artificial Intelligence in Education*.

Kanvinde, G., Rello, L., & Baeza-Yates, R., October 2012. IDEAL: a dyslexic-friendly ebook reader. In *Proceedings of the 14th international ACM SIGACCESS conference on Computers and accessibility* (pp. 205-206). ACM.

Kay, J., 1994. Lies, damned lies and stereotypes: Pragmatic approximations of users. Technical Report Number 482, Basser Department of Computer Science, University of Sydney. pp. 1- (1994)

Kay, J. and Kummerfeld, R.J., October 1994. An individualised course for the C programming language. In Proceedings of Second International WWW Conference, pp. 17-20.

Kay, J. and Thomas, R., 1995. Studying Long-Term Systems Use. Communications of the ACM, 38(7), pp. 61-69 (1995).

Kay, J., 1997. Vive la difference! Individualised internation with users. Technical Report Number 517, Basser Department of Computer Science, University of Sydney, pp. 1-8 (1997).

Kay, J., 1997b. Learner know thyself: Student models to give learner control and responsibility. In Control and Responsibility, International Conference on Computers in Education, AACE, 1997b, pp. 17-24.

Kay, J., 2001. Learner Control. User Modeling and User-Adapted Interaction. 11, pp. 111-127 (2001).

Kay, J., 2008. Lifelong learner modeling for lifelong personalized pervasive learning. *Learning Technologies, IEEE Transactions on*, *1*(4), 215-228.

Koedinger, K. R., Anderson, J. R., Hadley, W. H., & Mark, M. A., 1997. Intelligent tutoring goes to school in the big city. *International Journal of Artificial Intelligence in Education (IJAIED)*, *8*, 30-43.

Koedinger, K., Suthers, D. and Forbus, K., 1999. Component-Based Construction of a Science Learning Space. International Journal of Artificial Intelligence in Education, 10, pp. 292-313.
Kollock, P. The Production of Trust in Online Markets. In Advances in Group Processes. JAI Press, Greenwich, CT, 1999.

Kriplean, T., Beschastnikh, I. and McDonald, D.W., 2008. Articulations of wikiwork: uncovering valued work in wikipedia through barnstars. Proceedings of the 2008 ACM conference on Computer supported cooperative work, ACM (2008), p. 47-56.

Lee, S. J., & Bull, S., 2008. An open learner model to help parents help their children. *Technology Instruction Cognition and Learning*, *6*(1), 29.

Lepper, M. R., Woolverton, M., Mumme, D. L., & Gurtner, J., 1993. Motivational techniques of expert human tutors: Lessons for the design of computer-based tutors. *Computers as cognitive tools*, *1993*, 75-105.

Lesta, L., & Yacef, K., January 2002. An intelligent teaching assistant system for Logic. In *Intelligent Tutoring Systems* (pp. 421-431). Springer Berlin Heidelberg.

Ling, K., Beenen, G., Ludford, P., Wang, X., Chang, K., Li, X., & Kraut, R., 2005. Using social psychology to motivate contributions to online communities. *Journal of Computer-Mediated Communication*, *10*(4).

Liu, Y., Alexandrova, T., & Nakajima, T., December 2011. Gamifying intelligent environments. In *Proceedings of the 2011 international ACM workshop on Ubiquitous meta user interfaces* (pp. 7-12). ACM.

Lozano-Pérez, T. and Kaelbling, L., 2002. Lecture notes from Techniques in Artificial Intelligence, MIT Course Number 6.825, 2002. Lecture 17: Where do Bayesian Networks Come From? http://ocw.mit.edu/courses/electrical-engineering-and-computer-science/6-825-techniques-in-artificial-intelligence-sma-5504-fall-2002/lecture-notes/

Luckin, R., & Hammerton, L. 2002. Getting to Know Me: Helping Learners Understand Their Own Learning Needs through Metacognitive Scaffolding *Intelligent Tutoring Systems* (pp. 759-771. Berlin: Springer.

Lloyd, T., & Bull, S., 2006. A haptic learner model. *International Journal of Continuing Engineering Education and Life Long Learning*, *16*(1), 137-149.

Malone, T. W., 1981. Toward a theory of intrinsically motivating instruction. Cognitive Science 4 (1981), p. 333-370.

Mazza, R., & Dimitrova, V., May 2004. Visualising student tracking data to support instructors in web-based distance education. In *Proceedings of the 13th international World Wide Web conference on Alternate track papers & posters* (pp. 154-161). ACM.

McCalla, G. I., Peachey, D. R., & Ward, B., 1982. An architecture for the design of large scale intelligent teaching systems. In *Proceedings of the 4th National Conference of the CSCSI* (pp. 85-91).

McCallum, S., 2012. Gamification and serious games for personalized health. *Stud Health Technol Inform*, *177*, 85-96.

Merrill, D. C., Reiser, B. J., Ranney, M., & Trafton, J. G., 1992. Effective tutoring techniques: A comparison of human tutors and intelligent tutoring systems. *The Journal of the Learning Sciences*, *2*(3), 277-305.

Milne, S., Shiu, E. and Cook, J., 1996. Development of a model of user attributes and its implementation within an adaptive tutoring system. User modelling and user-adapted interaction, 6(4), p. 303-335.

Mitrovic, A., 2012. Fifteen years of constraint-based tutors: what we have achieved and where we are going. *User Modeling and User-Adapted Interaction*,*22*(1-2), 39-72.

Mitrovic, A., Koedinger, K. R., & Martin, B., 2003. A comparative analysis of cognitive tutoring and constraint-based modeling. In *User Modeling 2003* (pp. 313-322). Springer Berlin Heidelberg.

Mitrovic, A. & Martin, B., 2007. Evaluating the Effect of Open Student Models on Self- Assessment *International Journal of Artificial Intelligence in Education* 17(2) (2007), 121-144.

Mohanarajah, S., Kemp, R., & Kemp, E., 2005. Opening a fuzzy learner model. In *Proceedings of Workshop on Learner Modelling for Reflection. In: International Conference on Artificial Intelligence in Education* (pp. 62-71).

Montola, M., Nummenmaa, T., Lucero, A., Boberg, M., & Korhonen, H., September 2009. Applying game achievement systems to enhance user experience in a photo sharing service. In *Proceedings of the 13th International MindTrek Conference: Everyday Life in the Ubiquitous Era* (pp. 94-97). ACM.

Mota, S., & Picard, R. W., June 2003. Automated posture analysis for detecting learner's interest level. In *Computer Vision and Pattern Recognition Workshop, 2003. CVPRW'03. Conference on* (Vol. 5, pp. 49-49). IEEE.

Mühlenbrock, M., Tewissen, F., & Hoppe, U., 1998. A framework system for intelligent support in open distributed learning environments. *International Journal of Artificial Intelligence in Education (IJAIED), 9*, 256-274.

Ndombo, M. D., Ojo, S., & Osunmakinde, I. O., 2013. An Intelligent Integrative Assistive System for Dyslexic Learners. *Journal of Assistive Technologies, 7*(3).

Nicholson, S., 2012. A user-centered theoretical framework for meaningful gamification. *Proceedings GLS, 8*.

O'Donovan, S., 2012. Gamification of the games course. *Acesso em, 17*.

Ogan, A., Finkelstein, S., Mayfield, E., D'Adamo, C., Matsuda, N., & Cassell, J., May 2012. Oh dear stacy!: social interaction, elaboration, and learning with teachable agents. In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems* (pp. 39-48). ACM.

Ogan, A., Walker, E., Baker, R. S., Rebolledo Mendez, G., Jimenez Castro, M., Laurentino, T., & de Carvalho, A., May 2012b. Collaboration in cognitive tutor use in latin America: field study and design recommendations. In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems* (pp. 1381-1390). ACM.

Olson, R., 2002. Dyslexia: Nature and Nurture. Dyslexia, 8, pp. 143--159.

Orwant, J., 1996. For want of a bit the user was lost: Cheap user modelling. IBM Systems Journal, 35(3/4), pp. 398-416, (1996).

Orwant, J., 1994. Heterogeneous learning in the Doppelganger user modelling system. User Modeling and User-Adapted Interaction, 4(2), p. 107-130.

Pandey, S., & Srivastava, S., April 2011. SpellBound: a tangible spelling aid for the dyslexic child. In *Proceedings of the 3rd International Conference on Human Computer Interaction* (pp. 101-104). ACM.

Peachey, D. R., & McCalla, G. I., 1986. Using planning techniques in intelligent tutoring systems. *International Journal of Man-Machine Studies,24*(1), 77-98.

Radlinski, R., & McKendree, J., June 1992. Grace meets the "real world": tutoring COBOL as a second language. In *Proceedings of the SIGCHI conference on Human factors in computing systems* (pp. 343-350). ACM.

Ralph, P., 2010. Comparing two software design process theories. In International Conference on Design Science Research in Information Systems and Technology (DESRIST 2010), pages 139–153, St. Gallen, Switzerland, 2010. , Springer.

Rau, M. A., Aleven, V., Rummel, N., & Rohrbach, S., April 2013. Why interactive learning environments can have it all: resolving design conflicts between competing goals. In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems* (pp. 109-118). ACM.

Rebolledo-Mendez, G., Du Boulay, B., & Luckin, R., January 2006. Motivating the learner: an empirical evaluation. In *Intelligent Tutoring Systems* (pp. 545-554). Springer Berlin Heidelberg.

Reeves, B. and Read, J.L., 2009. Total Engagement: Using Games and Virtual Worlds to Change the Way People Work and Businesses Compete. Harvard Business School Press, Boston, MA, 2009.

Rello, L., Bayarri, C., & Gorriz, A., October 2012. What is wrong with this word? Dyseggxia: a game for children with dyslexia. In *Proceedings of the 14th international ACM SIGACCESS conference on Computers and accessibility*(pp. 219-220). ACM.

Rich, E., 1979. User Modeling via Stereotypes. Cognitive Science, 3, pp. 329-354 (1979)

Rose, J., 2009. Identifying and Teaching Children and Young People with Dyslexia and Literacy Difficulties. Report for the Department of Children, Schools and Families, June 2009.

Rueda, U., Larrañaga, M., Ferrero, B., Arruarte, A., & Elorriaga, J. A., 2003. Study of graphical issues in a tool for dynamically visualising student models. *Learner Modelling for Reflection*, 1.

Sampath, H., Sivaswamy, J., & Indurkhya, B., 2010. Assistive systems for children with dyslexia and autism. *ACM SIGACCESS Accessibility and Computing*, (96), 32-36.

Schneider, N., Dorr, M., Pomarjanschi, L., & Barth, E., August 2011. A gaze-contingent reading tutor program for children with developmental dyslexia. In *Proceedings of the ACM SIGGRAPH Symposium on Applied Perception in Graphics and Visualization* (pp. 117-117). ACM.

Schon, D. A., 1983. The reflective practitioner: how professionals think in action. Basic Books, USA, 1983.

Schwab, I. and Kobsa, A., 2002. Adaptivity through Unobstructive Learning. Künstliche Intelligenz, 3, p. 5-9.

Self, J., 1990. Bypassing the Intractable Problem of Student Modelling, In C. Frasson and G. Gauthier (eds.), Intelligent Tutoring Systems: at the Crossroads of Artificial Intelligence and Education, p. 107 – 23, 1990.

Simon, H. A., 1996. The Sciences of the Artificial. MIT Press, Cambridge, MA, USA, 1996.

Snowling, M.J., 2008. Dyslexia. A paper prepared as part of the Foresight Review on Mental Capital and Wellbeing, accessed from http://www.bis.gov.uk/assets/foresight/docs/mental-capital/sr-d2_mcw_v2.pdf

Soloway, E., Jackson, S. L., Klein, J., Quintana, C., Reed, J., Spitulnik, J., & Scala, N., April 1996. Learning theory in practice: Case studies of learner-centered design. In *Proceedings of the SIGCHI conference on Human factors in computing systems* (pp. 189-196). ACM.

Sonamthiang, S., Nariedomkul, K. and Cercone, N., 2006. Initliazing Student Models Using Dempster-Shafer Theory, In Proceedings of the Nint IASTED International Conference Computers and Advanced Technology in Education, Lima, Peru, p. 76-81.

Sparck Jones, K., 1989. Realism About User Modeling, pp. 341-363. In User Models in Dialog Systems, Kobsa, A. and Wahlster, W. (editors), Springer-Verlag.

Suchman, L., 1987. Plans and situated actions: the problem of human-machine communication, Cambridge University Press, Cambridge, 1987.

Suraweera, P., & Mitrovic, A., January 2002. KERMIT: a constraint-based tutor for database modeling. In *Intelligent Tutoring Systems* (pp. 377-387). Springer Berlin Heidelberg.

Tønnessen, F., 1997. How Can We Best Define `Dyslexia'? Dyslexia, 3, pp. 78-92.

Torgesen, J.K., Wagner, R.K., Rashotte, C.A., Rose, E., Lindamood, P. and Conway, T., 1999. Preventing reading failure in young children with phonological processing disabilities: Group and individual responses to instruction. Journal of Educational Psychology, 91, pp. 579-593.

Trusty, A., & Truong, K. N., May 2011. Augmenting the web for second language vocabulary learning. In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems* (pp. 3179-3188). ACM.

Tsiriga, V. and Virvou, M., 2004. A Framework for the Initialization of Student Models in Web-based Intelligent Tutoring Systems. User Modeling and User-Adapted Interaction, 14, p. 289-316, 2004.

Turner, M., 2008. Dyslexia Portfolio. GL assessment, London: UK.

Tzouveli, P., Schmidt, A., Schneider, M., Symvonis, A., & Kollias, S., July 2008. Adaptive reading assistance for the inclusion of students with dyslexia: the AGENT-DYSL approach. In *Advanced*

Learning Technologies, 2008. ICALT'08. Eighth IEEE International Conference on (pp. 167-171). IEEE.

Van Dam, A., Becker, S., & Simpson, R. M., 2005. Next-generation educational software. EDUCAUSE review, March/April 2005, 27-42.

VanLehn, K., Jordan, P. W., Rosé, C. P., Bhembe, D., Böttner, M., Gaydos, A., & Srivastava, R., January 2002. The architecture of Why2-Atlas: A coach for qualitative physics essay writing. In *Intelligent tutoring systems* (pp. 158-167). Springer Berlin Heidelberg.

VanLehn, K., Lynch, C., Taylor, L., Weinstein, A., Shelby, R., Schulze, K. & Wintersgill, M., January 2002b. Minimally invasive tutoring of complex physics problem solving. In *Intelligent Tutoring Systems* (pp. 367-376). Springer Berlin Heidelberg.

Virvou, M. and DuBoulay, B., 1999. Human plausible reasoning for intelligent help. User Modeling and User-Adapted Interaction, 9(4), p. 321-375.

Walker, J., Goldup, W. and Lomas, S., 2008. Dyslexia Institute Literacy Programme (DILP). Dyslexia Action: UK.

Weber, G., 1999. Adaptive learning systems in the World Wide Web, In: J. Kay (ed.), Proceedings of UM99: Seventh International Conference on User Modeling, pp. 371-378.

Weber, G. and Brusilovsky, P., 2001. ELM-ART: An Adaptive Versatile System for Web-based Instruction. International Journal of Intelligence in Education, 12, p. 351-384.

WHO, 1993. The international classification of diseases, vol. 10: classification of mental and behavioural disorders. Geneva: World Health Organisation, 1993.

Wood, C., 2005. Beginning readers' use of 'talking books' software can affect their reading strategies. *Journal of Research in Reading*, *28*(2), 170-182.

Yacef, K., 2005. The Logic-ITA in the classroom: a medium scale experiment. *International Journal of Artificial Intelligence in Education*, *15*(1), 41-62.

Yedelson, M., Medvedeva, O. and Crowley, R., 2008, A multifactor approach to student model evaluation. User Modeling and User-Adapted Interaction. 18, pp. 349-382 (2008).

Zapata-Rivera, J.D, 2003. Learning Environments based on Inspectable Student Models. Ph.D. Thesis. University of Saskatchewan. Department of Computer Science.

Zapata-Rivera, J.D., and Greer, J., 2004. Inspectable Bayesian Student Modelling Servers in Multi-Agent Tutoring Systems. *International Journal of Human Computer Studies.* 61(4). 535-563.

Zukerman, I. and Albrecht, D., 2001. Predictive Statistical Models for User Modeling. *User Modeling and User-Adapted Interaction* 11, 1-2 (March 2001), 5-18.