Contextual considerations for the design of Learner-adaptive computer support in collaborative classrooms

Marie Bodén
BSc in Systems Analysis, MSc in Informatics

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Abstract

This thesis takes a step towards identifying principles that should be considered when designing a computer based “teaching and learning environment”, that is suitable for typical, busy classrooms. Computer based technology that senses the ability of the student, and then adapts the level of difficulty of activities to strike a balance between challenge and encouragement are increasingly used in schools and the home. However, it is unclear how well such “learner adaptive” technologies work in primary school classrooms where the learner is just one of many, how well they fit into and aid existing teaching programs, and what the attitudes of students and teachers are when a computer takes some control away. This thesis investigates these questions by developing a learner adaptive system for spelling training that embraces interaction and collaboration, that aims to complement rather than replace current teaching practice, and evaluates it in an educational context, using both quantitative and qualitative analyses. Over the course of a year, the system serviced over a hundred students at three different primary schools. By inspecting computer logs and interviewing students and teachers, I find that there is place for learner adaptive systems in primary school classrooms, and more specifically, that a spelling program can be integrated with existing teaching programs. The successful application of learner adaptive systems is contingent on careful consideration of both students and teachers as stakeholders, that the system can operate in and embrace open, collaborative environments, and that individualisation is not nearly as important as an adaptive level of challenge.
Declaration by author

This thesis is composed of my original work, and contains no material previously published or written by another person except where due reference has been made in the text. I have clearly stated the contribution by others to jointly-authored works that I have included in my thesis.

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Analysis

Future work
A better design to suit the classroom

Research question
Collaboration
Seamless fit with existing teaching
Student engagement triggers teachers’ engagement
Learner adaptation and explaining success rates

Observations
Teacher Interviews
Spelling Tests

Phase 2: School A
Observations of Students

Phase 1: School A

Phase: School B

Phase 2: School C
Observations of teachers

Summary

Analysis

Learner adaptation and explaining success rates
Teachers’ confidence in using technology
Time poor and dedicated teachers
Student engagement triggers teachers’ engagement
Support for teaching
Seamless fit with existing teaching
Students engagement
Collaboration
Staying on the positive side of the “fine line” for challenges
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Discussion and Conclusion

Validity of results
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Future work

Conclusion

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1 Introduction

Imagine an educational system that can recognise individual students’ learning styles and also adapt learning activities to suit each student’s level of learning. Then also imagine that the system makes decisions in agreement with the school’s aims and curriculum goals. The system tries to choose learning activities at an appropriate skill and ability level for each student but disguises differences in a fun and engaging way. The system continually collects data so that statistics of progress are available for both students and teachers.

How well does such a system function in a primary school classroom?

1.1 Problem overview

An open learning environment such as a modern primary school classroom is busy with activities and under constant changes. Teachers are expected to deliver learning that is individualised to each and every student while having classes consisting of 25-30 students. It is therefore vital to have adequate support to create a teaching and learning environment that is best suited to such expectations. This thesis takes a step towards identifying principles that should be considered when designing a computer-based “teaching and learning environment” that is suitable for typical busy classrooms, while offering students (and teachers) the opportunity to engage “online” and “offline” in one-to-one and peer-to-peer learning (and, from the teacher’s point of view, evaluation).

Today it is commonplace that teachers apply modern administration tools for learning and communication, e.g. word-processing, spread sheets, Internet browsers and emails. Software to support learning, such as Mathletics and other web-based educational games, are often used but they are motivated by both educational goals, commercial interests and corporate agendas (Seiter, 2005; Chung and Grimes, 2005).
Below I will introduce typical examples of systems that have one or more characteristics that are sought in educational tools for “teaching and learning environments”. I also identify some features that are problematic that a design for this type of system may need to consider, before I introduce adaptive technology.

Mathletics and SpelloDrome are web-based resources for learning mathematics (www.3plearning.com), and used by numerous schools. Schools and parents can sign up for a subscription to one of the educational games, so their students and children have access to the resources at their leisure, from both home and school. Mathletics and SpelloDrome are thus intentionally designed to suit student learning, particularly in home environments, where parents allow educational computer games. Both these educational games are designed with a game methodology to stimulate students to answer mathematical questions or do spelling tasks, to earn rewards with medals and digital coins, and play a mini-game.

Mathletics and SpelloDrome have been found to be highly engaging for students but the educational outcomes have been suggested to be secondary due to commercial interests of the producers of the software (Nansen et. al., 2012). The need to keep students excited about the educational game may lead to the introduction of features that students can negotiate for entertainment rather than focusing on the actual learning (Nansen et. al., 2012), for instance, that they choose activities that are easier, for the benefit of achieving rewards.

For the purpose of supporting individualised learning in the classroom, my own work (Boden, 2004) evaluated the use of adaptive educational software in primary schools. The study showed how students, in a short period of time, improved their spelling through the use of an “adaptive” system for learning spelling, where spelling activities were selected by the computer to suit the individual students. However, the study observed that students interacted and collaborated with each other far more than expected from how the program was designed, quite possibly due to the open classroom environment of
primary schools. Even though students were instructed to work individually in front of computers (and rewarded for doing so) they naturally engaged in ongoing collaborations with each other. This unmonitored interaction may affect a number of outcomes, including how well the automatic tailoring of educational activities works for the individual student, the enthusiasm for learning, the development of communication, the need for supervision etc.

1.2 Adaptive Technology

Adaptation in an educational technology context means two things: the technology needs to be sensitive to a student’s response to activities. Second, the technology should change its behaviour in future interaction with the user in some way to become more tailored to the student’s level of ability.

Supporting children’s learning through the use of computer technology was initially known as Computer-Aided Learning (CAL) (Koschman, 1996). From this field of research, a number of related but sometimes independently viewed sub-fields have evolved, including Computer Supported Collaborative Learning (CSCL) and Intelligent Tutoring Systems (ITS). The sub-field of CSCL centres on the design of computer systems that aim to support and encourage collaboration between students. The sub-field of ITS on the other hand involves a computerised tutor component that aims to support the student as an individual. ITSs are usually based on a computer algorithm that chooses a suitable task that challenges the student at an appropriate level. If the adaptive system is successful in its choice of task the user should experience a learning challenge that is not too difficult to keep the user interested enough to continue, but hard enough to achieve a learning outcome (Sklar & Pollack, 2000).

Several successful computer-based ITSs already exist (Koedinger et al., 1997; Conati et al., 2002) and they have all been tested quantitatively with the aim of finding a system for selecting tasks that mimic what a human tutor would do. The main focus of this thesis is what I refer to as Learner Adaptive Technology. Learner Adaptive Technology is computerised educational
systems designed with the goal of supporting individual students in a classroom context. Learner Adaptive Technology is in addition designed to support teachers by offering features for assessing learning progress including generating reports for individual students.

ITS that uses learner-adaptation based on student modelling (Conati et al., 2002; Koedinger et al., 1995; Aleven & Koedinger, 2002; Millán & Pèrez-de-la-Cruz, 2002) is one of the most popular approaches in computer-aided education. This approach is designed to replace or supplement human teaching support. Such systems build and gradually refine an internal model of their user’s behaviour (to mirror its ability) and, based on the model, predict how to best challenge the student. ITSs are widely used in American schools today (Koedinger et al., 2014) with some success. Existing intelligent tutoring systems tend to focus on instructional support in mathematics and in some science domains. For example, ANDES (Conati et al, 2002) is designed to help students learn introductory university physics. ANDES offers individualised homework support. Another well-known example of ITS is the PAT algebra tutor (Koedinger and Andersson, 1997) which has proven better student learning compared to traditional algebra courses (Ritter et al., 2007).

Past work in the area of ITS, has primarily focused on testing the technical validity, effectiveness and efficiency of a system’s adaptation. For instance, Millán and Pèrez-de-la-Cruz (2002) showed that an ITS with a student model performed very well when tested on computer-simulated students. Experiments with ITS on real students have demonstrated that students’ knowledge within a particular domain can be effectively improved (Conati et al., 2002; Koedinger et al., 1997). While aforementioned intelligent tutoring systems have shown significant effectiveness in adapting to students, the design and construction of models can be a complicated and time consuming process (Sklar, 2000; Aleven et al., 2006). In addition, research that analyse of how users experience working with ITSs is very limited.

Existing ITSs have predominantly been designed for older students, in secondary and tertiary schooling. Some existing systems are also designed to
work in home environments. While they are often used in open learning environments such as classrooms, they focus on individualised learning in isolation from collaboration and interaction with peers, teachers and parents. In Mathletics and SpelloDrome students work through prepared material arranged into levels similar to traditional teaching and therefore these systems do not offer individualised learning except in the form of a gate-keeper, allowing a student to move to the next level. While ITSs have been evaluated rigorously in the context of older students, there is significant interest in evaluating how these techniques apply in primary school classrooms.

In a primary school classroom students are younger and not fully independent learners. This younger cohort constantly interacts and collaborates with their peers. An educational tool used for primary school students, that will be used in a classroom must manage interaction and collaboration, and support learning in their presence. There is also a potential for greater teacher support in such unstructured environments, with automatic computer logs of students' activities and progress. There is therefore significant value in finding and evaluating educational software suited to classroom environments, and for developing learning pedagogies for the future.

Adaptive Educational Systems (AES) are aimed at open learning environments such as classrooms. They pose an alternative to student model-based systems that are used in ITSs. Adaptive Educational Systems are computer-based systems that respond to its users with an activity at the right level of difficulty, and ideally also tailored to their users' learning style. If the adaptive system is successful in its choice of task, the user should experience learning challenges that are interesting but not too difficult (Sklar & Pollack, 2000). An alternative method for the design of learner-adaptive systems is “the evolution of educational content”, which is based on evolutionary algorithms (Sklar & Pollack, 2000). The method, first suggested by Sklar (2000), chooses the next activity to be presented to its user based on the immediate pattern of success. If the student succeeds the task chooser inside the computer “evolves” and “mutates” randomly to select a significantly different activity. If the student fails, the task chooser “evolves” more slowly
and is likely to pick an activity much like the previous, enforcing repetition until the student succeeds. While Sklar & Pollack used terminology based on evolutionary algorithms, we are using a so-called radial-basis function (RBF) to implement the same principle. Sklar’s model (which we refer to as RBF) is a lightweight technique, meaning that it is relatively easy and inexpensive to apply in different domains. After all, the only thing that is required is that each activity is represented as a point in a numeric space, which is organised such that similar activities are placed close to one another, and that the task chooser remembers where it is in that space. Once the user completes an activity, success is tested and then a big or small jump is taken in that space. This is in stark contrast to a heavyweight, purpose-built student-model. A popular technique that is used for student models is based on Bayesian Networks (BNs). These are complex probabilistic models that represent activities and learning outcomes as variables and relations between these variables. When used inside the ITSs, BNs learn how variables influence one another, to improve their ability to predict how a student will perform on any activity. By forcing designers to encode information about the domain that is being taught, it is clear that such techniques take a long time to develop and therefore more expensive.

1.3 Significance to the field

The focus of this thesis is on studying what contextual considerations are important when designing learner-adaptive systems in authentic classroom situ. This thesis aims to illustrate the suitability of a learner-adaptive system in a primary school context, in a classroom environment. The user study will focus on primary school spelling education, when introduced subtly in combination with normal activities. Importantly, in this study I will embrace the view that education software is a complement to an already existing and effectively running educational program. As a result, the study will consider schoolteachers’ already existing teaching of, and the schools’ proposed programs for spelling. This means the technology will not be designed as an add-on for teachers but rather an integral part of the existing spelling program. Prompted by the prevalence of the open learning environment in a primary
school classroom with collaboration between students and teachers, this research will focus on an overall perspective of how successful learner-adaptive systems can be integrated in learning and teaching.

This thesis is based on, and will contribute to the field of Interaction Design as applied to Education by identifying the design criteria, considering the context, users and other factors that have an impact on the successful use of a learner-adaptive system in a primary school classroom. Additionally, this thesis is based on and will contribute to the field of Education by investigating how learner-adaptive systems can support the existing teaching and learning in a primary school classroom.

1.4 Research Question

This study seeks to contribute to research by user testing and evaluating a Learner Adaptive System for learning spelling in a primary school classroom. This study will compare two adaptive techniques, to evaluate which works better within a classroom setting, or if their performance is irrelevant to learning outcomes. There is significant potential for other contributions within the scope of this research question, such as the development of a framework for design of educational software in primary school classrooms and an improved understanding of how technology can complement rather than supplement day-to-day teaching methods.

I pose the following questions in this study

1. What factors are important in the design of a learner adaptive system to be successfully used?
2. With what effectiveness can a learner adaptive system support spelling achievement?
3. How useful is learner adaptive system as a teaching aid?
4. How well does a learner adaptive system, capture and adapt to individual learning needs?
5. Can a learner adaptive system offer an experience that is both engaging and enjoyable? What are students’ and teachers’ attitudes to working with a learner adaptive system?

6. Can a learner adaptive system achieve an overall fit with teaching practice?

To answer these questions, learner-adaptive software for spelling will be designed and tested in three primary schools. There will be two different versions of the software, one based on student modelling and one based on an evolutionary algorithm, hidden to the user. Interviews of teachers and students together with observations will form the major part of the evaluation. Complementing the qualitative evaluation, data will be collected through a data log created by the software system.

In my evaluation of the learner adaptive system, I will also consider the technical merits of the two techniques that are used to select spelling exercises. Specifically, from the experience that I gained in my previous study (which is reviewed in chapter 3), I believe that heavyweight student models are unable to adapt quickly to students when only used as a complement to existing teaching practice, where students get very limited time on each activity. Moreover, within a collaborative environment the input of many students are likely to confuse a student model. A hypothesis is therefore formulated as following: The lightweight learner-adaptive method evolution of educational content performs overall (in regard to educational outcomes) as well as the heavyweight student modelling technique in a classroom environment. In terms of functionality, this thesis takes into consideration the educational and experiential goals.

1.5 Tangential studies

Technology is becoming increasingly pervasive in primary schools, including the use of Lego robots, Microcontrollers and other educational electronics. These can be used to complement current teaching practice, and in conjunction with specific topics such as engineering, maths, science and art.
To further enrich the present study I have undertaken a variety of short-term studies in collaboration with colleagues and students, to provide further perspective on the questions we posed previously. Specifically, we have as a group designed, built and user tested a range of educational technologies for learning in primary schools. In this way, I have drawn on my observations and experiences in the present study, to contribute to each of these case studies. Conversely, the short-term studies with non-adaptive technologies have helped develop a perspective that contributes to questions asked in the present study.

I refer to two case studies:

- **Discovery table**: Interaction design of learning activities for a preparatory school classroom, learning the alphabet without the need for supervision.
- **Save the wild**: The design and use of augmented reality for play and learning in primary school.

### 1.6 Thesis overview

Chapter 1 is an introduction to the thesis and its problem area. Research contributions are presented as well as the research question. The chapter is finished with a thesis overview.

Chapter 2 presents literature relevant to this thesis. The literature is presented in three main areas, Teaching and Learning, Technology for Education and Guided Discovery Learning.

Chapter 3 describes an earlier study, Magic Spell, which this thesis is building upon. I describe the former study and its findings for a better understanding of the base in this thesis.

Chapter 4 outlines the methodologies used in this thesis. A mixed-methods consisting of computer log, interviews, spelling tests and observations was used as data collecting sources.
In Chapter 5 the results from two iterations of user studies are presented.

An analysis of the results is presented in Chapter 6. The analysis presents themes found when analysing the results. The results are related to existing research.

Chapter 7 finishes the thesis with a discussion about the findings. It is followed by a conclusion.

A number of appendices follow to document supplementary material of relevance to the completion of the study.

Also as appendices, I include two publications identified in the previous section, which do not significantly overlap with the content in the chapters, but provide details of tangential studies that I have led. The direct relevance of these papers to the research questions above is discussed in Chapter 7.
2 Literature review

The focus of this thesis is on studying what contextual considerations are important when designing learner-adaptive systems in authentic classroom situ. This study builds upon two fields of research: Interaction Design and Education. The review begins with an overview of studies for the design of educational computer-based systems and their implications for learning. The review continues on to explain ITS (Intelligent Tutoring Systems) and different techniques for controlling adaptive educational technology. This is to set the scene to resolve what range of factors that play important roles in learner adaptive systems.

The second part of the literature review discusses learning theories upon which this research is based. The review shows a gap in existing literature where research has only focused on finding the most effective adaptive technique, by evaluating how well the systems adapt to its user. This thesis aims to fill the resulting gap by studying students and teachers attitudes to working with adaptive techniques that are implemented in real classroom environments, and as a teaching aid. In later chapters I will explore how effectively a learner adaptive system can support spelling achievement, so I take note in this chapter that there is a lack of emphasis in the literature about the broader fit of educational technology with teaching practice and their educational benefits.

2.1 Interaction Design

2.1.1 Design of technology for classroom environments

When technologies will be used in classroom environments, designers often focus on the enhancement of student learning. Learner-focused design aims to construct the best learning environment for the student. The aim of learner-focused design is to ensure the student can achieve a high rate of learning. Smith and Reiser (1998) and Loh et al. (1998) suggest that designers consider the whole context of a classroom when designing software for learning. Specifically, it is important to consider the context in which the
software operates. For successful learning at school, teaching, students’ learning styles, goals and aims of the curriculum need to be considered holistically. A well-designed learning technology should acknowledge how the technology can complement or improve already existing teaching and learning (Brown and Edelson, 1998). Ball and Cohen (1996) stress the importance of capturing the teachers’ interests when designing learning technology. Brown and Edelson (1998) suggest that learning technology should be designed so that teachers can integrate the system into their regular planning and teaching. The design of learning technology should consider both students and teachers in a way that is encouraging and satisfying (Hsi and Soloway, 1998).

So, there seems to be a consensus in the literature for the design of a system that encourages and attracts students by providing an individualised level of challenge. Also, the system should support teachers in their profession as teachers, for example by producing information about students’ progress individually as well as a group.

While computer systems that support and encourage collaboration is a well established research area the resulting focus lies mostly in how to design the systems so that the software can support its users when they wish to collaborate, or how the system can encourage the user to collaborate with other users. In applications used for learning, the part of the software that is designed to support collaboration is often created as a shared discussion forum or as activities that are designed so that it can easily be used together. Activities designed for collaboration often occur using two sides of the keyboard or through multiple input devices (Inkpen et al, 1999). It is not only the visual part of the computer system that is impacted by collaboration and interaction between users. Often game players (both pure entertainment games and learning games) find themselves wanting to help their peers improve their scores. As the more advanced player wants better competition, he/she therefore tries to encourage and support the weaker player (Hinn, Twidale & Wang, 2004; Boden, 2004). An informal collaboration and communication between students are natural in a classroom setting. It is therefore important to consider the collaboration and interaction between the
students when educational computer software is designed for classrooms. Computer systems will also need to consider the fact that students might find information in text books or elsewhere while working with the system. A learner-adaptive system does not necessarily have to facilitate an interface for multi-users but the system’s underlying technique has to cope with its user’s interaction with outside sources.

2.1.2 Learner-adaptive systems

2.1.3 ITS

The research of Hartley and Sleeman (1973), and a great deal of subsequent research into computers in education, focuses on the use of the computer as a tutor in a system-controlled learning environment. In such environments “teaching is concerned with the control of learning, the ability to store student responses, to summarise these into performance profiles, and to base decisions on this data” (Hartley and Sleeman, 1973, p 215). Computer software designed to support such educational processes may be considered as learning delivery systems. The earliest learning delivery systems are referred to as computer-aided instruction (CAI) programs, where the task of creating educational material involved translating a teacher’s pedagogical decisions into a computer program. The driving motivation in developing these systems was to capture the effective behaviours of teachers, thereby creating an optimal instructional tool (Andresen, 1993).

Instructional systems involving artificial intelligence (AI), such as intelligent tutoring systems (ITS), aim to capture the knowledge that allows experts to compose an instructional interaction (Wenger, 1987). Intelligent tutoring systems, a term coined by Sleeman and Brown (1982) over thirty years ago, explicitly represent a teaching expert’s knowledge and aim to make their own educational decisions based on this knowledge. They compose instructional interactions dynamically, making decisions through reference to the knowledge base that has been provided. This differs from the static method used by CAI systems in which the decisions resulting from a body of expert knowledge (as opposed to the knowledge itself) are explicitly represented. An
intelligent tutoring system differs from computer-aided instruction primarily in its focus on the representation of knowledge of the subject matter and of pedagogical knowledge (Self, 1988). They might alternatively be described as knowledge communication systems. Often intelligent tutoring systems are designed so that the components of the teaching process (knowledge of the student) are clearly differentiated and separated from knowledge of the domain, and both of these types of knowledge are separated from knowledge about how and what to teach (Woolf, 1988).

While intelligent tutoring systems grew out of the artificial intelligence discipline, today the field is considered an interdisciplinary area consisting of research from computer science, cognitive science, and educational science (Koedinger & Andersson, 1993; Kuhn, 1992; Wenger, 1987; McCalla, 1992; Greer & McCalla, 1994; Soloway & Spohrer, 1989a). Many examples of intelligent tutoring systems are designed to support homework or are single freestanding systems that will teach within a particular curriculum domain. Modern examples also tend to focus on instructional support in mathematics and science domains. Examples include the Geometry Explanation Tutor (Aleven & Koedinger, 2002) which supports students in solving mathematics problems particularly focussed on geometry, Andes (Conati et al., 2002), an intelligent tutoring system for introductory university physics, and the PUMP algebra tutor PAT, and later PAT Online (Koedinger, 2000), a computer-based tutor to help students solve algebraic problems (Ritter, 1997). In a way that is typical for Intelligent Tutoring Systems, these examples build a model of student behaviour and based on this model the system chooses the next task for the student to complete.

Research in the ITS domain has primarily focused on testing the technical validity, effectiveness and efficiency on the adaptive qualities of the software. There are several good examples of intelligent tutoring system evaluations based on large classes of students. ANDES was evaluated with over three hundred students across two studies (Conati et al., 2002) and PAT Online has been tested in 22 high schools, four middle schools and at two colleges (Koedinger et al., 2000). In both of these sets of studies, results from
examinations or tests of a control group were compared to the results of those students using the intelligent tutoring system. These results demonstrated the effectiveness of the systems in improving students’ knowledge within a particular domain. In addition, Conati et al., (2002), Bunt & Conati (2003) and Millán & Pèrez-de-la-Cruze (2002) have demonstrated intelligent tutoring systems that work well in supporting learning processes, although the last three examples have only been tested on university and with computer-simulated students.

2.2 Guided Discovery Learning

The guided discovery approach, which has been developed as an extension of the intelligent tutoring approach, aims to provide a tutoring system with different levels and forms of constraint on the activities of the student (Elsom-Cook, 1988). The underlying assumption in discovery learning is that the students learn by testing and experimenting (van Joolingen, 2000). The information retrieved during the experimentation is assessed and compared to knowledge students already have. The comparison of the new experience and the old knowledge leads to the formation of new knowledge. Elsom-Cook (1988) suggests that guided discovery teaching requires the computer system to constantly reassess the appropriateness of the teaching activities that it is performing, monitoring the success of the student, and ensuring that students follow paths corresponding to a productive educational experience. The expert-based modelling in an intelligent tutoring system is replaced by a learner-based modelling method. Student modelling is based upon the idea of keeping track of a student’s learning progress by studying the learner’s behaviour instead of assessing achieved knowledge. With the information about the learner’s domain knowledge and his/her reasoning strategies the computer system can organise the learning environment accordingly (McCalla, 1996). As the student model is a part of the ITS it is important that the model actually mirrors the student accurately or the ITS will not fulfil its purpose. According to McCalla (1996) it is extremely difficult to consider all factors that might influence a student’s learning. As the student model method is complex it can also be claimed as an expensive method to build (Aleven, McLaren, Sewall & Koedinger, 2006).
2.2.1 Evolution of Educational Content

Sklar and Pollack (2000) suggested an alternative to student modelling for selecting student tasks, an approach based on semi-random, evolutionary changes. Keyit and Pickey (developed by Sklar and Pollack, 2000) are two web-based typing games using information from the student’s latest performance. The aim with an evolutionary approach to guiding students is to let them work through a curriculum domain in a methodological way while they still feel encouragingly challenged. The level of difficulty is adapted to a level appropriate for each student with the view that such adaptation will effectively maintain a student’s interest. When a student is working with such a system, the AI will modify the learning environment based on how well a student performed during only the previous activity. This means that students do not follow a pre-defined path and may move flexibly within the curriculum domain. The system is adaptive without being prescriptive.

In comparison with a student model, the evolutionary approach does not build a model of the student’s performance. Instead, a numeric space is used to store any number of vectors representing educational exercises, where each dimension represents a different feature of the exercise (see Boden & Boden, 2006 for a more detailed explanation). A database would contain the complete set of exercises for a subject, e.g. words for spelling. Each word would be represented by its spelling features. Two words that are similar spelling-wise would then also be close to one another in the space. For example, house and mouse would be closely related from a spelling point of view as they belong to the group of words using ‘ou’, while horse and more would be found within the group using ‘silent e’ at the end of the word. Conversely, two words that are different in terms of their spelling are represented by distinct features and thus be placed far away in the space.

When the student is working in a computer program of this type, an algorithm based on basic evolutionary algorithms (Holland, 1975) selects words to show the student next. The selection process is based on the idea that the words
are divided in two different groups, those words that the student knows how to spell correctly and those words that are yet to be learned. When the student misspells a word the word is put in the group of ‘train again’ and the system chooses a new word that is similar to the misspelled word. If the student knows how to spell a word, the word is put in the ‘known’ group and the system will take a random leap in the space to find a new word that is most likely dissimilar to the correctly spelled word. The long leap is normally referred to as a large mutation (Sklar and Pollack, 2000) and the selection of a word similar to the misspelled word is called a small mutation. The evolutionary approach is a lightweight (meaning cost efficient and easy to build) method to work with compared to the complex process of achieving a well functioning student model (Boden and Boden, 2006; Sklar and Pollack, 2000).

2.2.2 Computer Collaboration Support

Both evolution of educational content and student model-based systems have shown efficiency when used in educational systems. Former studies observe that the systems work well when students are working individually and in home environments. The research so far does not report on, how the adaptive techniques perform in real classroom situations. In particular, one such perspective of how the systems respond to other external inputs (or feedback) has not been reported on. Several outside influences such as the teacher communicating with the student, peers collaborating and helping each other, as well as students looking up correct answers in literature, can possibly interfere with the prediction system.

Underlying theories of computer supported collaborative learning (CSCL) are based on a mixture of different sources. Socio-cultural theory, constructivism, self-regulation learning, cognitive apprenticeship, problem-based learning, cognitive flexibility theory and distributed cognition are all theories which assume that students are curious and actively want to learn. Common for all computer systems that support collaboration is the idea that learning happens when students socialise with their peers and tutors (Plötzner, Dillenbourg,
Preier & Traum, 1999), which is as per social constructivism theory. Students form their understanding and knowledge when formulating and discussing information they have already retrieved with others (Van der Linden, Erkens, Schmidt & Renshaw, 2000).

A definition for collaboration is groups working together for a common purpose (Resta, 1995). The two main research areas in computer-based collaboration are computer supported collaborative learning (CSCL) and computer supported cooperative work (CSCW). Both CSCW and CSCL are focused on facilitating computer support for group processes and group dynamics. Collaborative software is usually designed to complement face-to-face communication and aims to support collaboration in a way that normal face-to-face communications cannot (Ellis et al. 1991). CSCW is primarily focused on communication technologies and the use of collaborative systems in business settings although, it has recently been accepted that work can have a broader interpretation away from the workplace and towards human social activity in general (Crabtree, Rodden & Benford, 2005). CSCL on the other hand tends to study what is being communicated in most educational settings. Common for computer collaboration support is the purpose of finding computer systems that support learning and a system that function as a complement to already existing ways of working.

2.2.3 Example of CSCL

Existing computer systems that support collaboration are mainly built for the purpose of providing a computer based system that encourages collaboration as a way of building knowledge. Two researchers, Scardamalia and Bereitner (1993, 1996) introduced a version of CSCL called Computer Supported Intentional Learning Environments (CSILE). CSILE is designed as a collaborative learning environment where students can document their ideas and thoughts. CSILE then enables feedback to be received from student peers. From the beginning CSILE tried to realise the collaborative nature of the classroom but has since moved the emphasis to the ongoing improvement of ideas and building knowledge that has social value (Scardamalia, 2004).
The students learn the topic by having to express their own knowledge to their peers and by then continuing a discussion about the topic (Scardamalia & Bereitner, 1993). The platform for CSILE is both text and picture based and students of varying age can therefore use the system. This work has shown that systems that enable interaction within itself, supports learning outcomes. However, younger students naturally interact informally outside the system, and the inclusion of influences from the environment is not considered.

### 2.3 Teaching and Learning

#### 2.3.1 Constructivism Learning Theory

Theories of development and learning are core to the science of education. The variation in beliefs entertained is wide and ranges from those who believe in a strict instructional teaching style to those who suggest letting the students explore the world or subjects more freely (Bringuier, 1980; Vygotsky, 1978). Common to the below presented philosophies of learning is that they all belong to the realm of constructivism.

Constructivism is a general approach to the theories of human knowledge (epistemology) (Williams & Fromberg, 1992). The common belief is that knowledge is “built up over time as the result of constructive action by the knower”, (p 206). This means that students form their knowledge when actively working and interacting with their environment. The knowledge is “neither a copy of the external world nor a reflection of pre-formed structures in the mind” (p. 206).

Broadly, constructivists have different views on whether they see knowledge as an individual or a social construction. Jean Piaget, one of the early founders of constructivism, is an example of individualist constructivism. Piaget saw children as young researchers (McInerney & McInerney, 2002). By exploring and interacting with objects in the environment, children create their own understanding. On the other hand, the social constructivist philosophy
emphasizes the importance of individualised support for learning and the belief that learning only occurs when students interact with their surroundings (McInerney & McInerney, 2006). Lev Vygotsky (1978) found that children would be working at a certain level on their own but that they could be working at a higher level (at a potential level of development) if they were given the right support from a teacher or more experienced peer, also referred to as Zone of Proximal Development.

Vygotsky suggested a method, known as scaffolding (though Vygotsky did not coin the term), for how the teacher could work with the children so they can reach the potential level of development. Scaffolding is a teaching strategy for supporting the individual students so they can perform just a little better than they would have managed on their own.

The term scaffolding is a widely used concept in educational research (Pea, 2004). When scaffolding is used in educational contexts it is mentioned as a view on how children learn. Wood, Bruner and Ross (Pea, 2004) first mentioned the term scaffolding and described it as “a ‘scaffolding’ process that enables a child or novice to solve a problem, carry out a task or achieve a goal which would be beyond his unassisted efforts” (p. 90). The child creates new knowledge based on former experiences and already retrieved knowledge. When the teacher or tutor challenges the student at a suitable level the child can form new knowledge. Scaffolding should be seen as an ongoing process over time (Pea, 2004).

Vygotsky and John Dewey shared an interest in social progressivism which suggests that the school and its students should be a part of the social community and that the students should be taught to fit into the community by being treated as a part of the community. Dewey (1915; 1966) believed that teaching should be initiated by students’ interest in an area and then supported on an individual basis by the teachers. Vygotsky argued that learning is a social experience for students and therefore teachers need to support and interact with students on an individual basis (McInerney & McInerney, 2006). In Dewey’s theory, students’ learning is highly dependent
upon the teacher’s ability to expose students to different environmental features (Dewey, 1966). So for a teacher to be able to support students on an individual basis, teachers need to access individualised information of the ongoing learning for each student. This is a considerable task for any teacher. Traditionally, the approach taken would be to teach all students the same task together. The complication arises when there is belief in the idea that students learn as they construct their own understanding (McInerney & McInerney, 2006) and that children should be allowed to explore the curricula following their own ability and way of learning (Papert, 1993).

2.3.2 Teaching spelling

Spelling is a complex process and there is much debate among researchers on how to best teach spelling. Research has shown that when children learn to spell they need to know the sounds of the alphabet and by knowing these sounds reading is enhanced which can lead to a more advanced vocabulary (Frith, 1985). Templeton (1997) suggested that for a child, knowledge of spelling can be vital for understanding language. Earlier research hypothesised that spelling could be learnt by reading (Smith, 1971) while later researchers rather showed that spelling can be helpful knowledge when children are learning to read (Gentry, 2000). Spelling needs to be addressed and taught as its own topic (Gentry, 2000) but it should still be seen as one part of learning literacy. It is therefore important to see the relation between spelling, reading and writing. Gentry (2000) criticises the old training systems for spelling, for not actually teaching spelling but only assessing spelling of words.

The English language is quite complicated in terms of its spelling compared to, for example, Italian. English has 44 sounds and 1,120 different spelling combinations of these sounds while Italian has 25 sounds and only 33 spelling combinations for those sounds (Gentry, 2004). When young children start learning to spell, they normally spell a word according to its pronunciation (Read, 1986). Eventually, the children progress and increase their awareness of spelling patterns. When the children are taught the names
and sounds of the letters in the alphabet, the children start to discover patterns in the language (Ehri, 1985; Frith, 1985). Literature (Templeton & Morris, 2000; Venezky, 1999; Templeton, 1997; Gentry & Gillet, 1993; Ehri, 1994) suggests that teaching of spelling should include phonological (the sound of spelling), visual (patterns of spelling) and morphemic (the function of spelling) knowledge. Furthermore, researchers recommend that the history of words (etymological knowledge) also be taught for a complete understanding of word relations and families.

2.3.3 Teaching spelling in Queensland

As with any educational system, children’s spelling capacity and progress is an important part of the literacy curriculum. The Department of Education, Queensland Government has published a developmental package and spelling resources (Education Queensland, 2011). The purpose of the document is to assist and encourage primary schools in choosing and developing a programme for spelling. The document states it is based on the latest research findings in spelling and the government suggests a student-centred approach. The student-centred approach acknowledges that the complex process of spelling and that spelling, reading and writing are related.

Primary schools have been encouraged to produce their own spelling programmes. This has commonly resulted in a document detailing teaching and assessment strategies for the teachers. One example is Milton State School’s spelling programme (Milton State School, 2003). The written document contains aims and goals for spelling as well as word lists for each grade. Also, the programme advocates the view of learning to spell as an active process. The programme recommends teachers involve students in a wider individualised programme and to expose students to various features of the English spelling system. Furthermore, the document provides lists for monitoring individual student’s spelling progress. The monitoring lists follow the student from grade one up to grade seven. Teachers in Queensland schools apply the spelling programmes with hands-on activities for their students. All teachers I worked with gave their students
10-20 weekly spelling words. The students were supposed to learn how to spell these words during the week by practicing them as homework and by using the words during class, as work sheets with spelling activities. The activities could be writing the spelling words in sentences, making up a cross word, and looking up the words in a dictionary. Strategies for learning to spell such as “look-cover-listen-write” is commonly used in the classroom. This strategy means that the children would look at the list of spelling words, cover the words, listen for a friend to read out the word and then write the word.

2.4 **Teachers and technology use in the classroom**

Technology has been a natural part of living for at least 20 years, and there has been an ongoing effort to integrate technology to improve teaching and learning among schools all around the world (Voogt, Tilya & van den Akker, 2009; Williams, Linn, Ammon & Gearhart, 2004). The introduction of ICT is often promoted by a strong and widespread belief that technology will change the nature of teaching (Watson, 2006). While now widely available it still seems the use of technology in classrooms for actual teaching purposes is rare (Becta, 2008). The integration of technology into teaching is seen as a key driver for a modern school. Marcinkiewicz (1993) notes that teachers need to accept and reconcile computers before technology can be fully used in the classroom. Rozell and Gardner (1999) found that the more experience teachers have with the computer, they developed more positive attitudes towards the use of computers.

Obviously the availability of technology is important to create the opportunities for teachers to effectively integrate technology into teaching (Norris, Sullivan and Poirot, 2003). It may not be as clear though, that it is vital for teachers to have training in and knowledge of how to use technology. They need to learn how technology relates to pedagogy and content to appreciate the full potential of technologies for supporting teaching and learning (Mishra & Koehler, 2006).

Many schools have invested in technology and teachers have access to computers and Internet, but this does not mean that teachers will use the
technology (Cuban, 2001). Baek, Jung and Kim (2008) concluded that it is more complicated than first thought to incorporate technology in teaching. While the accessibility to technology and teacher training on how to use technology is vital, the teachers’ attitudes towards technology as a pedagogical tool in the classroom have been found to be at least as important as computer experience, and gender (Hermans, Tondeur, van Braak and Valcke, 2008).

2.4.1 Teachers beliefs and teaching styles

Research has shown that though teachers may express positive beliefs to integration of technology in the classroom, this does not mean they put this into practise (Spector and Merrill, 2008). In particular, the teachers who already have a constructivist approach have been found to have more positive beliefs towards the use of technology in the classroom (Hermans, Tondeur, van Braak and Valcke, 2008). In a busy classroom, teachers need to feel that technology is not going to be a hindrance for effective teaching. A positive attitude to ICT is not necessarily sufficient for a teacher to adopt technology, in particular if they feel it could cause them stress (Mumtaz, 2000).

Change of teachers’ attitudes is challenging, so Ertmer and Ottenbreit-Leftwich (2010) recommended that considering teacher beliefs is vital to facilitate change in the context of technology use. The use of strategies, such as observations, practice, reflection and social cultural support is recommended to promote change of teacher attitudes (Ertmer, 2005; Kim and Baylor, 2008). Chen (2008) added that these strategies are suitable to use for group work and would be suitable to practice in collaboration between teachers. Working with change of attitudes around technology in a collaborative manner could also lead to changes of the school culture. Furthermore, a collaborative environment provides teachers with the opportunity of seeing the different ways by which colleagues use teaching and technology in classrooms. This can in itself lead to a successful change of beliefs (Rogers, 1995). Change does not occur by teachers reading about
newer ideas, but through witnessing their implementation and through practise, each of which requires the teachers to recognise and evaluate their own beliefs (Kagan, 1992). The influence and support from mentor teachers and parents have also been identified as one of the primary factors to influence pre-service teachers’ confidence in using technology (Bullock, 2004).

To change attitudes in technology for teaching, it is vital to be sensitive to the current needs of teachers (Kim, Kim, Lee, Spector & DeMeester, 2013). To secure an active support from the school’s principal is recommended as this leadership can empower teachers to overcome weaknesses and accelerate their strengths (Ellesworth, 2000).

There is also a clear relation between teachers’ attitudes towards effective ways of teaching and how they practically integrate technology in their teaching (Kagan, 1992; Kim, Kim, Lee, Spector & DeMeester, 2013). This approach can be used for design interventions and for Professional Development for teachers.

The research studies make recommendations for change of teacher attitudes towards the use of technology. Many studies on teacher beliefs have been based upon interviews and questionnaires where teachers have been asked to provide reasons for their use of non-use of technology. Teachers are being asked to gauge their stress levels and evaluate their use of technology in classrooms. It may be argued that outcomes of implementing technology are not directly comparable since teachers independently assessed their own use. This could vary considerably between teachers. For example, one teacher might use Power Point to present material to his class and he then assesses this as high use of technology because he uses it everyday. On the other hand another teacher allows his students to use several educational applications and MS Word for writing classes, but he only reports his use as medium, as he feels he could incorporate much more technology into the curriculum. While the literature reports on extensive research around teacher beliefs it is primarily presented as recommendations and considerations. There is a fundamental need for implementing ideas and observe if they have the expected effect on teachers’ attitudes.
3 Genesis of Spelling Bug

3.1 Background

Spelling Bug is a computer-based spelling program to be used in a primary school classroom, to complement ordinary teaching activities for spelling. I designed Spelling Bug partly on the basis of experiences drawn from Magic Spell, another computer-based spelling program that I designed and tested from an information system’s usability point of view (see Boden, 2004). This chapter puts the development of the Spelling Bug into a context. It does so by describing some of its history, referencing its predecessor Magic Spell, and the practical features that were considered to be important.

Magic Spell was trialled in two grade four classes over a period of five weeks, to evaluate the usability of an educational computer program in authentic classroom situations. This study was squarely focused on system usability. That is, if the design of the program fulfilled users’ needs. At the time, I came across a technique referred to as evolution of educational content (first explored by Sklar and Pollack, 2000, see earlier chapter for a review) that was straightforward to implement for purposes of putting a program in the hands of students. That it aimed to adapt to how well students performed was regarded as a bonus.

To make the program more fun and to keep the students motivated (Reeve, 2005) I included a game-like element, which rewarded students. The idea is based "gamification" principles on how to make a traditional, non-game like activity (such as training spelling) to have a reward-element (Deterding, Sicart, Nacke, O’Hara and Dixon, 2011). To make the reward more exciting, I designed the system to include a feature to trade them via the computer system. (Apart from the fact that the theme of the program was Harry Potter, and that rewards were beans and magic wands, the trading was what made it "magic" at least to the students.)
I carried out student and teacher interviews, and classroom observations to collect qualitative data on the usability of the system. Quantitative data on students’ computer activities were also collected via the computer program’s database. Results indicated high usability from both the teachers’ and students’ perspectives (described in detail in Boden, 2004) and students seem to improve their general ability to spell.

The usability study was pivotal, as it prompted many questions outside the scope of traditional usability testing, that we pursue in the present study: adaptation to user, interaction between users, educational environment and, most important of all, learning. I will list some of them here, as they informed what I did to Spelling Bug.

- Teachers displayed hesitation of using computers in the classroom, but by introducing them on their own conditions, as a complement to what they were doing anyway, they engaged in the process of designing and carrying out the usability study.

- The evolution of educational content idea worked very well to find an appropriate level of challenge for each student, even if they were to the observer at very different levels of competency. It was easy to implement and I could explain to teachers why students were given certain exercises to do. I was also able to verify that the algorithm explored the space of spelling exercises quite well.

- Students collaborated and engaged with each other whilst using Magic Spell. This surprised me at first, as the program was requiring students to wear headphones. More importantly, the program was engaging the user in a one-to-one manner, repeatedly suggesting individual tasks, and only occasionally rewarding the user. The student was not required at any time to interact with anyone, but still did.
• The classroom environment was often busy and noisy, but students were engaged with the program, displayed enthusiasm for their progress, and then according to the tests we did, displayed an overall improvement in spelling proficiency.

To design a system to be truly used for learning for primary school students, all of the above reflections need serious consideration. I needed a system that embraced all of them.

3.2 Magic Spell to Spelling Bug

Spelling Bug, and Magic Spell before it, was not intended to be a computerised tutor, but to be used by students for practicing their spelling. It presents an uncomplicated training problem that lends itself to answer the questions posed in the introduction.

Key features of Magic Spell were highlighted through its usability testing. Teachers felt that a program should complement the existing spelling program. I designed Spelling Bug using the feedback I received from teachers who used Magic Spell. This is highlighted in a later section.

The adaptation to students’ success was seen as important to balance challenges. I therefore wanted to design Spelling Bug to contain a level of adaptation, based on interactions with a specific student. A main motivation behind Spelling Bug was to accommodate and take account of students working together whilst practicing their spelling. This is discussed next.

3.3 Learner adaptation

Magic Spell did not incorporate a student model to determine what spelling activities the student should be working with. As reviewed previously, student models are commonly used in Intelligent Tutoring Systems. Since I knew that students tended to help one another I was interested in exploring the fidelity of adaptation, i.e. if it was important that the system had an accurate view of the student who had logged on. I wanted to test how well a student model-based
program for spelling would compare to a simpler model, such as one based on the evolution of educational content (here referred to as RBF; see Chapter 2 for the literature context). The RBF uses the two last rounds of student activities to determine the next set of activities for students. The RBF method is faster to develop and therefore cheaper to use in an educational system. It will not, however, build up a model of the student over time as the student model aims to do, highlighting its lesser complexity.

Two versions of Spelling Bug were created hence. Spelling Bug 1 is built on the idea of evolving educational content using a Radial Basis Function; Spelling Bug 2 is based on a student model inspired by the Bayesian network (BN) in Millán and Perez-de-la-Cruz (2002) but adapted to work for spelling and to use the same spelling features as used in Spelling Bug 1. I presented Spelling Bug as one system but the software either operates as Spelling Bug 1 or Spelling Bug 2 according to how students were randomly allocated into the two groups (see the Methodology chapter for details). Thus, the students were presented with the same interface and backend features when they began working with Spelling Bug. The methods are described in some detail in the next section. The interface and features of Spelling Bug, and modifications as a result of the Magic Spell analysis, are detailed following that. Later, I give some practical examples of how the methods operate within the system.

3.3.1 Choosing educational activities suited to a student

An underlying assumption of this work is that by choosing learning activities with the right level of difficulty, the learning experience and outcome of a student is enhanced. In other words, we wish to maximise the ability of the student to successfully deal with future educational challenges by subjecting him or her to a minimal number of activities.

There are a couple of general objectives that the program manages, independently of the method that selects specific activities. The program will keep track of whether an activity was a success, the number of times each activity resulted in success, and the number of times an activity has been tried. The program will always present six spelling activities on a screen,
which are at a current level of difficulty. It monitors the success rate of these activities, and will move the student up a level if that is consistently achieved, which is the same for both methods. This will keep the level of difficulty at a level that will encourage the student to keep on working (not too hard but not too easy either).

The problem then is to find activities that give the student a high success rate but with as little practice as possible. This balancing act is where the methods are different: RBF does not attempt to model how success is achieved on basis of past experiences with that student, but BN does.

3.3.2 Features of educational activities
Each spelling word is represented by a series of Boolean values, each indicating the presence of a feature (true) or not (false). A feature is defined in terms of a regular expression that either matches or does not match a word. The regular expressions were composed to represent a range of spelling rules and patterns that are commonly problematic. The full set of 68 (non-exclusive) regular expressions is listed in Appendix 10.

For a spelling activity, the word to be spelled is scanned for matches to all regular expressions and the corresponding features are set to true (match) or false (no match). Intuitively, morphologically similar words are assigned similar spelling features.

3.3.3 Radial Basis Function (RBF) method
The RBF method is described and evaluated in detail in (Boden and Boden, 2006). Briefly, it considers each spelling word (activity) as occupying a point in a 68-dimensional binary space (where 0 means false, 1 means true). Using a mathematical technique known as singular value decomposition, this large space is compressed into a new, much more compact, 10-dimensional “activity space”. Each spelling word still maps to a location but with fewer dimensions, which can be traversed by taking “random leaps”. Singular value decomposition will ensure that the variance present in the original space is largely retained in the new compact space. This in turn implies that spelling words that share a lot of features in the original space will be close to one another also in the compact activity space.
With six activities chosen for each new screen, the method keeps track of their locations in the activity space. A radial-basis function (RBF) defines what it means to take a big leap as opposed to a small leap. Small leaps are taken when the activity was unsuccessful, and big leaps are taken otherwise. This has the effect that failures will be replaced on the next screen by activities that are close to in space, and similar in terms of spelling features. Conversely, successes will be replaced on the next screen by new activities that are potentially distant, and therefore different in terms of spelling features.

All students can use the same activity space. Besides information that is required for results to be presented later, the only information that is saved for a student for the RBF method to work are the locations of the next six activities that should be attempted.

3.3.4 Bayesian Network (BN) method

The Bayesian network is specific to a student, and explicitly models his or her “success" as a variable, given spelling feature values. The spelling features are the same for both methods (see above) but in the case of BN they are not compacted in any way. Instead they are considered as separate variables. In addition, the BN models student preparation via a variable “practice”, which indicates the extent to which given feature values have been seen by the student.

The student model thus represents the choice of activity, the outcome and a degree of preparation. The word determines which features that are matched. According to the model, the features cause the outcome (i.e. determines the probability of success). Similarly, the features decide the student's degree of preparation (i.e. the probability of having seen the spelling word features). For each screen, the program uses the model to select six spelling words that collectively optimise the probability of success and practice, i.e. that success is at a desired level and practice is false.

When a student finishes a screen of spelling words the program updates model parameters to improve the model's ability to accurately predict the success if the same words had been presented again, and to correctly
indicate the practice on the feature values.

When a student exits a session, all parameters defining the model are saved so that they can be reloaded next time the student uses the program.

3.4 User Interface

The user interface of the earlier program, Magic Spell, was satisfactory. Students found the interface easy to use and understand, and the teachers liked a simple interface with bright colours, with easy to understand instructions. The teachers were particularly fond of the idea of only having one main focus on the screen (the spelling feature) so that students would concentrate and not be distracted by several features occurring at the same time on the screen. Spelling Bug was therefore designed with a similar interface as Magic Spell.

The user interface of Spelling Bug was generally influenced by suggestions made by teachers who used Magic Spell. For instance, I sought to improve the speech quality of the pronunciation of the words to be spelled. Freely available synthesized speech databases from the Internet were used for Magic Spell. For Spelling Bug, three different databases were combined to ensure the best quality of speech was attained for each word the database. A new feature of Spelling Bug was the “hint” button. The hint button provides a resort for users who repeatedly misspell certain words, as it produces examples of sentences where the spelling word is used, with the sought word blanked out. This feature was prompted by teacher suggestions for the need for children to understand the semantics of words that sounded similar but are spelled differently (homophones) (e.g. bow – bough two-too-to and there - there).

3.5 Spelling Bug

All results were logged in a database and were recalled for each user at the next session. The particular method of choosing spelling challenges was also specific to each user. Each session therefore started with authentication (see Figure 1).
Spelling Bug was designed to suit visual, auditory and tactile learners in a primary classroom. The interface consists of both text and pictures to support the student. When a student starts working with Spelling Bug the student is directed to the main window with functions for spelling, exiting and playing.

There is human recorded speech for all words in the database and this is the primary means of communicating with the student. In the main cycle of the program, the student is repeatedly presented with a list of six words (see Figure 2). The student can click on the “klaxon” in the main window and hear the word spoken. At this stage, the student can become familiar with the spelling words by listening before continuing. As discussed previously, I added a “hint” feature, that can be seen as “i” in Figure 2. The hint feature will display sentences in which the word can occur and/or explanations of what the word means, so that the student can identify the word without actually seeing it.
Figure 2: The main interface of Spelling Bug. The user can "exit" the program, which means that the session is suspended. The student can check out his/her collection of beans on the right hand side. The student can choose to inspect his/her collection of bugs. The main purpose of this screen is to allow the student to type in words.

The student can ask the robot to repeat the pronunciation of the word as many times as they like. When the student feels ready, he/she can type in his/her response using a simplified textbox. The system allows the student to jump between the words and re-spell them until they feel happy with their spelling attempt (or attempts). It is only when the “tick” is clicked that the response is definitive. The program will indicate by changing the colour of the tick to red if the word was misspelled. If misspelled, the program will reveal the word in dimmed characters, to guide the student type it in correctly (see Figure 2). The student retypes the word correctly until all spelling has been corrected.

A reward system aims to encourage students to continue spelling. Every time a student correctly spells at least four words correctly out of the six words presented, a bean appears (see Figure 2) on the right side of the screen. After collecting a total of five beans the student is rewarded with an animated bug. As a bonus, the beans fall into a “bucket”, which the student can “empty” in
the “Bugs” screen by pressing a button (see Figure 3). On this screen all the bugs wander around, bump into one another and eat the beans. The animated bugs can be traded between students who use Spelling Bug. A student initiates a trade by selecting a bug of the ones he/she has. The intended recipient of the trade must reciprocate during a short time interval. If both students engage this way, the trade is completed and the bugs are swapped.

Figure 3: The Bugs’ world in Spelling Bug.
3.6 Spelling

At total of 3622 spelling words for grades 1-5 (according to the US primary school system; here labelled as level 1-5) were arbitrarily collected for Spelling Bug. Also, words that are frequently misspelled were included (here labelled as level 6). All words were selected from Roget’s thesaurus, matched against a free US spelling resource (e.g. www.spellingtime.com) from which grade levels were determined. The words were then checked for conformity to Australian English spelling. The levels of 1 to 6 were used to ensure students would not be intimidated by the sudden appearance of words that may be too complicated for them to spell. It was important that the program adapted the appropriate level so that users experienced a constant success rate. A new user to Spelling Bug is always introduced to level 1 words, and after ten rounds of first successful spelling (meaning the student has succeeded the first attempt at spelling each word in the round), the student is moved up to the next level.

English has a diverse set of spelling rules and a substantial number of exceptions. The collection of words was associated with 68 spelling patterns. The patterns either related to spelling rules, or particular letter combinations known to be difficult to spell. Other patterns were associated with a family of spelling constructs (e.g. double consonants or double vowels). Finally, since it has been argued that words that rhyme are typically spelled correctly (Treiman, 1997), a number of frequent word endings were included (e.g. –ouse as in house and mouse; -fully as in wistfully and beautifully). Each word was thus associated with a yes/no for each spelling pattern: either the word had the pattern or not. For Spelling Bug 1, this mean that words would be organised according to their shared spelling patterns, leading to words such as “house” and “mouse” being close to one another, and therefore alternately selected if the student had problems with either. For Spelling Bug 2, each spelling pattern was represented as a variable that was set to either true or false, depending on the word that was looked at. The student model would learn to pick up associations between spelling patterns to predict the success or failure of the word challenge. The student model would then pick the next
word so that the student would have a reasonable chance of being successful. Both the evolutionary and model-based versions of Spelling Bug (1 and 2, respectively) would target the same success rate at about 4/6 words. Subject to maintaining the appropriate level of challenge, both of the versions also try maximising the diversity of spelling patterns covered by the selection.

3.7 Worked example

There are 68 different spelling patterns, each of which is defined in terms of a regular expression (see Appendix 10). Assuming that the system has decided on a word, it can be mapped to a binary feature vector (see Figure 4). However, the selection of the word given a feature vector is more complicated, and this is where the two methods RBF and BN differ.

<table>
<thead>
<tr>
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<th>soft-c</th>
<th>hard-c</th>
<th>ie</th>
<th>cons-y</th>
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<td>1</td>
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<td>0</td>
<td>1</td>
</tr>
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<td>0</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>FIERY</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>1</td>
<td>1</td>
</tr>
</tbody>
</table>

Figure 4: Words are presented six at a time. Each word is encoded internally by a large number of features that are either true or false, depending on its spelling.

As described previously RBF uses a more compact activity space, which is determined from the feature vectors representing the full vocabulary. Each word is represented as a point in this activity space. Essentially, selecting a word means first picking a reference point and then identifying one word within reach of that point (see Figure 5). A so-called radial-basis function determines the chance of picking a word, which will be greater if close to the reference point. There are only two settings of the radial-basis function, a narrow and a broad, which correspond to assigning much greater weight to close points, and less weight to close points. These two settings correspond to the two possible outcomes for each spelling activity: incorrect and correct spelling, respectively.
In Figure 5 the word “CONCIERGE” is assumed to be misspelled, and then used as a reference point to select a new word using a narrow band, resulting in the selection of “SIEVE”, which is close because they share the “ie” pattern amongst others. The word “GLOOMY” is correctly spelled and therefore replaced in the next round by a word in a much larger portion of the activity space, e.g. “MESSAGE”.

Figure 5: A fictitious visualisation of the activity space used by the RBF method. Here two reference points are chosen around “CONCIERGE” and around “GLOOMY”, and then surrounded by a narrow and a broad radial-basis function, respectively.

The system keeps track of six reference points in the activity space at all times, and replace them according to the success of the student. To reduce the risk of the same word coming up again and again, the system keeps a log of which words have been seen so that it can prefer a new word if many exist at the same point. In addition, the system will always pick words at the current level of difficulty.

The BN method chooses words differently, on basis of a model. As described previously, the model associates the feature vectors with a probability of “success”, and a probability of “practice” (that the feature vector has been seen by the student). The parameters of the model are adjusted after each round so that the spelling features for all six words that were seen by the student result in a greater probability of “practice”, and that the probability of success for the features for each word is in agreement with how the student did. This does not override the rounds before though.
After a few rounds, the model will be able to “predict” the success and practice for any word. The system selects the six words by first scanning through all words at the current level of difficulty, finding the joint probability of success and practice. Second, it identifies a set of words that have a desired probability of success (an imperfect success rate of 4/6 words), and that minimises practice. The former will ensure that words are at a suitable level of difficulty within the level, and the latter will reduce repetition while maximising exploration.

If the six words in Figure 4 are presented, the model will associate the features for all words with practice being true. Assuming the student correctly spells “GLOOMY”, and misspells “CONCIERGE”, the model will associate the features of “GLOOMY” with success being true, and the features of “CONCIERGE” with success being false.

For the next screen, the chances of the system picking words such as “SIEVE” will increase because the student is expected to be challenged by it (imperfect success rate). The probability of picking a word like “MESSAGE” will increase because it has a low probability of practice, i.e. the features of that word has not been seen before. It is the overall selection of six words that need to be close to the ideal of a success rate of around 4/6, and lowest possible practice, so a mix of words will ensure that on average the student will have the right success rate, and explore new words as much as this allows.

3.8 Design to support teaching

The teachers initially found it difficult to understand how a computer program could be designed to meet needs in a classroom setting; they were also unaware of the potential benefits with computer technology. After using Magic Spell in their classrooms, teachers were impressed with how one program could suit all their students with their individual learning needs and learning styles. From the usability study with Magic Spell, I identified some valuable
suggestions for future development of learner-adaptive systems and this has been used for the design of Spelling Bug.

An interesting finding that emerged from interview data in the study of Magic Spell was that the teachers did not think of computer software as a tool to support their teaching. Teachers told me in interviews how they draw diagrams by hand, using one year of weekly spelling tests as the data, for each individual student in their class. The diagrams are used to show parents how their children have progressed in spelling over a year. As I wanted the teachers to be able to use the full potential in computerised educational systems, I incorporated such a teacher feature.

Every student’s action when interacting with Spelling Bug is collected and stored in the database. The computer system keeps a log of every time (time and date recorded) the student uses Spelling Bug. The number of words the students has attempted to spell, the level to which the words belong, the particular patterns that the words are associated, and whether the student is successful or unsuccessful in spelling a word.

From the feedback collected from Magic Spell I wanted Spelling Bug to support teachers in their planning processes. Spelling Bug was therefore designed to produce computer-generated graphical diagrams. This feature is only accessible by teachers. The outcomes of the spelling activities can be summarised over time, and split up into spelling patterns. The statistics can also be viewed for the whole class or in groups of gender. Figure 6 and Figure 7 show two examples of what reports can be extracted: finding out for a student or a group, the error rate for specific spelling patterns (Figure 6; here: all words ending with “th” at difficulty levels 1 and 2); the error rates and number of attempts for all spelling patterns (Figure 7).
Figure 6: Spelling Bug can visualise the error rate for spelling features at different levels. The teacher can see the error rates for features of individual or groups of students, here for a specified spelling pattern (words ending with “th”) for all levels of difficulty.

Figure 7: Spelling Bug can visualise the error rate of individual or groups of students, here across all spelling patterns, for a chosen level of difficulty.
Teachers can thus readily view the success rate on each of the levels that the student has attempted, and the success rate for each of the spell patterns. Students cannot access this feature of the system so therefore have no knowledge of which level of difficulty they are operating at.

Using the visual graphs produced by the software it is simple to inspect the range of spelling rules that the student has been subjected to, and therefore to make an assessment whether they have been missing out.
4 Methodology

This thesis will argue that designers of educational software need to have a holistic view of designing educational computer based technology that can complement and support already existing teaching and learning programmes. What factors are important in the design of learner-adaptive systems for it to be successfully used? Initially the thesis focused on a comparison of how two adaptive techniques for choosing educational content in a spelling activity for primary school children. When the design of the study occurred I found the complex nature of a classroom had a significant impact on the use of educational computer software. I found that the choice of adaptive algorithm had no significant impact on the success of the software but situational factors surrounding the use of the software in the classroom had a much stronger influence. I wanted to investigate both students’ and teachers’ experiences of working with adaptive software as a complement to other ongoing teaching/learning practice in the classroom.

As the study involved children it was important to find a research method that considered this sensitive research group.

This chapter starts with a review of the theoretical basis for the choice of methods selected to answer the research questions. Continuing, I describe the study’s research design followed by the participants, data sources and procedure.

4.1 Theoretical Basis - Evaluating Educational Software

4.1.1 Mixed Methods

Approaches to educational research are many and varied. Researchers who perform research with a quantitative approach belong to the philosophical view of scientific realism (Lodico, Spaulding & Voegtle, 2006). To investigate questions about learning outcomes and their causes in the classroom, it is essential to combine qualitative and quantitative methods. This is sometimes referred to as a “mixed-methods” approach. If a research question cannot be completely answered or explained by using either quantitative or qualitative
methods, a mixed method is recommended as the various methods can complement each other and provide a more complete analysis (Tashakkori and Teddlie, 1998; Creswell, 2002; Lodico, Spaulding and Voegtle, 2006). Combining quantitative and qualitative methods seeks a richer answer and understanding of the research, (Cambell & Fiske, 1959).

4.1.2 Action Research
A popular practitioner research approach in educational settings, that uses quantitative and qualitative methods, is action research. Action research incorporates a mixture of ethnographic and case study techniques (Freebody, 2003). The approach is divided into two categories: practical and critical action research. Practical action research is most commonly used by practising teachers who also want to undertake research. Action research is a way for teachers to improve themselves (Freebody, 2003) and is used as a method for challenging traditional educational practice. Critical action research on the other hand is used by researchers who normally do not belong to the community being studied. The trained researcher can identify problems that are of interest for participants and the researcher (Fraenkel & Wallen, 2005) and view the activities with a more holistic approach than the more involved existing practitioner (Tacchi, Slater & Hearn, 2003). The more holistic approach means the researcher looks at the social relationships as well as the context within which the actions occur.

4.1.3 Ethnography
Ethnography originates from Anthropology where researchers observed foreign cultures in other countries. To gain an understanding of the social setting and interactions, ethnography was traditionally used for studying a context. The researcher participated and observed in the context of the research for a first hand experience of situations. The method was seen as a natural fit for understanding a social perspective of the system (Crabtree, et.al., 2005). Dourish (2001) suggested that ethnography is a common method used for social computing design. The method of making observations and the writing about the observations produces results that not
only report exactly what has been observed but also provides an analysis of the actions, which results in a “thick description” (Geertz, 1973).

According to Twidale, Randall and Bentley (1994) ethnographic work can be seen, and should be used, as a continuing evaluation process of a design. In their study, they used the informal evaluation method of ethnography to evaluate a cooperative system for Air Traffic Control. Stories and interactions from specific situations were observed during the user testing and they became important information for understanding problems with the more general issues with the system. Paolo Freire (1970) declared that research should always be made in collaboration with involved participants for a complete understanding of the research.

Action Research was used to inform and underpin the framework for the methods in this study. As the study aimed to find out how learner-adaptive software for spelling is working in a primary school classroom, I wanted to have an understanding of the environment and culture of the classroom. According to Tacchi, Slater and Hearn (2003) ethnography is traditionally used for learning and understanding different cultures, while Action Research is used when research wants to introduce new activities into a culture. To be able to seek an answer to the research question, the usability of learner-adaptive systems was evaluated. Both quantitative and qualitative methods were combined to enable triangulation of data (Easterby-Smith et al., 1991).

4.1.4 Iterative Design Process
An iterative design process is suitable to fully understand which design works best for a particular context: The iterations of designing a prototype, deploying, evaluating and re-designing gives the designer a better understanding of exactly how and when the system is being used. The iterations allow for a design based upon a dialogue with the users and their environment (Zimmerman, 2003).
4.1.5 Evaluation of Software in general (HCI)

Evaluating how well computer software functions in real environments has been found to be a complex task. Usability is well known in the field of Human-Computer Interaction (Lowgren & Stolterman, 1998), and is used to measure the efficiency, effectiveness and satisfaction of a system in a specific context (ISO 9241:11). Several attempts have been made to suggest how usability tests should be performed. One of the most commonly known suggestions is Nielsen’s (1994) checklist of usability heuristics. Nielsen’s checklist has been found to be easy and quick to follow. Though Nielsen’s checklist is a popular choice for testing usability, it has some restrictions when evaluating educational systems. The checklist does not consider learning issues (Squires and Preece, 1999) or the teachers’ uses of the system (Squires and McDougall, 1994). Mayes and Fowler, (1999) further discussed the issue of also evaluating how well educational systems support the student’s understanding for his or her learning.

4.1.6 Evaluating with children

There are several aspects to consider including finding a method that considers all user groups for evaluation of learner-adaptive systems (LAS). There are two main user groups involved in evaluation of LAS: students and teachers; both of which need to be considered.

The evaluation method has to suit involvement with children. Usability studies typically focus on adults (Bruckleitner, 1999; Baauw and Markopoulos, 2004). Hanna, Risden and Alexander (1997) however, noted that adult experimenters are unable to identify all obstacles children will experience. In the 1970’s and the 1980’s children were rarely used in usability tests (Druin, 2002) but this has changed in the last 15 years and is now increasingly common. Hanna, Risden and Alexander (1997) have performed several usability evaluations with children in usability laboratories. They suggest that while normal rules for testing apply, the testers should try to tailor the test environment so that it suits the child’s developmental level. Instructions and questions need to be customized to a suitable level to provide a comfortable
feeling for the involved child. As Hanna, Risden and Alexander say “these are all part of respectfully testing children” (1997, p. 14).

Since everyone is different, have different experiences with computer software and education, and think differently, it is important to find a representative sample of users when testing computer software or systems (Donker and Reitsma, 2004). Gender can also be a differentiating factor in usability tests (Markopolous and Bekker, 2003). Novice and expert users will have different comments on software. Donker and Reitsma (2004) say that novices experience more problems using a system compared to an expert user but the expert user will provide comments that are useful for extended use of a system. Where working with children is concerned, Markopoulos and Donker (2002) found that think-aloud protocols do not work particularly well with children. Think-aloud protocols ask participants to verbally express how they are thinking, but, children often find it difficult to articulate their thoughts. The think-aloud protocol thus distracts children from the task at hand. Moreover, it is disruptive for children when they are placed in a situation where they work on a computer, verbally commenting on their own thoughts while a stranger takes notes every time they say or do something. Later studies have shown (Donker and Markopoulos, 2002; Markopolous and Bekker, 2003) that think-aloud protocols render more usability issues than other methods such as interviews after a test session. Donker and Reitsma used a refined method called talk-aloud in their research studies. In talk-aloud the child is asked to say aloud what they are doing instead of what they are thinking. As a result of using talk-aloud method (Donker and Reitsma, 2004) the children do not talk a lot during the test sessions but the researcher still finds it valuable to record comments since these give an insight into the child’s thoughts about the software, without overly disrupting their thought process.

4.2 Research Design
The focus of this thesis was to explore which factors are important to consider when designing educational software for classroom use. To understand the
hypothesis and ultimately the way I approached the research question, I needed to consider several aspects. Both teachers and students are users of a learner-adaptive system and for it to qualify as successful, both groups need to be satisfied. The two user groups share the desire that the students should gain the best possible learning outcomes, so the classroom context will have an impact on how and when students can successfully work with educational software. Teachers prefer a tool that naturally complements their teaching and monitors their students’ progress. Also, students tend to discuss and collaborate even though they are given tasks to solve as individuals (Hinn, Twidale & Wang, 2004; Boden, 2004).

For a start, the aim of this thesis was to find a suitable learner-adaptive computer technique that supports teachers in their profession and students on an individual basis while working in a classroom. In order to evaluate which technique is best suited in a primary school classroom, two versions of Spelling Bug were designed and tested in situ. To test the two different techniques a hypothesis was formulated.

*A lightweight learner-adaptive method as exemplified by the ‘evolution of educational content’ functions at least as well as a student modelling technique as exemplified by Millán and Perez-de-la-Cruz (2002) in a classroom environment.*

The study was designed as an iterative process with the researcher participating in the classroom. I wanted to become a part of the classroom context so the students would not view me as an outsider and feel confident to speak freely with me about their experiences. Another reason for integrating myself into the classroom context was to develop a better understanding of the various activities that occur in daily teaching and learning. Ethnographic methods such as observation and note taking were used over the complete study period. While pre- and post interviews were made with teachers and students, I continuously kept taking notes of informal discussions where teachers and students approached me to make comments or discuss Spelling Bug.
The study was designed to be iterated twice, analysing the results after the first study, making design changes based upon the results of the first study and then a second user study followed by an analysis of the outcomes. Using the observations and computer based data logging of data served as the basis for a redesign of particular parts of Spelling Bug for the second iteration.

Being mindful that a computer system needs to perform satisfactory for its users or it will not be practical and used in a classroom (Grudin, 1988); The success of a learner adaptive system depends on many factors, some of which are technical but as this thesis will argue, many essential factors are qualitative. The following questions arose (originally listed in chapter 1).

7. What factors are important in the design of a learner adaptive system to be successfully used? 
8. With what effectiveness can a learner adaptive system support spelling achievement? 
9. How useful is learner adaptive system as a teaching aid? 
10. How well does a learner adaptive system captures and adapt to individual learning needs? 
11. Can a learner adaptive system offer an experience that is both engaging and enjoyable? What are students’ and teachers’ attitudes to working with a learner adaptive system?
12. Can a learner adaptive system achieve an overall fit with teaching practice?

4.3 Study participants
The study participants consisted of teachers and students from three primary schools in Brisbane’s metropolitan area (here referred to as School A, School B and School C). 
There were 145 students and seven teachers participating in the study (see below Table 4-1).

Table 4-1
Table of participants in the user studies of Spelling Bug
I approached teachers and students from classes in grade 4 as these students are at an age where they are able to communicate their opinion of a computer system (Hanna, Risden and Alexander, 1997).

All participants freely volunteered to participate in the research study. The study endeavoured to have an equal number of male and female participants.

Seven teachers participated in the study. Three of the teachers taught grade 4 students, one teacher taught a composite class of grade 3 and 4 and two teachers had composite classes of grade 4 and 5 students. Two of the teachers had between 1-5 years of teaching experience, while the other five teachers had over 15 years of teaching experience. All participating teachers were class teachers of the children recruited for this study.

School B initially intended to continue with their participation in the study of Spelling Bug through two school terms but the school had a change of principal and this resulted in some changes of teaching staff. Both participating teachers from School B were transferred to other schools and while the new principal was interested in the study of learner-adaptive systems, she wanted to delay the user study for another year until her teaching staff and students had settled in under the new leadership. I then approached a third school (C) so that the user study could continue to plan.

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4.4 Data sources

Multiple sources of data were used in the study. Below I present each data source I used. The various sources of data were used in a mixed-method to evaluate and analyse the use of learner-adaptive systems in the primary school classroom.

4.4.1 Spelling Tests

All participating students were asked to sit a hand-written pre- and post-test in spelling. The test was split up into two tests that together consisted of 96 words for grade three students and 87 words for grade four students.

The first test was based upon the Australian National Assessment Program – Literacy and Numeracy (NAPLAN, 2008, 2009 for grade 3 and 5). I made up my own version of a NAPLAN test (See Appendix 11 and 12), choosing to test words that were already in the database for Spelling Bug and that had the same spelling difficulty level and spelling patterns as in already existing NAPLAN tests. The words were selected after studying several existing tests for the age group of 8-10 year old students from the Australian Curriculum Assessment and Reporting Authority (ACARA)’s website. I made one version of the NAPLAN test for each of grade three and grade four so the test would suit the age groups. The test I designed focused on the kind of spelling patterns NAPLAN tested. I looked up words containing the same spelling pattern and difficulty level to suit the age group. In a former NAPLAN (2009) test, words with the spelling of ‘ea’ were tested. The word using ‘ea’ was compiled in a sentence with the instruction to find the one word in the sentence that is misspelled and to write the correctly spelled word in the box at the end of the sentence, e.g. bred – bread, insted – instead.

The second part of the hand-written test was a list of 61 words to be spelled after hearing the words orally pronounced. This style of testing mimics the style the teachers said they use for testing the weekly spelling words. The teacher was given the list of words to be spelled. Each word had an example sentence where the word was used to illustrate the semantics of the word. The first 48 words in the second list were words taken from the word database
used in Spelling Bug. The last 13 words on the list belonged to a list of most commonly misspelled words in English, which was also a part of the word database used in Spelling Bug.

4.4.2 Interviews
Interviews with participating teachers and students were organised before and after the participants had worked with Spelling Bug. The pre-interviews aimed at finding out how spelling was taught and tested in the classroom. I also wanted to learn about attitudes to working and learning with spelling before and after using Spelling Bug. The post-interviews were therefore focused on finding out about the experience of working with Spelling Bug following its use. All interviews were undertaken in the respective classrooms of the participating teachers and students and they were audio recorded.

Students
The planning and design of interviews with children is critical to the quality of discussion (Stewart, Shamdasani & Rook, 2007). It is important that the children feel comfortable to speak freely at an interview. Thus, for the pre-study interviews I interviewed the participating students in groups of four. To ensure the interviewed students felt comfortable and to maximise the outcome of the interview, I asked one student to bring three other friends to the interview. While I had a set of questions I wanted to ask (see attachment x), the questions were kept semi-open (Kvale, 1997). Kvale (1997) suggested to use semi-open questions when the researcher wants certain questions answered but also wants the interviewees to talk more freely about what they have noticed. The questions produced information about the students’ thoughts about spelling, how they perceive spelling activities in the classroom and the students’ awareness of their own spelling ability. In total 16 boys and 14 girls were interviewed for 20-25 minutes per group, there were seven groups in total.
After the user testing had finished students were interviewed again. The second interviews were made individually or in pairs for between 15-20 minutes per interview. The students were now familiar with the researcher and I invited individual students to come for the interview. Again, to ensure they felt comfortable while being interviewed, students were given the option of bringing another student with them. The same students who had been interviewed before the study commenced were approached for the post interview. The post interview data consisted of attitudes to working with spelling and awareness of their own spelling ability. In total I interviewed 8 boys and 11 girls. The interviewed students had an even representation from four of the participating classes, School A (9 girls, 9 boys) and school C (3 girls, 3 boys). School B finished their participation before phase 2 so there is no post-interview data from the school.

Teachers

In the pre-study interviews, all teachers were individually interviewed in their classrooms after school hours. I used a semi-formal structure (Kvale, 1997) for the questions (see Appendix 5). The semi-formal questions were used to initiate a conversation with the teachers around the topics I was researching (Gay, Mills, & Airasian, 2006). Data from the pre-interviews consisted of information about the teachers’ existing spelling programs, their attitudes to using technology in teaching and how they keep records of students’ progress in spelling.

After the user study, I interviewed participating teachers from school A and C. Two of the teachers were interviewed individually and two teachers from school A asked to be interviewed together as they had been working closely together during the study. The same format of semi-formal questions was used for the post-interview and the teachers were interviewed for 30 minutes after school hours in their respective classrooms. Post-study interviews collected information about teachers’ attitudes to using Spelling Bug in their teaching and attitudes to technology in teaching.
4.4.3 Computerised data logging
The students’ interactions with Spelling Bug was automatically logged and saved by the computer system. The data registered by the computer kept a log of each single interaction, start time and end time of the activity and the kind of activity of spelling pattern the student was tested on.

4.4.4 Classroom observations
While the students were working with Spelling Bug in their respective classrooms, I participated and made observations. The observations were noted in a diary during and after the classes. The notes consisted of observations of how students interacted with each other, how they used Spelling Bug and the teachers’ interactions with students.

4.5 Procedure
Spelling Bug was user-tested in two phases. School A and B participated in the first phase and School A and C participated in the second phase. Phase 1 was used as a first iteration of the user testing. Following phase 1, I evaluated Spelling Bug and the use of the software in the classroom context and this was used as a basis for changes made to phase 2. The iterative process of designing, user testing, making revisions and then user testing again, is a design process where the design evolves through an ongoing conversation with the users (Zimmerman, 2003).

To test Spelling Bug in primary school classrooms, I approached three inner-city suburban schools in Brisbane. In the first instance the principal at each school was asked if he or she would be interested in participating in the study. When the principals approved for the study to take part at their respective schools, I personally made contact with the schools’ grade four teachers. The teachers were introduced to the research study at a meeting with them and their principal. I made clear to the teachers that participation was voluntary and there would be no penalty if they declined participation. At this meeting Participant Information and a Consent Form was handed out to the teachers. The teachers were left to read over the information and to consider their
participation in the study for a week. After one week the teachers were approached by email in which they were asked if they would like to participate in the study. The teachers who agreed to participate were asked to sign a Consent Form (see Appendix 5).

All participating teachers were interviewed before I introduced their students to Spelling Bug. The audio-recorded interview was held in each of the teacher’s respective classrooms after teaching hours. The interviews gave me an occasion to learn about the teacher’s knowledge and attitude to using technology in their teaching. The interview also informed me about how the teachers approached the teaching of spelling in their classrooms. The interview questions (see Appendix 6) were written as semi-open questions in order to encourage a further discussion if the teacher introduced a topic that could be of further interest for the research study. All interviewees were informed about the anonymity and the confidentiality of the interview. The interviews lasted for 20 minutes.

Continuing, the school students were orally informed about the research study in one of their English classes. I visited the three classrooms and informed the students about working with Spelling Bug and the research study. The students were told that it was a voluntary participation in the study, there would be no penalties if they did not want to participate and that they could still work with Spelling Bug without being part of the study. The students were encouraged to ask questions about Spelling Bug which I answered. At the end of the session, students were given a written Information Sheet and Consent Form (see Appendix 3 and 4) to take home to their parents.

Once the Consent Forms had been collected, all consenting students sat a hand-written spelling test. The spelling test was made up in two separate tests, one was mimicking a NAPLAN test and one was a traditional test where the teacher reads the spelling word aloud and the students then write down the word on a piece of paper. The results from the test were shared with each teacher.
Before the students started using Spelling Bug, I interviewed a selection of the students in groups of four about their views on working with spelling. The interviews were audio-recorded and I ran the interviews as group discussions around spelling. The purpose of interviewing in groups was to ensure the students felt comfortable talking with me as I was an outsider they did not know well at this stage. The interviews questions (see Appendix 7) were kept semi-open and used to encourage a discussion among the students about their attitudes and experiences of learning to spell.

After all the interviews had finished, the students were introduced to working with Spelling Bug. The teachers and I had a discussion on how Spelling Bug could be used and integrated into their classrooms. Each individual teacher then decided how she wanted to incorporate Spelling Bug into her lessons. The teachers were asked to allow students to work with Spelling Bug for a minimum of 15 minutes each week.

I participated in the computer laboratory as an assisting teacher when needed and as a non-participating observer at other times. The benefit of being an active participant during the observations was that students became familiar with me and they felt comfortable to express their opinion freely.

The user study was conducted over two Phases over two school terms. Each phase was approximately 6 weeks duration. After Phase 1 the observations and computer log data were analysed. The analysis was used to gain information on changes to Spelling Bug's interface and technical selection criteria.

The week after phase 2, when students had finished using Spelling Bug, they sat the hand written spelling test again. I used the same test for to find out about each student's progress in spelling.

A post interview was conducted with participating teachers after Phase 2. The interview gave the teachers an opportunity to analyse and express how they had experienced incorporating Spelling Bug into their classroom activities.
The audio-recorded interviews were held one week after finishing the user study in the classrooms. Teachers were interviewed after school hours in their respective classrooms.

A selection of the students were chosen for individual post-interviews. The interviews investigated the students’ experiences of using Spelling Bug, their awareness of their own spelling ability and attitudes to using a computer based spelling program.

During the whole study I made observations and kept a diary over the various research activities. While some notes were taken during interactions with teachers and students, the diary was written up and dated after each interaction.

The procedure was the same for all three participating schools.

4.6 Analysis

4.6.1 Spelling Tests
The results from the pre- and post study spelling tests were entered into an Excel spread sheet. I calculated each individual student’s failure rate in percentage and then compared the percentage from pre and post tests. The spelling tests were used as they are a traditional form of testing school students in their progress of learning and the results were used for showing students’ learning over time.

4.6.2 Interviews
All interviews were audio-recorded and then transcribed. I listened through the interviews while identifying and taking notes on themes, in particular around areas such as attitudes to spelling, learning and teaching strategies, awareness of learning, attitudes to the use of technology for educational purposes. The interview material was analysed in stages, as the iterative design process is constantly ongoing. The material from the analysis was also
treated with “openness” rather than looking for preconceived frameworks or hypotheses (Glaser & Strass, 1967) to ensure I did not miss important factors as to why technology is useful or not in the teaching and learning taking place in the classroom.

4.6.3 Computerised Data log
The computer system kept a log of all student activities such as number of times using Spelling Bug, number of attempts at each spelling patterns, level of difficulty etc. Data were collected and summarized to indicate for each student the number of activities and the maximum level achieved during the full duration of the trial. For each participating student I ranked them in descending order of activities and labeled them with gender, school and method. The null hypothesis is that these labels were ordered randomly. Wilcoxon Ranksum test was used (a.k.a. the Mann-Whitney U-test) to determine the cumulative probability of the null hypothesis (its P-value), and whether any label was associated with higher (or lower) number of activities. The p-value indicated the extent to which such labeling can be explained by chance. I considered a p-value of 0.05 or less to support a statistical significant deviation from the null-hypothesis. The data were grouped so that I could distinguish between gender (boys vs. girls), school (A vs. C; actual names withheld) and method for selecting exercises (Radial Basis Function (RBF) versus Bayesian Network (BN)). The data groups were visualized in histograms.

4.6.4 Observations
During the whole study, I made observations, and wrote up a diary after each interaction with students and teachers. The diary was written by hand with pen and a notebook. After each phase in the study, the researcher read through the diary and looked for themes and comments made by students and teachers on their experiences of working with Spelling Bug. The observations were used as a basis for changes to Spelling Bugs interface and functions in the second iteration of the study.
4.6.5 Summary
Data from interviews, observations and the data log were compared to see if there were any matching themes or data to explain phenomenon occurring in the study. The data log provided the study with data to demonstrate the students’ progress but it cannot explain the kind of computer program that would suit a classroom of 30 students, nor can it show if the program can be integrated into existing teaching. Combining the above-mentioned methods served to provide a clearer understanding of how technology can function as a support for teaching and learning in the classroom.
5 Results

The results are presented in three parts. The first part reports on the deployment of Spelling Bug at each school. The deployment is written to provide an understanding of the different schools’ contexts and how each teacher used Spelling Bug. The deployment is followed by a presentation of computer-logged data of usage from Spelling Bug together with results from the hand-written pre- and post-deployment spelling tests. The last part reports on the results attained from teacher and student interviews, as well as observations from the user studies.

5.1 Deploying Spelling Bug

Below follows a description of how each of the three schools chose to deploy Spelling Bug in their teaching and learning. The description is written to provide an understanding of each school’s context and how each teacher decided to integrate Spelling Bug and the use of the software. The study was made in two iterations with School A and School B using Spelling Bug over one school term (referred to as Phase 1) and School A and School C participating in the second iteration (referred to as Phase 2) also over a single school term. All names of the participants have been changed to ensure anonymity.

5.1.1 Phase 1

School A
School A is located in an inner city suburb with high-socio-economic background families. The school has 355 students ranging from preparatory year up to grade seven. The principal is a young and ambitious principal in his early 30s and the school also has one middle-aged female pro-principal.

Computer set-up
School A has a computer laboratory with 30 desktop computers and one smart board (interactive white board). The school had hired out the service of having the school’s computers checked and updated regularly to an IT company. In the computer lab there were normally at least 25 computers
working each day. All classes in the school shared this laboratory and a schedule on which each class have been given a one and a half hour time slot. The room was fully booked during the week but as the preparatory and grade one classes did not use their time slot every week, teachers from the senior grades (grade 4-7) negotiated in between them who would be able to use the laboratory. In addition to the laboratory, between two to four personal computers were placed in each classroom, with the lower number of computers in the lower grades and with four computers in each of grade 6’s and 7’s classrooms. The classroom computers were spare computers from the computer laboratory that had been replaced with newer machines. The classroom computers were often not working and it took up to three weeks before the IT person attended to not working machines. The problem with the classroom computers was that often the teachers only had one or two working machines to be shared between all their students.

Teachers
Three female, grade four teachers were involved in Phase 1. One of the teachers, here called Ms Bengtsson, was teaching her first year since graduating from her teaching degree. The two other teachers, here called Ms Andersson and Ms Svensson, were over 45 years old and have many years of teaching experience through out all primary years. Ms Svensson and Ms Bengtsson worked part-time and shared the teaching of one class. The three teachers had a close collaboration between their classrooms and they used a roller door in between the two classrooms to open up the two spaces into one big classroom. Ms Andersson was also in the role of mentoring Ms Bengtsson.

Ms Bengtsson and Ms Andersson are “computer literate” and they used computers and the Smart Board in their classrooms in all their teaching. The Smart boards were used for showing worksheets to the whole class, instructions on what the students are to do and then for demonstrating correct answers. Ms Svensson only used the computer for writing letters to parents and she felt unqualified to use technology in her teaching.
Class composition

The two grade four classes consisted of an even spread of 27 boys and 26 girls altogether. In total there were two students with special needs; both students had been diagnosed with ADHD.

Incorporating Spelling Bug into the classroom

In phase one, two grade 4 classes participated in the study. The teachers had been asked how they would like to incorporate Spelling Bug in their teaching. Ms Andersson and Ms Bengtsson who were closely located next to the computer laboratory, decided to make up a schedule where they sent ten students at a time into the computer laboratory to work with Spelling Bug. The students were told to bring paper and a pen with them. The teachers instructed their students to write down any words they found difficult to spell or if they did not understand their meaning. Students were also told to log out and come back into the classroom when they had worked for a maximum of 15 minutes in the computer laboratory. Group sessions were repeated until all students had worked with Spelling Bug or until the scheduled hour was finished. I observed that the students worked intensively with Spelling Bug and they became tired after around 10-15 minutes of work. The work on Spelling Bug was scheduled once a week. Meanwhile in the classrooms, teachers were able to use the occasion of having a reduced number of students in the classroom. In the classroom, students were working with paper based spelling activities and the teachers focused on providing individual feedback to students who needed attention.

School B

The second school participating in the study was located in the neighbouring suburb to school A. School B had 176 students ranging from preparatory to grade seven. The school is considered a small school and it was struggling to meet a growing demand of more students. At school B they had a female principal, over 55 years old, who expressed a positive attitude to allowing students to learn with technology.
Computer set-up
School B used a space in the library as a computer laboratory. The space had 15 personal computers. The room was not built with the intention of being used as a computer laboratory and the machines were placed on tables around the bookshelves. The space was narrow and it was difficult for teachers to move around to help their students. The computers were old “left-over” machines that had been given to the school and most weeks only half of the machines were working.
One of the participating classes had three personal computers for students to use. The machines were of regular desktop PC’s and were primarily used for word processing.
The school had employed a male pre-service teacher to work as their IT specialist. The pre-service teacher visited the school one day a week for a few hours, having been trained in the state wide computer system that was used at the school. When the teachers had questions or problems with the computers, they would send an email to the IT specialist and he would help them on his next visit. This meant that when teachers had problems with the computers, they would either have to cancel the class or the students had to wait until they could use another computer to finish their computer-based activities. If the timing of computer problems occurred just after the specialist had visited the school, it meant the teachers had to wait for a whole week to resolve the problems so they could continue with their planned lesson.

Teachers
Two female teachers, Ms Davidsson and Ms Fredriksson volunteered to participate in the study. Both teachers had over 10 years of teaching experience. The two teachers told us they had no training in how to use computers in their teaching and they did not have much experience of using computers in general.
The teachers collaborated when planning for the material to be taught to their students but they taught their classes separately. The existing teaching of spelling relied on procured textbooks. The books were based around 10-15 weekly spelling words and associated spelling rules. Following the weekly
words list and the spelling rules, two pages of hand-written activities for practicing the words and rules followed.

Incorporating Spelling Bug into the classroom work
Ms Davidsson and Ms Fredriksson decided they wanted their students to use Spelling Bug once per week during an English class. Half of Ms Davidsson’s class walked over to the library and worked with Spelling Bug while the second half were working with spelling and grammar activities in their spelling books in the classroom. The librarian was supervising the students while they were working in the library. The students swapped activities after 15 minutes so that both groups of students had worked with Spelling Bug. After 30 minutes, the same procedure was repeated for Ms Fredriksson’s class.
Both classroom teachers stayed back in the classroom with the students who worked with the spelling activities from their English books.

5.1.2 Phase 2:
School A
In phase 2 Ms Svensson had transferred to another school so Ms Bengtsson was teaching the class. Ms Andersson and Ms Bengtsson were keen to continue using Spelling Bug as they believed it was a positive experience to their students’ learning. After Phase 1, a third teacher, here called Ms Karlsson, approached me. She had heard about Spelling Bug from Ms Andersson and she asked if she and her class could try it. The new class was a composition of grade 3 and 4 students.
Ms Karlsson was a senior teacher who had two more years until her retirement. Ms Karlsson had an interested approach to new technology but she expressed insecurity on how to use the technology in her teaching. Ms Karlsson said that she had been one of the last teachers to have a Smart Board installed in her classroom and she was now experimenting with ways of how to use the board in her teaching.
Class composition
Ms Bengtsson and Ms Andersson’s class composition stayed the same as in Phase 1. Ms Karlsson’s class consisted of 22 grade three students and 4 grade four boys. In total the class had 12 girls and 14 boys. There were no children with a diagnosed learning disability but two of the boys were recently emigrated from Asia and neither of the boys spoke English before they started school in Australia, six weeks before using Spelling Bug.

Incorporating Spelling Bug into the classroom work
Again Ms Andersson and Ms Bengtsson used Spelling bug by sending groups of 10 students in to the computer laboratory for working with Spelling Bug. Groups in the two classes took turns until all students had been in the computer laboratory or until the English class was finished (one hour class). Ms Karlsson had also made an arrangement with the librarian. Once a week half the class went to the library for literature studies while the second half of the class worked in the computer laboratory with the classroom teacher. The teacher decided to use the computer laboratory for working with Spelling Bug. The laboratory was booked for half an hour but the students would normally spend around 20 minutes on the computers, as they had to walk with the rest of the class to the library first and then to the computer laboratory. The two groups in the class alternated every second week so all students spent time with Spelling Bug every second week. While the other two classes would use Spelling Bug for around 10 minutes per occasion (based upon observations in Phase 1), Ms Karlsson’s class spent 20 minutes per occasion. These students would work between 10-15 minutes with their spelling and the teacher would then propose the students to spend 5 minutes on trading bugs.

School C
A third school participated in Phase 2 and used Spelling Bug for one school term of 6 weeks. School C was located in the outer suburbs of the main city. The school was situated on large open grounds with plenty of space for the students to play in. The school had 565 students ranging from preparatory level up to grade seven.
The principal was a senior male. He said he was interested in the school learning about modern technologies for classrooms but he had found that individuals amongst his staff resisted change.

Computer set-up
This school had six personal computers located in each grade four classroom. Five of the computers were one-year-old machines that worked well without problems. The sixth computer was over four years old and would not work on most occasions when we trialled Spelling Bug. As the school did not have a dedicated computer laboratory, the teacher negotiated using the computers in the next-door classroom when she needed more than six computers in one session. Moving between classrooms complicates the work for the teachers, as it can be disruptive for working students when other students are moving in and out of the classroom.

The six computers were placed in one of the classroom’s corners, next to the teacher’s desk.

The school did have good IT support, based on one young man who would come to the school two days per week to deal with jobs the teachers had logged. An IT-specialist was hired to keep the computers and intranet working. The IT-specialist arrived once a week to the school and he would then work through a list of problems that had been reported by teachers to the school administration. The IT-specialist had no training in education and simply provided hardware support and installation of software.

Teachers
Three grade four teachers were approached and asked if they would like to participate in the study. All three teachers were female, and in their upper middle age. One of the teachers, here called Ms Larsson, was working her first year as a graduated teacher. Ms Larsson had over 20 years of experience of working within classrooms as a teacher’s aid. Ms Larsson was very positive about Spelling Bug and even before she had heard about the participation in Spelling Bug, she said “I want to participate with my class in this study, I have heard that it’s fantastic”. The two other teachers had each been teaching for more than 20 years. They were quiet and expressed a
hesitation to using technology in their teaching as they felt they did not have appropriate training. After we had presented how Spelling Bug works together with some of the results from other participating schools all the teachers seemed more positive about participating. Although the two senior teachers decided to not participate in the study, they both were positive to visit the first teacher and her students to learn more about how the software was working. The two ladies said they would reconsider participation after seeing how Ms Larsson found using Spelling Bug.

Class composition
The participating class was mixed gender, grade four with 14 girls and 16 boys. There were no students with any diagnosed learning disabilities.

Incorporating Spelling Bug into the classroom work
The students normally had a writing essay session once per week in their English class and Ms Larsson decided this would be a good time to also work with Spelling Bug. The class teacher decided that she wanted the students to take turns with working for 10 minutes with Spelling Bug. During the English class, the teacher would call out names of five students and these students would then work with Spelling Bug at the computers in the classroom corner. When a student had finished his or her session, they reported to the teacher and she called out for another student to work with Spelling Bug. This pattern was repeated through the lesson so that most students had a chance to work with the spelling software each week. Once students had become familiar with using Spelling Bug, the teacher would start encouraging weak spellers to work for another 10 minutes with Spelling Bug on other occasions during the week.

5.1.3 Summary
Spelling Bug was deployed in three primary schools in the western suburbs of Brisbane. Spelling Bug was used and integrated into English classes in all three schools. Each teacher made a choice of how they wanted Spelling Bug to be incorporated into their English lesson. All teachers had to consider what computers they had available and functioning to be able to use Spelling Bug.
This meant that some of the teachers had to re-schedule their English classes to times when they could access computer laboratories.

5.2 Spelling Tests

One pre- and one post-deployment spelling test were designed for the participants. The spelling test was designed in the same style as Australian NAPLAN spelling tests, as pen and paper test. The words chosen for testing were to match the difficulty levels and spelling categories of NAPLAN tests. All the words used in the spelling tests also exist in the word database used for Spelling Bug.

The students did the pre-spelling test in the week before the students were introduced to Spelling Bug. All students present in the classroom sat the hand written, individual test during an ordinary English class.

A post-deployment spelling-test was done again one week after the conclusion of using Spelling Bug. While School A had used Spelling Bug over two terms (term 2 and 4) and therefore had 8 months between the pre- and post deployment tests, School C only used Spelling Bug over one term meaning they had 7 weeks between the two hand-written tests. Students at School B never did the post-deployment spelling test so there are no results on the hand-written test from this school.

In total 85 students, 41 female and 44 male, took both pre- and post-deployment spelling tests. Other participating students missed either the pre-, post- or both tests because of absence on the day the test was held.

School A used Spelling Bug for term two and four. In total 59 students at School A did both the pre- and post-deployment tests. 43 students at School A improved their post-deployment test results. The average percentage of correct response increased from 51.38% to 63.52% in their spelling test. 13 students from School A tested at a lower score in the post-deployment test compared with their pre-deployment test. Four students tested the same in both tests.

School C used Spelling Bug for one term (6 weeks) and 26 students did both the pre- and post-deployment spelling tests. Spelling Bug was used in the last
term of the school year. Out of the 26 students from school C, only two students presented a positive result in their hand written spelling tests, with an average results changing from 73.08% at the pre-deployment test to 76% in the post-test. The remaining group of students at school C had a negative trend in their pre- and post-deployment tests. For this group the average at the pre-deployment test was 70.83% compared to 57.33% correctly spelled words in the post-deployment test.

The students from both School A and C were tested in the same last week of the school year, which is during a very warm time of the year. This meant that the children find it harder to focus on schoolwork, and this may have negatively impacted on the post-deployment result. The consistently lower test results at School C may also have been influenced by the shorter time between pre- and post-tests.

In the section below I present the data log of the spelling activities that were collected automatically by the system. At the end of section 1.3 I provide the results of a triangulation of the hand-written spelling tests and the number of spelling activities each child did with Spelling Bug.

5.3 Data log of progress

Spelling Bug collected data logs from 96 students, including 51 boys and 45 girls. The students used Spelling Bug for 10 minutes each session and they had an average of 227 entries per student for School A and 65 entries per student at School C. The computer logs from school B are not presented as their data was collected before we had calibrated the weighting used by Spelling Bug when the student-model (BN) was employed. The version used by schools A and C, explored new words with the same probability, irrespective of whether BN or RBF was employed.

The method for selecting spelling activities for a particular student had been randomly allocated to the student. The student was not aware of which model they were using. The null-hypothesis is that there is no difference in number of activities completed between students using BN and students using RBF.
Figure 8 shows the number of spelling activities students had been completing over the duration of the study. The data are divided by the method that students were using (BN or RBF). The scale on the x-axis is broken up in intervals of 80 activities so each bar in the graph covers a number of students indicated by the y-axis. The data show no significant difference in number of activities completed between students using BN and students using RBF (P = 0.29; Wilcoxon Ranksum test). This means that the method of choosing words appears to have no impact on the number of spelling activities that a student completes.

**Figure 8**: The histogram shows number of activities grouped according to method for selecting exercises e.g. Bayesian Network (BN) aka student-model or Radial Basis Function (RBF).
Figure 9: Number of activities for each gender group.

Boys and girls equally enjoyed working with Spelling Bug and within each school each student spent the same amount of time working with Spelling Bug. Looking at the graph showing the spread between boys and girls number of activities (see Figure 9), we can see that a large group of boys only reached around 200 activities of spelling before they stopped using Spelling Bug. That said there is not a significant difference between the genders and the computer log shows an fairly even spread between the number of activities done.
Figure 10: The distribution of activities compared between School A (here labelled “M”) and School C.

School A have a much higher frequency of activities compared to school C (see Figure 10) which only used Spelling Bug with one class for one school term. School A had three participating classes over two school terms.

Figure 11 and Figure 12 show histograms across the maximum level of difficulty achieved during the study and the number of students that fell into each of the five levels (where five was the highest level). Figure 4 show that there is a slight skew towards girls achieving a higher level of difficulty, but this tendency is not statistically significant.
Figure 11: The number of students reaching their highest level of spelling challenge, comparing boys and girls.

Figure 12: The number of students reaching their maximum level of spelling challenge, comparing chooser method.
To further explore if there was any significant evidence of the students learning I triangulated the results from the hand-written pre- and post spelling tests with the number of spelling activities each individual student had done on the computer. In the pre- and post-deployment tests, all spelling activities were marked as successful or not. The two tests contained the same words. I determined a rate of success for each test and determined their difference. I refer to this difference as the “post-test result”. The computer recorded all spelling activities completed within the system, and determined amongst many things the number of activities for each student. Each student was ranked and then sorted according to the completed number of activities. I expected that a greater number of activities would result in a better post-test result. The correlation supports this expectation at $r = 0.24$ (Pearson correlation; $P = 0.04$). It needs to be noted that 11 students out of the 96 students that we have a computer log recorded for, did not take the hand-written test.

The data for each student is shown in Figure 13 in which we also show the method each student were using to select words. The method had no statistically significant effect on the post-test result (Wilcoxon Ranksum $P = 0.61$).

Spelling activities were selected adaptively as described previously, and it is therefore difficult to measure learning effectively using the data recorded by the system. In order to measure progress, I identified two metrics: All word spelling activities were first marked as either successful or not. They were also labelled as either repeated or novel, depending on whether the student had seen the word before or not, respectively. Activities were then divided into two halves. I was then able to check the success rate on words that were presented for the first time (“novel”), at an early stage (“first half”) and compare that to the success rate of words that were presented for the first time (still “novel”) at a later stage (second half”). My first metric is therefore based on these “novel system-selected words”.

Comparing these two success rates, would indicate if a student has improved his or her ability to spell new words over the course of the study. As shown in
Figure 14, I noticed no significant correlation between the number of activities and the result on the novel system-selected words ($r = -0.17$, $P = 0.10$). Furthermore, the method had no significant influence on the result on these words ($P = 0.96$).
Figure 13: The number of spelling activities reported for the system was used to sort and rank all 96 students. Hence each number on the x-axis corresponds to a unique student, which is the same for both panels. The top panel shows the number of activities (y-axis) and then each bar is labelled according to their result in the post-deployment test relative that of the pre-deployment test. The bottom panel shows the post-test difference (y-axis) and each bar is labelled with the method that the student was using.
Figure 14: Both panels show different metrics for the same students, ranked by the number of spelling activities that they completed. I determined for each student the progress of spelling novel words correctly over the whole trial period, by comparing the latter half with that of the former half. The top panel shows the number of activities, with each student/bar labelled with a positive or negative differential on novel words. The bottom panel shows the precise difference in spelling novel words, with students/bars labelled with method they used.
It can be noted that as the student progresses through the system, success will imply that they are moved up in level of difficulty. It is therefore possible that the difference in success rates is skewed by the increase in difficulty inherent in this adaptation. My second metric is thus one which looks only at the highest (max) level that the student achieved before the study was ended. Within this level, all novel activities were divided into two halves, and the difference between the success rate on the latter and the former halves were calculated. The number of words was reduced overall as only one level was used. The difference in time elapsed between spelling the two sets of words was also reduced, but at least the level of difficulty should be the same.

Figure 15 shows that there is no correlation between the number of activities and the success on novel words within the highest level that the student achieved (r = -0.04, P = 0.68). It is interesting to note that the greatest variation of this spelling success is for students who have completed fewer activities. Speculatively this supports that both methods (most clearly BN) in the long term achieves a neutral level of success.
Figure 15: Both panels show different metrics for the same students, ranked by the number of spelling activities that they completed. Here, I measure the difference in spelling success between two sets of novel words, both collected during the highest level that each student achieved. The top panel labels each student/bar with this difference, and the bottom panel shows it in the y-axis, now labelled with method,
Over the course of the study, students were presented with words that were selected via their spelling features. Some features are very common, but some are seen quite infrequently in the vocabulary. To understand if the success rates as measured by the system varied across these spelling features, I identified the features that were presented in 500 words or more. For each student, I measured the success rates of each feature within the first half of the spelling activities, and then the second (last) half. The mean differences (last 50% minus the first 50%) across all students are shown in Figure 16.

![Figure 16: The change in success rates broken down into spelling features. The most frequent spelling features are shown on the x-axis, either as a rule, or as a regular expression. The y-axis shows the mean and standard deviation of the success rate for the last 50% of spelling activities minus the success rate for the first 50%.](image)

### 5.4 Student interviews

Before the user study, we interviewed students from School A and B about their thoughts on working with spelling. The students were interviewed in groups of four, where one of the students had been asked to identify three other friends to bring for the interview. The method was chosen as we wanted to create a discussion around spelling and to ensure the students felt comfortable talking, we used the group discussion to foster this. For the post study interviews we did individual interviews with students from School A and C, as the students were now familiar with the researcher. The interviews are
presented below as a summary from all the three involved schools. There is no difference in the perception or attitude to working with spelling and Spelling Bug between the different schools.

5.4.1 Pre-study interviews

Thoughts about spelling
29 students were interviewed before they started using Spelling Bug. All students spoke about how spelling was an easy task when they first started school, “the words used to be really easy, like mum and dad”, Albin said. The students continued telling me how they thought that spelling was becoming a more difficult task, as they were moving up in year levels. When the students were discussing various words they considered complicated to spell, they said the easiest way to know how to spell a word is to listen for each sound in the word and then write it. They students also said that unfortunately, this was not a method that applied for all types of words and often they found that the words were not correctly spelled, when using this method.

Perception of spelling abilities
The teachers had classified all students and grouped them into spelling abilities, low, low average, average, high average and high level. When talking to the students they generally were not aware of which level they performed at. Two students confidently knew their actual level of spelling ability: One boy (Anders) who was an extreme low achiever and one girl (Astrid) who was a high achiever (Astrid competed in national spelling competitions).

Homework and computer use
Spelling homework was given on a weekly basis to all students. However, the students expressed abhorrence to doing their weekly spelling tasks. Only a few students said they would do their homework, as their parents force them to finish their homework. All homework is paper based but one boy suggested that if they could have a spelling game on the computer, he might want to play it.
Two boys spoke of a computer based typing program that they used at school. They realised however that the software was not about spelling correctly, but about the positioning of their fingers on the keyboard. Most of the students have computers at home and around half of the students said they play computer games. The games that were mentioned as examples of games they play, were educational mathematical games such as Age of Empires, Club Penguin and Runescape. While the students conclude that none of these games are about training spelling, the boys who play Runescape said that they type messages to each other and so they believed that was a good exercise for spelling. There was only one boy, Anders, who had a computer-based program for spelling training at home: Spelling City. Anders expressed his dislike for working with spelling and he tried to change the subject during the interview to subjects that interested him more such as food and Game Boy games. The perception from the students was that they thought spelling activities at school were not exciting and something they had to attend. While Anders clearly expressed his dislike for working with spelling most of the other students were not excited about the spelling activities they worked with.

5.4.2 Post-study interviews

After finishing the user study of Spelling Bug, 20 students were interviewed about their experiences of using it. 11 students were individually interviewed and nine students were interviewed in groups of two or three. Both gender groups were equally covered with 10 girls and 10 boys all randomly chosen for interview from participating students at School A and School C.

Impressions from using Spelling Bug

Although all students found the robot’s voice in Spelling Bug difficult to understand when they started using the program, they also all expressed a very positive attitude to working with Spelling Bug. The students used phrases such as “I really liked it” and “Spelling Bug was learning and fun”. When the students discussed the quality of the robot’s voice, most of them agreed that improving this feature in the software should be prioritised. Astrid (School A) said she too thought the robot’s voice should be improved but “I actually don’t
think I would do so much better; I think it is because most of the time when I make a spelling mistake it is because I actually do not know how to spell the word”.

All the interviewed students thought it was easy and quick to learn how to use Spelling Bug. All students enjoyed working with Spelling Bug and they particularly liked collecting bugs as a reward for their spelling. While the students said they enjoyed the collection of bugs it was only half of the students who expressed the trading of bugs as the most enjoyable part of the system. In the observations we noticed that the other half of students seemed to enjoy collecting the bugs and they treated them as their pets who they would not trade but rather work more on their spelling so they could feed their collected bugs. The students said they liked collecting new bugs and they would have liked this part of the system to contain a larger variety of bugs to collect. The students said they were focused on their spelling while working they would speak with each other about the bugs they had collected but never really about how to spell words.

Perceptions of spelling ability
All interviewed students believed they had improved their spelling ability by using Spelling Bug. A few of the students said they had not improved their weekly spelling test results, but that they had improved their spelling in story writing. We asked the students why they thought they had improved their spelling ability. The students explained their improved spelling by referencing how the computer software showed how to spell the word, which prompts the student to re-write the word correctly. A girl said, “When I did not know how to spell a word I had to re-type the word and then it came up again, after a while I remembered how to spell the word correctly.” Two male students explained that Spelling Bug remembers when you do not know how to spell a word and keep on testing you until you do remember how to spell the word. One of the boys said “it made me have to think”. While most of the students believed Spelling Bug had a positive effect on their improvement for spelling, one of the girls said that she believed her improved spelling was due to not only Spelling Bug but also all the other spelling activities they did at school.
The students also spoke about how they had to use words they would not have tried to spell before and that once they knew these words they could use them in their writing. Albin said that he “learnt big words like distinguish, exercise and dehydrate”.

Weak spellers
Within the interviewed students, their teachers identified five of the students as spelling low achievers. These students all expressed their enjoyment of working with spelling and they thought they had improved their spelling ability since starting to work with Spelling Bug. Three of the low achievers talked about how much they enjoyed working with spelling when using Spelling Bug. Anna, one of the low achieving girls said that she “likes spelling” when working with Spelling Bug. The low achieving students continued explaining how they worked with Spelling Bug and they said that most of the time they just gave the spelling of a word “a go”, meaning they attempted the spelling to see how it went. The low achieving students found the use of the “Hint” button useful when they were struggling to know their spelling words. One girl explained how the “Hint” button gave her hints on how to spell the word by providing her a sentence the word would be used in.

5.5 Teacher Interviews

5.5.1 Pre-study interviews
Three teachers from School A and two teachers from School B were interviewed before they started using Spelling Bug with their students. The purpose of the interviews were to find out about teachers’ attitudes to using technology and what spelling activities they used in their teaching.

Spelling Activities
All involved teachers became sincere and serious when they spoke about their teaching of spelling. Teachers at School A already had a spelling program they were supposed to follow. In the program the teachers could find word lists the students should know after finishing each grade. The program
also contained suggestions on various classroom activities for training spelling e.g. “Look, cover and check”, “find-a-word”, and “crosswords”. School A had a policy of not using textbooks and the teachers at this school spoke about the effort of putting together good teaching material for their classes. Ms Svensson said that “in a text book someone has made sure all parts are covered but we have to make sure we don’t miss anything ourselves. It takes years to produce good material”. She said she spends many hours on planning for activities that will keep all students engaged. Ms Svensson continued, “I cheat somewhat as I often make photo copies from a text book that I really like. Oh well, I sometimes make a copy of the activities on the Smart Board and then the students can copy this into their books, but this is a bit slow.”

Ms Bengtsson said it was important to ensure the spelling activities suit all her students and their learning styles. Ms Bengtsson spoke about the importance of offering individual teaching for each student and their particular learning style, but then she concluded that this is an impossible task for her. She also said she constantly feels stressed for not being able to fulfil each individual student’s needs.

Existing Spelling Program
School A had a written spelling program consisting of information about what spelling rules and word lists should be taught for each year. The teachers at School A liked this as they said they knew what the students had been taught in their previous years. School B and School C did not have a written documentation for a Spelling Program and Ms Davidsson and Ms Fredriksson relied upon following the program of the spelling books they used in their classes. Ms Larsson said the teachers teaching the same grades met at the beginning of the year and decided what parts in the curriculum they were going to teach over each school term. Then it was up to each teacher to make up their own material and Ms Larsson used a combination of textbooks with writing books and teaching material she had collected over the years as a teacher’s aid.
Existing technology-use in the classroom

Ms Andersson and Ms Bengtsson said they like to use new technology in their teaching, but their enthusiasm for technology was tempered by practical concerns. “Of course it needs to fit in with what we are teaching. I cannot spend all my morning trying to make the Smart Board work when I have 30 kids waiting for me”, Ms Andersson said. Both the teachers used Smart Boards every day in their teaching for the most part with existing interactive “games” or for displaying word or excel spread sheets. The interactive games came with the Smart Board and the teachers used these as a full class activity for learning mathematics. One student would be invited up to the Smart Board to solve a mathematical problem while the rest of the class interact by helping the student at the front to solve the problem. Ms Bengtsson said that she likes to write up a word document and display it on the Smart Board when she is teaching. The problems she has written up on the document can be displayed from her computer and when students offer solutions, these are added to the document and the Smart Board will save the document with the solutions.

Ms Svensson who is working in the same classrooms as Ms Andersson and Ms Bengtsson expressed her insecurity with using technology. “I have no training in how to use the technology and it just takes too much time for me. I need to focus on my students and not try to figure out how to work the Smart Board.” (Ms Svensson, School A). Ms Davidsson at School B said that she did not know at all how to integrate technology in her teaching and that her students knew more about computers than she did. Ms Davidsson said she rarely used a computer at all and when she did use a computer it is to write the report cards that have to be word-processed. “I do not mind if the students use computers as long as I do not have to sort out any computer problems”, (Ms Davidsson, School B).

Ms Karlsson (School A) and Ms Fredriksson (School B) were both senior teachers who were curious about using technology in their classrooms but both of them said they felt insecure as they did not know what to do when the computers were not working. Both of these teachers talked about how they were not trained to see where they potentially could use technology in a beneficial way. Ms Larsson at School C had a very positive attitude to using technology. She said “it is great and I think there is a lot of potentials for the
future. You know, the students are so clever and they know exactly what to do straight away”, (Ms Larsson, School C). There was no Smart Board in Ms Larsson’s classroom but she used her laptop daily for emails, word-processing and searching on Internet.

Student progress and tests
All teachers gave their students a set (between 10 and 20) of words to focus on at the beginning of a new week. The students would work with these words as homework and sometimes the teacher planned for classroom activities using the weekly spelling words. At the end of the week the students were tested on their weekly spelling words. The teacher would read each word aloud and the students would then write down the word.

All teachers kept record of how well the students performed in their weekly spelling tests by recording the weekly spelling test results in a notebook. The spelling progress was not shared with new teachers, when the students graduated from the year. Ms Svensson said she did not think it was important to keep records of each weekly spelling test, as she felt she knew her students’ ability anyway. (Although she kept the records so she could show proof to parents if needed.) Ms Svensson said, “it is not important if they score 10 out of 12, it is about doing your homework”.

5.5.2 Post interview teachers
Post interviews were made with Ms Andersson, Ms Bengtsson and Ms Karlsson from School A and Ms Larsson from School C. Ms Svensson (School A), Ms Davidsson and Ms Fredriksson (School B) had moved to other schools and were not accessible for an interview. The post-deployment interviews aimed to find out if teachers had changes to their attitudes towards technology-use in education and their thoughts about using Spelling Bug with their students.

Integration of Spelling Bug
All teachers found Spelling Bug had been a positive activity in their classes. The teachers liked the simple interface and the reward system and they
believed the rewards made students keen on working with the software. Ms Larsson said classroom activities needed to be engaging and she found Spelling Bug had definitely engaged all and suited all of her students. Spelling Bug only required 10-15 minutes of each student’s time and the teachers said this made it easy to plan for how to fit Spelling Bug with the other classroom activities. The short time slots of working with Spelling Bug were seen as “good value” for the effort and time spent on the computer. The simple interface of Spelling Bug was considered excellent to keep the students focused on the task of spelling but they all agreed that the computer program would be improved with a higher quality voice, which pronounced the words selected to be spelled. All teachers said they would have liked to use the software two to three times per week with their students. Ms Andersson said that while she had only considered Spelling Bug as a research study from the start, she had then not thought much about how she could use the software. But now, Ms Andersson, Ms Bengtsson and Ms Karlsson said they discussed how they would definitely like to plan for using Spelling Bug as part of their English classes in the future.

Spelling Bug as a learning support
While no teacher believed Spelling Bug on its own had improved their students’ spelling they all agreed the software engaged their students and resulted in a stronger self-confidence. The teachers spoke about how the software helped the students to be more aware of their own spelling ability when the students could follow their spelling success. Ms Karlsson, one of the senior teachers thought Spelling Bug worked well as it helped improve the students’ ability to listen to a word. Ms Karlsson said she had observed how the students needed to pay attention to the sound they heard and think about how the sounds would be spelled in the word. The teacher continued talking about how she was particularly pleased with the combination of visuals, listening and physical typing. Ms Andersson and Ms Bengtsson also spoke about how the students had been discussing their collections of bugs but then the students had also discussed spelling of various words, which the teachers said indicated an improved awareness of spelling among their students.
Software to match the ongoing teaching
Ms Karlsson talked about not having enough working computers in her classroom, and that this was restricting her from computer-based activities. She could only plan for computer-based activities when she had her weekly booking of the school’s computer laboratory. She said “The one hour booking I have is not enough for all the activities I would like the students to do. If I had computers working in my classroom I could send students to work for 10 minutes and when there was spare time.”

Ms Bengtsson said that she had not found any software that suited her teaching and she was therefore wary of using computer software with her students. The same teacher expressed her surprise in the way Spelling Bug suited her teaching style and her planning of classes. Ms Bengtsson said, “I have not actually found any computer programs for training spelling that have worked with my students and my teaching. Spelling Bug matched our existing spelling goals and programs.” The interviewed teachers spoke about how they would like to use Spelling Bug with their students in the future. With the knowledge they had attained by the research study, they now felt they could plan and use the software for an optimal outcome of the software.

The teachers said that Spelling Bug had complemented their teaching well after they had been teaching, the students would work with Spelling Bug and the spelling activities would force the students to use their new teachings when working on their spelling. The teachers also found Spelling Bug provided an environment where the students could work independently from the teachers’ attention and this gave them much valued one-on-one time with individual students who needed extra support.

Verification and support for teachers
An experienced teacher normally is well aware of his/her students’ level of ability and the teachers did at first not find too many surprises in the results in the program’s teacher features. They said they felt the teacher feature verified their understanding of each student’s knowledge. When the teachers spent some more time exploring the information in the teacher feature, they found some surprises when realising that low achieving students actually had
achieved a lower rate of success than the teachers had assumed. Ms Bengtsson also found that while she had been teaching a particular spelling pattern, Spelling Bug clearly demonstrated that the students had not been able to adopt the rules she had been teaching. She said that most of the class had failed when being tested on these spelling patterns while she had believed the whole class had understood what she taught them.

It was suggested that having the option of printing the results so they could be shown to parents would be useful. The teachers also would prefer to have control over the word database so they could prioritise the weekly spelling words to appear when the students should learn them. By having insight into the word database the teachers felt they could better plan and make connections between the computer program and their teaching.

The idea of having a long-term documentation of a student’s progress from year two to year five was suggested useful for teachers. This way the teachers could gain a better insight into the student’s learning progress in spelling and new teachers would have a documented history to work with.

Software for all students
Teachers believed Spelling Bug would be suitable from grade two up to grade five or six but they also thought the database of words might need to be populated with an even larger set of words to cater for advanced students in later years in primary school.

From the teachers’ observations they concluded Spelling Bug had suited all of their students. Ms Bengtsson remarked “I would be concerned if my poor spellers were getting frustrated.” Other teachers confirmed the suitability of the software for all students with various spelling abilities. The teachers had been very pleased to find some of the weaker students actually working with their spelling, and not only working, but also enjoying and requesting to work with Spelling Bug. Ms Andersson told us how one of her students, August, had seemed to improve his social participation with his classmates when using Spelling Bug. August is diagnosed with autism and he can sometimes be disruptive to the class. August is not very good at socialising with the other students in his class and he is often seen wandering on his own in the schoolyard. Working with Spelling Bug suited August and he enjoyed working
with the software. The teacher was impressed with how August found a ground for socialising with his classmates by participating in the discussions around the bugs’ collection and the spelling of words.

5.6 Observations

This section presents my observations from the study for each school. School A used Spelling Bug over two terms (8+6 weeks) and therefore more data was collected from this school. School B and C used Spelling Bug over one school term (6 weeks). School C used Spelling Bug over one term (6 weeks) but the participating teacher had already experienced Spelling Bug while she did her classroom practice at School A during her teacher training.

5.6.1 Observations of Students

Observations were made when the students worked with Spelling Bug. Notes were taken during the user test and I wrote up a diary after each occasion. The observations of the students are presented for Phase 1 and Phase 2, each school, starting with observations from School A and B and then School A and C.

At all three schools I gave the students a short briefing on how to log on to Spelling Bug and on functionalities in the computer program. The students easily adapted to the new program and they were all working with spelling within 5 minutes of the introduction.

5.6.2 Phase 1: School A

Introduction to Spelling Bug

The teachers at School A had booked the computer laboratory, located next to the two classrooms of Ms Andersson, Ms Bengtsson and Ms Svensson. The teachers selected 10 students to work with Spelling Bug. I gave the students a brief introduction on how to log on and how to work with Spelling Bug. The students were keen to try this new spelling program and they gave very positive feedback during their first session. Several students came and asked “Can I please stay in at lunch break and work with Spelling Bug”.

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When it was time for a second group of students to work with Spelling Bug, the reputation of the software had spread among the students. The first group working with Spelling Bug had been telling their classmates about the spelling program. The new group arriving to the computer laboratory was larger than 10 students. Some extra students who slipped out of their classroom to have a go at the new spelling program had joined the group. The second group did not need much of introduction on how to work with Spelling Bug. Some of the students told me they had been talking to their peers who had already started working with Spelling Bug. The new students had already been told what they needed to do to start the software. The teachers did not need to show the reward system, “bugs’ world” as the students already knew about it. The students were cheerful and chatty when they started their sessions but within 5 minutes of arriving, all students were settled and intensively at work. I observed some giggles about funny pronunciations and over the flavours of the beans they were rewarded with.

-“Yeow, do the bugs really like booger flavoured jelly beans?” (Anna)
-“Yuk, sounds disgusting. I hope I get one next time. (giggles).” (Alma)

Working with Spelling Bug

In the second week of working with Spelling Bug, the students were quick to log in and they all started working independently. Some students were typing fast but struggled to receive their rewards. Aron complained that the words were too difficult to spell. I explained to the students that the computer was learning their spelling ability for a start and that if they persisted; it would soon feels easier to work with the software. The students were satisfied with this explanation and happily continued working, after only 5 minutes Aron told me that he was earning new bugs.

Astrid was an extremely good speller for the age group. The teacher told me that it was difficult to find suitable challenges for this student. Astrid was working very hard with Spelling Bug and later the teacher asked Astrid if she had found any challenges in the software. Astrid replied “Yes, once I had to spell ‘challenge’. I did not know how to spell challenge… I like this program Mrs Andersson.”
One of the girls, Anna had big difficulties with earning her rewards. Anna found it difficult to understand the recorded voice and when she understood which word to spell her spelling ability was not as good as required for success. Even though Anna kept working persistently for 20 minutes the system did not adjust well enough for her to feel successful. Anna asked me if she could come back and work with Spelling Bug the following week. Surprised I asked her why she was keen to come back. Anna said “I really like Spelling Bug and I want to earn my own bugs”. Anna continued working with Spelling Bug and at the next occasion she started earning rewards and she was very pleased with her progress.

Ms Andersson later told me how difficult it was to make Anna work with her spelling and that the teacher was very pleased to see Anna working so well with Spelling Bug.

Anders, a low performer, had problems understanding the robot’s voice and he was not successful with his spelling when working with Spelling Bug. When Anders asked for help with listening to the word he was supposed to spell, I asked him what he thought the word was and then I listened. I found that the student did not seem to recognise any of the phonetic sounds in the word and just took a wild guess at what word to write. I spoke to the teacher and asked if hearing could be a problem. The teacher later told me that because of me asking about Anders’ hearing, parents had organised a hearing test that resulted in discovering a bad ear infection in both ears, bad enough to cause very limited hearing. Afterwards the student had no problems with hearing the recorded voice. Anders continued struggling with his spelling attempts but when I observed him, it was clear that he knew which word was being pronounced. The teacher had identified Anders as being a “difficult” student to have in the classroom. The teacher said that he did not pay attention and listen very well. He was also not keen to work with his spelling activities. Anders was enthusiastic about working with Spelling Bug by the computer even though he struggled with poor spelling ability. Though the technology did not identify Anders’ hearing problems, the use of individualised technology helped the adult to identify possible causes to his problems with spelling.
Every week the students were showing how excited they were to work with Spelling Bug. The students were coming up to me as soon as they saw me in the corridor and they asked if they would be working with Spelling Bug today. I always replied that they can work with Spelling Bug any time their teacher allowed them to.

Trading system
After two weeks of working with Spelling Bug, the students were introduced to the trading of bugs. All students seemed interested in learning about the trading but they were not keen to test the trading yet. When I asked them, the students said they wanted to collect more bugs first. Slowly the students started trying to trade bugs with each other. I noticed that the students always started off by working with the spelling and after they had received a new bug they started looking for a partner to trade with. Only one or two students in each class would go straight to the trading part when they started up the software, often they found that no-one wanted to trade with them; they were already caught up in the spelling. Abel came and said “You know, this program is really great when you understand the voice. Not totally great when you don’t, but I like it anyway”.

Normally the whole group of students worked well and independently. The teachers only needed to help when there was a word that a student did not understand the recorded pronunciation for. Even the students who teachers said would not have a long attention span, managed to work through the same amount of spelling words as their classmates. The students would work through 12 rounds of spelling (equal to 72 words) in 10-15 minutes. The students received a reward in the form of a little creature after 6 rounds of successful spelling and most students stopped working after receiving two creatures. For the good spellers this took around 10 minutes and for the slower spellers it meant they worked for up to 15 minutes. To ensure all students in the class would have a chance to work with Spelling Bug, the teachers had decided to keep the spelling activity for each student to 10-15 minutes.
I noticed a lot of giggling between students when they were discussing the pronunciation of words. In spite of this, the interactions between the students did not seem to disturb other students and the discussions only occurred when one student needed help to understand the robot voice in Spelling Bug.

5.6.3 Phase 1: School B
Getting Started
Half of Ms Fredriksson’s class was invited to working with Spelling Bug on the first occasion. The students were quiet and did not appear enthusiastic about working with spelling. The students listened to a short briefing about how Spelling Bug worked and they quickly were all working with their spelling activities. The students found the interface easy to understand and they had no problems of getting started. Some of the students found it difficult to understand the recorded voice and Berit complained that it was difficult to know if the word was “for” or “four”. Bodil suggested it would be easier to get the word in a sentence. When the first group of students had finished their session of Spelling Bug they all seemed much happier and positive about the experience. After the first lesson, the teacher came and reported of how positive the students had been when they had told their classmates about working with Spelling Bug.

Persistence
The students at school B were weaker spellers compared to school A. The students struggled more with understanding the recorded voices in the software and therefore they had to work harder to receive the rewards. After the first session, students were now very happy and cheerful when they returned to work with Spelling Bug. The students were changing their attitude towards spelling; they said they love spelling now. Bertil joked with me, he said, “I seriously think your spelling Bug needs to consider his pronunciation” and then he giggled. The issue with the recorded voice remained and I found these students had to work very hard compared to the first test school. I noticed that for many students the system seemed to adjust to an appropriate level of spelling word difficulty but there were a few students who struggled
with spelling the words. I found that every time there was a new student who had not been working with Spelling Bug, they easily grasped how the software worked and that it only took five minutes until the student was working independently.

Beata had major troubles with understanding the recorded voice and she was complaining about how stupid Spelling Bug was. I offered the option to stop working and to do another spelling activity off the computer. Beata then promptly said “No, I want to continue.” In fact, it was very difficult to get this student to stop working with Spelling Bug; she ended up working for 30 minutes.

Another student, Bosse, was a fairly good speller but he kept talking aloud while he was working with Spelling Bug. Bosse complained about “how stupid this is. How am I to know which word it means? I’m sick of this”. Meanwhile the other boys in the group were working actively with the spelling tasks but Bosse kept complaining about the “stupid program”. I offered Bosse “Do you want to stop working with Spelling Bug?” Bosse looked surprised at me and bursts out “No, definitely not!” When I looked at the words Bosse was challenged with I could see the system had moved him up to a higher level and the words were getting harder to spell. The higher level of spelling was making it more challenging for Bosse and he encountered words that were new to him.

Independence
The students were working well and independently. They rarely asked their teacher for help with spelling. Every now and then, a student would ask the student next to them, to listen to the “robot” and tell them what word they believe they should be spelling. When Beda asked Beata to listen to her “robot”, the girls giggled and whispered between themselves and soon they had decided which word they though Beda should type. Beata asked if Beda needed help with the spelling but Beda said, “No I’m doing this myself”.

After the initial introduction to Spelling Bug all students were easily convinced to come into the library each week. They knew exactly how to start working with the software. The librarian teacher was browsing around the computers
watching what the students were working with, but the students rarely asked for any help with the spelling. With each week passing I noticed how the librarian was working further away from the computers while the students worked quietly by the computers.

Trading bugs
The students at School B were shown how to trade bugs after their first session of working with Spelling Bug. Although the students seemed to like the idea of being able to trade, they rarely used this part. Bertil was proudly showing me his collection of bugs and when I asked if he would like to trade he said “no, I like my bugs”. Bosse was keen to trade but there was no one who wanted to trade with him. After asking around all the others if they wanted to trade, Bodil finally agreed to trade with him but then the bell rang and computers were logged off. On the next occasion, Bosse seemed to have forgotten about the trading and he happily kept spelling and earning new bugs.

Technical constraints
School B’s computers were old and slow-running personal computers and there were many problems with them, causing them not to work. Each week only half of the computers were working when it was time to use Spelling Bug. The technical problems that occurred during the user study were most often broken screens, not enough primary memory and slow processors, which means that the students had to sit and wait for most of the dedicated 15 minutes they had for working on Spelling Bug. During the user study, the teachers became concerned when students had been upset about the poor-working computers in the library. The teachers made contact with the IT-responsible pre-service teacher and arranged for him to be present each week when Spelling Bug activities were scheduled. The pre-service teacher was also interested in the spelling activities and he decided to come along each week when the students worked with Spelling Bug. The pre-service teacher managed to have enough computers working each week so that all students could work for 10 minutes each week.
Changes to Spelling Bug after Phase 1

In phase 1 I had observed that some students had to work harder to receive rewards in Spelling Bug. When I looked closer at the words the students worked with, I noticed they were not successful in each round of spelling and this was one of the aims with Spelling Bug. When I tracked these particular students’ results in the computer log, I noticed that the Student-model version of Spelling Bug was not adapting to its users as quickly as the RBF-model was. The student-model algorithm for selection criteria was then adjusted to be comparable with the RBF-model.

A “Hint”-button was also added in the interface of Spelling Bug. Students had been frustrated by not knowing which spelling was intended for certain words, like “too”, “two”, or “to”. To help the students identify which word was intended, the “Hint” button would provide a sentence (leaving the spelling word out of the sentence) in which the word could be used. The explanations of the words originated from Cambridge online (http://dictionary.cambridge.org/dictionary/).

5.6.4 Phase 2: School A

Getting Started

For the second test round all students were given the same type of introduction to Spelling Bug as in the first test. The students were told about the feature of a “Hint” button. The teachers sent smaller groups of 6 students to the computer laboratory. Every week the teachers had planned for a set of spelling activities in which the students worked with in groups of six; each activity lasted for 20 minutes and Spelling Bug was one of these activities. None of the students had problems understanding how to get started working with Spelling Bug and they all worked without difficulties.

After one or two occasions of working with Spelling Bug, the students were familiarised to the robot voice and could understand which word was pronounced. Students who initially thought it was difficult to understand the robot voice used the ‘Hint’ button and found this useful as a complement for understanding which word they were to spell.
All students normally worked quite independently and it took them around 10 minutes to finish six rounds of spelling words. As the students were getting used to Spelling Bug the trading part was becoming a more attractive part of the game. A few students would start the Spelling Bug session by trying to convince friends to trade bugs. But most students would forget about the trading as soon as they had logged on to Spelling Bug and they would be immersed in spelling words. Once the students had finished their first round of spelling and they had received a new bug, a few of the boys were negotiating trading. The rest of the group would wait until the end of the session. At the beginning of one session Anton asked Albin if he wanted to trade bugs, but Albin turned down the offer. I later asked Albin why he did not want to trade bugs with Anton and he said he wanted to earn some new bugs so he knew what would be the best trade at the end of the session.

Collaboration
When observing the students working I noticed how they rarely asked each other how to spell a word. The students spoke about what flavours they received on the beans and what bugs they had collected. The students also discussed and helped each other listening to the recorded voice if one of them was unsure which word was intended. The students normally attempted spelling words even if they were unsure on how to spell. Only a few students asked their teacher to help them with spelling and the teachers normally told the students to just have a go at the word. This routine of “just having a go” was well accepted by the students and I overheard two girls talking.
-“Miss, how do I spell ... ?, Agata asked me.
-“Don’t ask her. Just give it a go, you know”, Alma quickly replied.
Agata looked surprised at Alma but then she turned to her computer and typed in the word. Agata said the word aloud to herself and then she tried spelling the word, and she was successful.

I heard two boys sitting chatting while they worked with their spelling. The boys discussed and commented on the flavours they got on the beans. There was a lot of giggling going on. In between commenting on flavours I heard the boys saying spelling words aloud or they read the hints out loud. This seemed
to be a way of getting the other students involved in discussing which word
the system would like them to spell.

One morning I found Albin working on Anders computer. I asked Anders if he
needed help with his spelling but Anders said, "No I need to get some more
bugs so I can trade with Albin". Albin finished six rounds of spelling for Anders
so he was awarded with a new bug. Before Albin finished his work, he quickly
traded the bug he wanted from Anders. Anders who had looked very pleased
with the help he got, changed his face expression and then told Albin that he
would not need his help anymore. Anders who was a weak speller and who
worked quite slowly through his spelling words, saw the opportunity of earning
some extra bugs by asking one of his friends to work through a few rounds for
him. This illustrate that students are smart and will always find a way to
improve their results (in this case achieving more rewards). This can
adversely influence algorithms such as the student-model, to choose words
for Anders that are unsuitable. It is important for system designers to note that
students are creative and will use existing technology in ways which can be
difficult to anticipate.

Girls and Boys
Both boys and girls were involved in the study of Spelling Bug. The girls were
all very quick at getting to work with Spelling Bug. The girls quietly walked
over to the computers and when they were working they rarely needed any
help from teachers. The boys would be running to the computers when they
were allowed to work with Spelling Bug. Often I found that the boys were
negotiating trading bugs as they walked up to the computers but once they
got working on the first round of spelling they forgot about the trading and
instead focused on gaining new rewards. The girls on the other hand, were
focused on spelling and receiving new bugs. I was surprised to find it was the
girls who first tried trading bugs with each other. As soon as the boys saw
what the girls were doing they quickly tried the trading too.
Engagement
All students showed great enthusiasm for working with Spelling Bug. The students were always cheerful and happy to work with Spelling Bug and there was never anyone who preferred to do other spelling activities. The teachers did ask the students if they wanted to work with Spelling Bug but they said none of the students would ever miss their opportunity on the computer.

I noticed one boy, Assar, only attempted to spell four words out of six words. I asked him what he was doing and he told me “you only need to spell four words correctly to gain a reward” Assar continued explaining that there was no need to attempt spelling the remaining two words if you already had succeeded in spelling the first four words. I continued observing the boy and noticed that he did not follow his own advice; he started spelling all six words even if he got the first four words correct. I then asked him about the change of mind and Assar then told me that he might as well give the two last words a go since it was actually quite fun to see if he could spell them correctly. Assar said he enjoyed feeling successful.

“I hate re-typing the words” Alma suddenly called out. Alma was working by the computer and she appeared frustrated. I asked if she would like a break from Spelling Bug but Alma looked surprised at me and said, “no, I’m not done yet”. Alma continued working with her spelling for the rest of her 10 minutes session. Later during the interview, I reminded Alma about her not enjoying re-typing words. Alma then said she thought it was a good way of remembering how to spell the words correctly.

Coping with challenges
When the computer system moved the students up to a higher lever I noticed how the students seemed to slow down their working tempo. The words were getting more advanced and I noticed that many of the students changed their strategies on how they worked with Spelling Bug. At the beginning of the user study when all words were fairly easy to spell, the students just typed in the pronounced word and then checked their spelling by pressing the ‘Check’ buttons after each word. As the level of difficulties was getting higher the
students listened through all pronounced words first, then attempted to type
the words and last they read through their list of words, made corrections if
needed, before pressing the ‘check’ buttons.
Ms Karlsson took notice of one particular boy, Albin. She said that Albin had
been struggling with his spelling, but now he was improving his rate of
success. Albin worked intensely with Spelling Bug and he took great pleasure
in receiving rewards by the system. On one occasion at the end of the user
test Albin told me he now has to spell very difficult words. When I looked at
the screen he had been given words such as ‘arithmetic, scent and
imperishable’. Albin is proudly showing his teacher the words he was working
on and he persisted very well even though the words were now more
advanced. The working pace was slower compared to when he started
working with Spelling Bug. I observed, Albin typed in the words he knew first,
then he attempted the words he was unsure of how to spell. Before Albin
checked his spelling, he read through the words out loud to himself, listened
to the sounds in the words and then he corrected some of his spelling. The
computer system seems to adapt well as I noticed that Albin was still usually
successful with four words out of six.

Spelling Bug for individual students
Anna found it difficult to understand the recorded voice for a start. Anna was
identified by the teacher as one of the “low performers” in spelling. After one
of the occasions with Spelling Bug, Anna asked if she would be allowed to
stay for a bit longer. Ms Andersson was very pleased to see Anna working so
intensely with spelling and encouraged Anna for her persistence. Anna ended
up working with Spelling Bug for 40 minutes in total, after 20 minutes she had
no more problems with understanding the recorded voice and she told her
teacher she felt quite successful with her game.

Anton who was diagnosed with a severe ear infection during Phase 1
continued to use Spelling Bug in the second phase. Ms Andersson described
Anton as a student who never listens and who is a constant chatterbox in the
classroom. Anton was still failing his spelling attempts but at least he knew
which word was being pronounced. Ms Andersson demonstrated how to work
with the “Hint” button and Anton seemed to find this useful, he started using the button all the time to confirm which word was intended. Ms Andersson told me stories of how Anton always tried to make excuses for skipping his spelling activities. When Spelling Bug was on the agenda Anton had started behaving very differently; he behaved well so the teacher would notice him and allow him to be in the first group to work with Spelling Bug. Anton was often allowed to work longer than other students (20 – 30 minutes rather than 15 minutes) with Spelling Bug as he was a slower worker compared to other students. Even though spelling was difficult for him, Anton persisted and he would often ask if he could stay longer or have a second session.

Abel was a low achieving student who had great difficulties with all of his subjects. Abel was constantly taken out of his ordinary classes to go to the special needs teacher. Abel was apprehensive about Spelling Bug and he seemed to have given up on Spelling Bug before he had tried the software. I did not want to force any of the students to try Spelling Bug so instead I invited Abel to come and watch the other students when they were working. Soon Abel was keen to have a look at the game but he seemed doubtful about his own success with the game. When Abel walked into the computer laboratory he had a grumpy, clouded look on his face. After only 5 minutes, Abel wanted to try Spelling Bug. The boy persisted through the first couple of spelling rounds, even though he was not very successful in gaining rewards. Ms Bengtsson who had been watching Abel showed him how to use the ‘Hint’ button. Abel continued working and with the help of the ‘hint’ button he started gaining jellybeans. The rewards encouraged Abel and he kept persisting without giving up. Both Abel and Ms Bengtsson expressed how very pleased they were with this progress. On the next occasion Abel arrived back to Spelling Bug with a more confident attitude. He was still struggling with his spelling but he was focused and concentrated. The rewards kept Abel working without giving up. The teacher had expressed concerns about Abel’s ability to work with Spelling Bug. She said that Abel was likely to “give up” before he even had tried an activity. He had become used to never being successful and he lacked self-confidence in relation to his learning. The teacher told me
that Spelling Bug was a task that he stayed with longer than any other task he was asked to complete.

Later in the test period I found Abel begging his teacher to be allowed to work with Spelling Bug. He told Ms Bengtsson that “Spelling Bug is soo much fun.”

Anton had heard about Spelling Bug from his friends. When Anton tried Spelling Bug the first time, he had a serious and determined expression on his face. Anton first attempted spelling the pronounced words on the computer and then checked his spelling. Before continuing Anton wrote down each word he had been given to spell in a writing book. I asked why he wrote down all the words in his writing book and he replied that this would teach him to spell the words correctly next time, because he wanted to win new bugs. After a little while I noticed Anton working intensely with Spelling Bug and that he had abandoned his writing book. Ms Karlsson told me how pleased she was to see Anton working so well, “Spelling Bug really suits Anton and he’s more confident when we work in class” (Ms Karlsson, School A).

English as second language and disabilities

One boy, Hassan had English as second language (ESL). Hassan struggled in the beginning to understand the recorded voice. Hassan stopped working with Spelling Bug after the first screen and he would then sit and look at his peers’ screens instead to see what was going on. Hassan tried to talk with the other students in his group but they were not interested in paying him attention as they enjoy working with Spelling Bug themselves. Ms Karlsson noticed Hassan and she sat down with him. Ms Karlsson explained how to use the “Hint” button and after two minutes Hassan was happily and successfully working with Spelling Bug.

In the second test round there was one student, August who was diagnosed as autistic. August was very good at English so the teacher did not think that Spelling Bug would be for August. August came into the computer laboratory during the morning tea break and he approached me and started asking what Spelling Bug was. I showed August what the students did with Spelling Bug, August asked if he could have a play with Spelling Bug. I explained that this
was fine by me but he had to ask his teacher for permission. August started his first session and was soon working well with the spelling program. August told his teacher and I how much he enjoyed the game. August was successful and quickly moved up a level to more advanced spelling but this did not seem to concern him. At the second session with Spelling Bug, August discovered how the other students were trading bugs. August asked the boy sitting next to him if he wanted to trade bugs. After the class Ms Andersson said “August was working and interacting just like any other student now, he normally just sits by himself and does not like interruptions.”

Technical constraints
Some difficulties occurred at the start up, for instance there were problems with screen resolutions. The school’s computer system was set up with the Managed Operating Environment (MOE) system. This means that student accounts were use-restricted by the state education government. When changes to the interface were required, it was difficult to amend the setup so we could make necessary changes. School A had hired an external IT professional but this person was not trained on the MOE system and he would only visit the school once a week. (This did not include the days when we used Spelling Bug.) Also, not all computers recognised the USB headphones we used when working with Spelling Bug. The teachers did not know how to resolve technical issues and for them the only option when issues occurred, was to cancel the computerised activity until next week when IT staff had visited and resolved the issue. To keep the lessons running I, rather than staff or students, resolved the technical issues we had when working with Spelling Bug.

5.6.5 Phase 2: School C
Ms Larsson had decided to use the existing computers in her classroom for the Spelling Bug activity during one of the weekly English classes. Normally the students were working on a variety of spelling activities and the teacher expected the students to be working quietly and individually. At the beginning of each class Ms Larsson called out five names and these students would
proceed to work with Spelling Bug for 10 minutes. When they had finished with Spelling Bug, the students reported to Ms Larsson and she would call out the names of the next group to work with Spelling Bug. This procedure was repeated until the one-hour class was finished.

Engagement and collaboration
As with the other participating schools the students were quick to adopt how to work with Spelling Bug. All the students were positive to working with Spelling Bug. “I like to do work on the computer”, Cecilia said when she arrived to one of her sessions. I asked her why and she continued, “I think I concentrate more when I’m on the computer because I really want to earn more jelly beans and bugs”.

When I arrived at the school for the second week of user testing, Ms Larsson told me the students had given her very positive feedback after using Spelling Bug. She therefore wanted her weaker students to use Spelling Bug a few times per week. Two girls, Carin and Cajsa had volunteered to demonstrate to other students how to use Spelling Bug, and now all students in the class knew how to work with Spelling Bug. Carl was spurring on Casper to keep working with Spelling Bug so he could build up his bugs’ world.

The students at School C were not particularly interested in the trading of bugs. Though the students kept working individually, they were having discussions between them while spelling. The students discussed and compared their collections of bugs. Mostly they spoke about what jelly bean flavours they had been given. “I think booger flavour is quite interesting”, Cornelius said to Christer.

On some occasions students did not know which word they were supposed to spell.
-“Miss, which ‘to’ am I supposed to spell?”, Clara asked me.
-“Have you looked at the “Hint” button?”, Cecilia said.
-“No. Oh, now I know it’s too”, Clara replied.
Technical constraints
At School C the computers in the classroom were working well. On the first session with Spelling Bug, the sound would not work when the students plugged in their headphones. One driver was missing and Ms Larsson emailed the school’s IT-resource. The next week everything was running smoothly and the students did not experience any problems with the computers.

5.6.6 Observations of teachers

School A
Teacher feature
One of the main aims in the second test round was to get the teachers to start using the teacher’s section of Spelling Bug. As soon as I introduced Spelling Bug in the school, teachers were told about the teacher section and that they could ask for help and an introduction when it suited them. Every third week of the test period, the teachers were reminded about the teacher section and that they could start using it. The teachers all responded positively to the existence of a teacher’s section but they said they did not “have time right now” to learn about the feature. Only at the end of the year when the teachers were writing report cards, I received an answer saying, “yes, I would love to learn about the teacher’s section. Will it take very long?” Still the teachers decided they did not have time to look at the teacher feature at that moment and said they would look at it at another time.

At the very end of the school year, Ms Andersson and Ms Bengtsson came looking for me when I was visiting the school on another errand. They asked if I perhaps had time to help them log on to the teacher’s section. Ms Bengtsson said that they were writing report cards and thought they should have a look at the results from Spelling Bug. As I agreed to show them the feature, Ms Andersson called Ms Karlsson and she joined us too. Looking at the teacher’s features, the teachers were pleased to find that overall their students had performed to the level they had anticipated. Ms Andersson said, “yes, just as I thought”, “This is just confirming what I’ve been telling the parents. Can I print out the results to show the parents?” The teachers continued studying the
results as they discovered how they could look at various spelling patterns to see how the students had performed. Ms Bengtsson was taken by surprise when she called out “oh my, and I thought the students had understood what I was talking about … but obviously here it shows they did not … I really need to think through how I teach this spelling rule”. Ms Karlsson said she found the teacher’s section fascinating as she would never have thought this feature could be of much use for her. The three teachers got into conversations about individual students’ results and how they could possibly plan to use Spelling Bug next year.

Technology as a support for individualised learning
The teachers all seemed positive to letting their students work with Spelling Bug but they also seemed to think that this was one way of having some students out of the way for a while so the teachers were given time to work with other individual students. Ms Andersson told me how good it was that she could focus on helping some of her students that had fallen behind with their schoolwork when other students used Spelling Bug. At first all teachers seemed to send their average spellers to work with Spelling Bug. When the teachers had feedback from this group of students, the teachers sent those students who were considered to be struggling with spelling to work with Spelling Bug.

Teacher attitudes to technology
After around two months (which is equal to a full school term in Australia) of working with Spelling Bug I noticed how the teachers started paying more attention to what the students were doing when they were sitting at the computer. Ms Karlsson started to peek over the shoulder of her students while walking around in the computer laboratory. Next the teacher leant forward and asked the students to explain what the different things on the screen meant. On another occasion I found Ms Karlsson sitting down and collaborating with a student, and afterwards the teacher came up and happily said “this is great”. Ms Karlsson then started asking more detailed questions on how the software was working and what word database was being used. Ms Andersson and Ms Bengtsson were not spending much time with the students in the computer
laboratory but preferred to use the time in the classroom with the smaller group of students. While they did not participate actively in the use of Spelling Bug they started visiting the computer laboratory to see their students at the end of each session. Both the teachers started talking about how they could see that their students were enjoying their work with Spelling Bug. Ms Bengtsson noted how two of her poor-spelling students were happy to work with Spelling Bug even though she could not get them to do any of the pen and paper spelling activities in the classroom. Ms Bengtsson was pleased that the students were at least doing some training of their spelling. Ms Svensson told me in the pre-deployment interviews that she was not feeling comfortable using computers. She expressed how upset she was that the principal was forcing the teachers to use computers and Smart boards in their classes. During the user testing of Spelling Bug, Ms Svensson seemed to relax as she noticed the students could use Spelling Bug without her interaction. She also commented on how Spelling Bug was good for some of her weaker spellers, as they seemed to enjoy working with Spelling Bug. She asked questions about how Spelling Bug was working and if she could put in her own word lists in the database.

School B
When I visited the school each week, the teachers were eager to update me on the fact that the students were very keen on working with Spelling Bug. Although the teachers never accompanied their students to the library when it was time to work with Spelling Bug. Both Ms Davidsson and Ms Fredriksson stayed in their classrooms and let the librarian look after their students while they worked on the computers. The two teachers seemed to think only of Spelling Bug as beneficial for the students’ learning and not necessarily for the benefit of their own teaching. While Ms Davidsson was always polite and keen to send her students to work with Spelling Bug, she rarely expressed any questions or interest in how Spelling Bug worked. For a start, Ms Fredriksson also took a moderate interest in Spelling Bug. Later during the term she started to show more interest. By the end of the term Ms Fredriksson was asking me to visit her classroom to discuss opportunities with computer based educational activities. She asked me for advice on the use of
technology for her existing teaching commitments in mathematics, as well as for her weaker students. Ms Fredriksson discussed the problems of not having modern and well-working computers, and that how she felt it is difficult to introduce new technology when you do not have support from colleagues and principal.

When I instigated a discussion about the teacher’s section of the software, the teachers mentioned how good it would be with a system that could serve them as well as the students. The teachers in School B had been told there was a feature for the teachers in Spelling Bug and this was repeated to them. I asked if Ms Davidsson and Ms Fredriksson would like to see the teacher’s section in Spelling Bug. The teachers’ reply was “that would be good but can we wait until later in the year when we are not so stressed with other things”, (Ms Fredriksson, School B). The study was cancelled at School B so the teachers never got to see and comment on this feature.

School C
Ms Larsson was already enthusiastic about using Spelling Bug before I came to her school. Ms Larsson had seen students at School A using Spelling Bug and she knew that this supported a spelling activity the students enjoyed.

While the students in Ms Larsson’s class were working with various activities during the English lesson, she expected the students to work quietly without disturbing other students. The teacher positioned herself at the front of the classroom for the lessons and students were encouraged to come and seek help from her when they did not know how to solve a problem. During the first weeks of using Spelling Bug, Ms Larsson stayed busy helping her students but after three weeks, she located herself closer to the computer corner where the students were working with Spelling Bug. After the lesson, Ms Larsson said she had been “keeping an eye” on the activities the students’ activity on the computers. She told me how much her students enjoyed working with Spelling Bug. The following week she stayed close to the computer corner and after the lesson she approached me and asked me questions and requested more details about how Spelling Bug was working. I offered to show the teacher’s section of the software and she thanked but declined referring to time constraints.
After week four’s lesson, Ms Larsson told me she had offered her weaker spelling students to work with Spelling Bug. She had been positively surprised as it was easy for the students to start it up by themselves. One of her students had shown her how the software was working. Ms Larsson now expressed how pleased she was with participating in the study but she again declined looking at the teacher’s section.

5.6.7 Summary
In this I have presented the findings from two iterations, phase 1 and phase 2 of user testing of Spelling Bug. Data was collected from a computer log, pre- and post hand written spelling tests, pre- and post interviews with participating students and teachers. During the full study I also participated in the classroom environments and made observations that I kept recorded in a diary.
6 Analysis

“Number one for me is that a program needs to engage the students. Before we even talk about what Spelling Bug has taught them we need to ensure it engages them. Spelling Bug absolutely fulfils this criteria.” (Miss Larsson, School C)

In this chapter I first discuss quantitative observations relating to the hypothesis posed in relation to the two different techniques used to select spelling exercises, and more broadly if there were trends in the quantitative data that pointed to explanations of varying success rates. There were other qualitative factors impacting on how the computerised individualised learning to be beneficial for the classroom learning and teaching. When analysing the data that have been collected in this research study, eight themes stand out of from the results and these should be considered important factors when designing Learner-Adaptive Systems. Below follows a presentation of the themes and how these relate to already existing research.

6.1 Learner adaptation and explaining success rates

A significant number of student progressed through spelling exercises and half of them used evolution of educational content and half of them used a student model. The collected data tracing the progress of students did not show any significant difference to support the choice of which selective algorithm to use for individualised computerised learning. Anecdotally, there were no indications during the tests that students or teachers noticed any difference between the choices made by the two techniques. The story about Anders and his attempt to gain more rewards by letting his friend do a few rounds of spelling for him shows how students are always creative in their use of technology. The impact of having another student working with Spelling Bug could be difficult if Anders was working with a student-model as the student-model would take longer to recover than the RBF-model. If any choice had to be made, I advocate the simpler, and easier to understand evolution of educational content.
I divided the data into groups including gender and school. I triangulated the number of spelling activities done with Spelling Bug and the results from pre- and post-deployment spelling tests. This triangulation showed that the number of Spelling Bug activities correlated with higher accuracy at the post-deployment spelling test. It is worth noting that it is difficult to measure students' progress with a system that uses learner-adoption.

6.2 Teachers' confidence in using technology

In the pre-test interviews most teachers spoke of how they felt comfortable to use technology for word processing and making simple spread sheets. They also said they had not had any formal training in the use of technology but they have learned how to word-process to suit their own professional needs. The teachers can be split up in two categories, those who felt they were able to use existing technologies in their professional capacity and those who felt it was overwhelming to learn how to use new technologies.

The first category of teachers did not pretend to be experts in the use of teaching technologies but they said they felt comfortable to try to use technology. They were talking about how they believed technology could be used in the classrooms. During the interviews it became evident that the teachers knew little of what exist on the market and in research for learning and teaching. Teachers used the equipment that the school had provided them.

Teachers are using laptops for documentation, planning and displaying material on the Smart Board. The school's computer laboratory is used for students to word process and to do research on the Internet. Sometimes the students are allowed to play online games, or an educational game the school had bought. The teachers largely see the educational games as a reward for good behaviour or for keeping the students busy until all students have finished an activity. None of the teachers used existing software as a part of teaching and learning programs, which is what Becta (2008) also found.
The second group of teachers spoke about how they felt insecure and uneducated to use any kind of technology in their teaching. Both Ms Karlsson and Ms Svensson said they had to ask their students to instruct them how to use existing technologies in the classroom. Two teachers said they let their students have a play with the existing technologies and then they asked the children to show them how to use it. The second group of teachers expressed a frustration of feeling they were being asked to work to incorporate technology into teaching but they were only trained on how to use the hardware once. Teachers need support to learn how they can use technology for teaching and learning so they can fully integrate it in their curriculum (Norris, Sullivan and Poirot, 2003).

All but one teacher, Ms Davidsson showed a change in her attitude to using technology as a tool for teaching and learning. Ms Davidsson was happy to let her students participate in the research study but she did not show any curiosity for Spelling Bug. All the other teachers showed an interest in Spelling Bug once they saw their students’ enthusiasm for the software. The teachers would ask me questions on how Spelling Bug worked and they started participating in the sessions with Spelling Bug. While Ms Davidsson voluntarily reported the satisfaction of her students work with Spelling Bug, she never attempted to learn more about the software or to attend one of the student sessions. Ms Davidsson worked at School B and was therefore only part of the study over one term of school. Judging from the other participating teachers, it was from about mid-way through to the end of the first term or beginning of the second term that they started to take an active interest in using Spelling Bug.

Scrimshaw (2004) suggested teachers’ insecurity for using technology in their teaching might be based on lack of professional development and technical support, which is supported by the findings from this thesis. While the teachers did not express the need for more technical support, I observed the lack of day-to-day support when computers were not working. On occasions when computers were not working, the teachers had to cancel planned activities until the IT-staff could attend the problems.
In this study, I noticed how I became a mentor for the teachers I worked with. Mentors and parents who support teachers have been found to be important for supporting pre-service teachers to use technology in their teaching (Bullock, 2004). I suggest it is important for in-service teachers to have the opportunity of observing practices of how to integrate technology. The use of mentors in schools challenges teachers to reflect upon their own practices (Kagan, 1992) and provides successful changes to teachers’ beliefs (Rogers, 1995) for new teaching practices to develop. At first, the teachers took a passive role in the use of Spelling Bug. They demonstrated acceptance by volunteering to participate in the study but they seemed confused to how it would work. When they discovered how motivated and engaged the students were, the teachers took a more active interest in the computer system. They approached students and myself to ask questions about the system. Once the teachers became more confident about how the system was working, they started to take control of and lead the computer laboratory sessions. This indicates that time is also of essence for a successful integration of technology in classrooms.

6.3 Time poor and dedicated teachers

All teachers were all highly dedicated to their teaching and they spent many hours on preparations of materials. The preparations are time consuming and leave little time for documenting student progress. One of the teachers spoke about how it is impossible to for her to keep records of every week’s progress for each student. The teacher said, “I check the weekly spelling each week and I get a feeling for how successful each student is.” (Mrs Andersson, School A)

If technology is considered to be too difficult to learn and use, it is not likely the teachers will not make the effort to find out how they can use the technology for their own benefits (Teo, 2009). As technology is becoming more pervasive (and accepted) in education, schools tend to cut down on written materials and promoting use of online material. The teachers who had not found a way to work with the technology therefore felt stressed as they felt
the need to produce their own teaching material. All but two classrooms had smart boards fitted on the walls. Not all teachers use the smart boards and they tell about how they are so busy preparing teaching material they do not have time to learn new technologies. “…our school do not use text books so I have to make up all my material. Look, I’ve got posters for all other areas but where are my spelling posters?” one teacher says.” (Ms Svensson, School A)

Again, we see examples of how hardware is introduced into schools but there is no training in how to use the technology, in an integrated fashion with teaching practices and curriculum. The risk of stressing teachers can cause a negative attitude to technology and the teachers will not adopt technology in the classroom (Mumtaz, 2000).

6.4 Student engagement triggers teachers’ engagement
The key to successful use of technology in education is the teacher (Zhao, Hueyshan & Mishra, 2001), Spelling Bug was well accepted by students and when the teachers observed their students’ enthusiasm this triggered the teachers’ engagement. All teachers had volunteered to try the software in their classes but when we started working with the students, the teachers left the researcher with an extra teacher aid to support the students. When the teachers were asked what their thoughts on Spelling Bug were, they replied that their students loved working with Spelling Bug and it gave them time to work with students who needed individual support. It appeared the teachers were happy to have an activity to keep their students busy but they did not actively participate in learning Spelling Bug or to even supervise their students while they worked on the computer. After a couple of weeks, I noticed a change with most teachers, they became more interested in Spelling Bug and they started asking questions about the activities the students had worked with. One comment was “I’ve worked so hard to get this student to do his spelling and it’s been pretty much impossible but now he asks if he can work on Spelling Bug.” (Ms Bengtsson, School A) The students’ enthusiasm and engagement created a curiosity among the teachers and they subsequently left the teacher aid with the students who were not working with Spelling Bug. At first the teachers walked around the computers and watched from behind
what the students were doing and soon they sat down with students and started asking them what they were doing. The teachers were now excited about how all their students wanted to work with spelling and they expressed their admiration for a computer program that worked so well in the classroom setting and still kept the students engaged.

The teachers need to see how the software will function in their classroom with all their students before they make the effort of engaging with the technology. Acceptability (Grudin, 1988) is the key to use of technology and once there is evidence of how well the technology engages the learning activities, the teachers are prepared to engage and learn the software. This study can confirm that generalisation.

The positive engagement within this study appeared to cultivate overall engagement. It was clear that the students’ enthusiasm triggered the teachers’ interest but students were also encouraged when the teachers gave them positive feedback for having worked with their spelling. This phenomenon cuts both ways: student to teacher, teacher to student

6.5 Support for teaching

When I first introduced Spelling Bug to the teachers, I told them about the feature for teachers. I showed the feature to the teachers but as none of their students had yet done any work, there was no data to view. After the students had been working a few times with Spelling Bug, I started reminding the teachers about the statistics they could retrieve but though the teachers said they were interested in seeing the data, they did not have time at the occasion and asked to do the viewing later. We had given the teachers all instructions on how to retrieve the data on their own but none of the teachers attempted to log on to the system. At the end of the year, one teacher asked if I could help her to log on to Spelling Bug to view the statistics. When we came into the teacher’s classroom, she had gathered the two other teachers who had tried Spelling Bug. The teachers explained to us that they were writing the report cards and it had dawned on them that perhaps it could be useful to see the Spelling Bug statistics. They were quite excited to see the statistics from the computer log, and thought it was interesting to see how much data had been
collected. They all agreed the data was providing them with evidence of how each student was performing. “Ah, now I can finally show the parents what I have been trying to tell them” (Ms Bengtsson), was one comment. Another teacher became surprised when she discovered how poorly her whole class had done on a particular spelling rule that she had been teaching. The teachers said, “I thought the students had understood what I was talking about but this shows almost none of the students understood I need to re-think how I explain this rule.” (Ms Larsson, School C)

When we interviewed the teachers after the test period, the teachers started talking about how useful the teacher part was as a tool for them. The teachers were now highly engaged in discussing how Spelling Bug can be an integrated part of their school’s existing spelling program. They had a few suggestions on the interface design to make it easier for reading the statistics and they also wanted some of the features to be visible for the students. “I showed my students their statistics and I think it is great if the students can get that immediate feedback on how they are progressing. Then they know if they need to go back to the books to learn a particular spelling rule or they can come and ask me. Also, I think it’s rewarding to see a positive learning curve, it triggers the students to want to do more.” (Ms Karlsson)

The teachers, who initially showed a low confidence level around using technology, were now enthusiastically suggesting how learning and teaching technology should be designed. The teachers spoke about how they would have liked to have a teacher access to the word database used for Spelling Bug. The teachers would also prefer to have an option of highlighting weekly spelling words so that their students will work on these when they use Spelling Bug. During the discussion about improvements and future use of Spelling Bug, the teachers did not seem concerned about their own knowledge or restrictions about how to manage the technology anymore. Instead the teachers showed a confidence in how educational technology could support them in their teaching. In fact, Ms Andersson, got excited when she spoke about the potential of collecting data on students’ progress over a longer period and she spoke about how this was important information for the teachers when they take over new students. The results’ showing the positive
change of thinking around educational technology is similar to findings from Scardamalia, Bereiter and Lamon, 1994). Teachers who had used CSILE technology expressed how they used to believe they had to fit the technology into their teaching but they had discovered the technology should support their existing teaching.

While visualisation provides a quick overview of progress, my impression is that teachers wish to generate more detailed, written reports. Teachers also expressed that greater control over what activities that are presented could help demonstrate fulfilment of curriculum requirement. This is in stark contrast to the current trends in learner adaptation technologies, which promote more flexibility to allow individuals to drive their own learning.

6.6 Seamless fit with existing teaching
The context, in which technology is placed, has a great impact on how the technology will be used. Dourish (2003) uses the term “appropriation” which refers to how people will make use of interactive technologies. In the study of Spelling Bug the teachers expressed their appreciation of a simple interface with very little distractions from their actual tasks. They said that the 10-15 minutes of work by the computer made it very easy to plan the teaching around. The short start period meant students could move easily between various spelling activities without missing important teaching time. “I have not found any software that complements my teaching and is worth the cost to invest for a whole class” (Ms Fredriksson, School B).

The combination of working with visuals, listening and physical typing of the words attracted the teachers and they were pleased that Spelling Bug had suited all their students and their various learning styles.

“Spelling Bug matched our existing spelling goals and programs……..we would like to plan for using Spelling Bug with our students next year.” (Ms Bengtsson & Ms Andersson, School A)

The seamless fit of technology, informed the design to suit the primary school classroom. Teachers found Spelling Bug was easily adopted into existing teaching and it was technology that gave them add-on value to complement their teaching.
Developers and designers are not teachers. Teachers are not developers and designers, and generally do not appreciate the potential of using technology. It is therefore important that developers and designers engage with teachers and their context. My experience from developing Spelling Bug with teachers supports this observation.

6.7 Students engagement
The teachers were slow to become engaged with Spelling Bug until they saw that the software was a success with their students. The students responded much faster to Spelling Bug and they demonstrated their engagement after just one session of working with the software with cheerful comments of how much fun they had had.

The teachers had invited the students to try Spelling Bug and once a first group had tried Spelling Bug the other students heard from the first group about the software. We noticed how the rumours of Spelling Bug had started spreading as new students from classes in the corridor started sneaking into the sessions of Spelling Bug even though they were due elsewhere. All students expressed positive feedback on working with Spelling Bug. Common feedback was “I really liked it” and “Spelling Bug was learning and fun”.

One of the girls talked about how she found spelling difficult to concentrate on as she thinks it boring. “But when I was on the computer I tried to concentrate because I actually thought it was quite fun.” (Anna, School A)

Carl had told his teacher, “I normally hate working with spelling but this program is not bad at all.” (Carl, School C)

We observed the same phenomena with other weak spellers. One boy expressed a strong dislike to spelling and he was one of the last students to try Spelling Bug. While we normally allowed 15 minutes for working with Spelling Bug, this boy worked slowly and he needed more time so he started asking to stay longer. Spelling Bug fascinated this boy and he persisted with his spelling, as he loved being rewarded with the jellybeans in the system. The reward system and selection system that challenged the students at a level of where they felt an appropriate level of success worked well with the
struggling students and is in line with Reeve (2005) and Vygotsky (1978). Both the teacher and this particular student expressed their surprise to how engaged the boy became in spelling. The teacher said the boy would never work on spelling in the classroom as he struggled so much. The student told us that Spelling Bug had made him think about the meaning of words and that words can be spelled differently depending upon the meaning of the word. The boy said, “I never thought about this before” (Anton, School A). The example of Anton illustrates the importance of students taking ownership and construct of their own learning (McInerney and McInerney, 2006).

This positive view was also demonstrated when students continuously came back to work more with the software and when they brought their friends from other classes to show Spelling Bug. The teachers told us about the positive discussions they had overheard from the students when talking about Spelling Bug. One teacher was surprised to have overheard how the students had been discussing the spelling of various words the students had encountered in Spelling Bug. She said, “I have never seen the children discussing spelling with such an enthusiasm.” (Ms Andersson, School A)

The observations and the students’ comments show that a simple system such as Spelling Bug can trigger children to start thinking about their spelling strategies. While the reward system was much enjoyed by the students it did not overtake the focus from the learning of spelling. In contrast to educational software such as Mathletics which promises the student a short time of playing a game if they work well and students might choose too simple educational tasks for the purpose of winning a game (Nansen, et. al., 2012).

6.8 Collaboration

As a classroom is a natural environment for children where they interact by talking and helping each other, collaboration was one part of interest for how our learner-adaptive methods would perform. When observing the students working by the computer we found the students would talk and interact with each other for a short period of 1-2 minutes before they started working with Spelling Bug. Once the students started working with Spelling Bug they were quickly absorbed in spelling and working towards receiving a new bug. While
the students are working quite independently, there are a few weaker students who ask the teacher how to spell a word or someone will call out loud.

“-Miss, how do I spell rain? (Anna, School A)

Before the teacher has time to reply one of the other students say:

“-Don’t ask her. Just give it a go, you know.” (Alma, School A)

Spelling Bug cultivated an environment in the classroom where students were working individually and still helping one another not by giving answers but by encouraging each other. Teachers spoke about how the students were discussing spelling of words during their lunch breaks. The teachers were fascinated of how Spelling Bug had made the students aware of spelling and the discussion it fostered.

Spelling Bug was popular among all students; low achievers to high achievers and students with diagnosed disabilities could all work independently with the spelling software. It was observed by teachers and researchers that all students worked well with Spelling Bug. One student, diagnosed with autism was considered not suitable to work with Spelling Bug by his teacher. The boy used to sneak around and watch when the other students were working with the software. After a few weeks into the trial, the boy asked his teacher if he could try Spelling Bug so the teacher approved. Later the teacher said, “This is amazing! For the first time this year August is interacting with the other classmates on the same terms as everyone else. He is superior to most of his classmates when it comes to spelling but watching him engaging with the other students at the end of a session and negotiating trading of bugs is fantastic. August accepts when other students do not want to trade, without throwing a tantrum. He is negotiating. If I didn’t know I would think he is just like one of the other boys.” (Ms Andersson, School A)

Spelling Bug suited all students and the software became a social trigger to start conversations and to be part of discussions among students.

6.9 Staying on the positive side of the “fine line” for challenges

One of the teachers spoke about how games engage the students but the games can be too competitive for the lower achieving students. “These games
are great but they activate the students who already are good at spelling and those who are not so good, try to avoid having to answer any questions.” (Ms Fredriksson, School B)

All teachers had expressed concerns about some of their weaker spellers not wanting to work on spelling tasks and these students initially kept a distance from Spelling Bug activities by not volunteering to try the software. These students would soon volunteer to try Spelling Bug as they had heard positive comments from other students. The weaker spellers soon asked to try the software and they all demonstrated their satisfaction with working with Spelling Bug by asking to stay longer or coming back. One of the participating boys, Abel was very hesitant to trying Spelling Bug. Abel did not volunteer to try the software but he was pleased when the teacher sent him on errands to visit the computer laboratory when his classmates were working with Spelling Bug. Abel worked intensely with his spelling even though he found spelling difficult. As Abel persisted he enjoyed his success with the spelling. The computer log showed that Abel was slower to move up in difficulty level compared to his class friends.

In the post-interviews the classroom teacher commented on how amazed she was to see the weak students’ engagement with Spelling Bug. “They never want to do their spelling tasks but they keep asking me if they can work with Spelling Bug. I’m so happy to let them work with it”. (Miss Bengtsson, School A)

We saw the same phenomenon in all participating schools, where low achieving students engaged and worked with Spelling Bug even though they had strongly argued their dislike for working with spelling. One boy said “I normally hate working with spelling but this program is not bad at all”. (Anders, School A) The fact that weaker spellers enjoyed working with Spelling Bug was of great satisfaction and interest for the teachers. One of the teachers was talking about how she liked that Spelling Bug “walked the fine line” between being easy and enjoyable and challenging the students with their spelling. “Like there’s a fine line between being pushed and frustrated
but Spelling Bug seems to follow that fine line on the positive side.” (Ms Larsson, School C)

All teachers said their students loved working with Spelling Bug. “I didn’t find any students I have, who did not want to or could not work with Spelling Bug.” (Ms Larsson, School C)

Ms Karlsson from School A spoke about how she had noticed a higher level of confidence in her students. The teacher said she had noticed how her students use the spelling strategies from Spelling Bug when they were writing and how they were “having a go” at trying to spell new words. When the students were working on their spelling, the teachers reported overhearing the students often discussing what words they had to spell in Spelling Bug.

6.10 Students’ awareness over their own learning

In the pre-interviews with students, almost everyone believed they were quite good spellers. In fact there were only two students who identified themselves as poor spellers and one said she was an extremely good speller. But when we asked about their spelling when writing essays and assignments many students said they always get their writing back with plenty of spelling mistakes to correct. The students also spoke about how boring they found the weekly spelling tasks and that they did not put much effort into finishing these. Teachers confirmed the low efforts students put into their weekly spelling homework and they spoke of how this was a constant struggle with students.

In the post-interviews with the students I found they had not gained an improved insight into what level of spelling they were performing at, but they had a much better perception of how to improve their spelling and methods for working out spelling of various words. Students said that they found their spelling had improved as they had better spelling when writing on assignments.

Two of the boys said they believed the reason for improving their spelling ability was because the system allowed them to work through a wider range of words rather than just the ten weekly spelling words. “I think Spelling Bug is
good for improving your spelling when writing reports and stories as Spelling Bug uses so many different words and not just the ten weekly spelling words.” (Cornelius, School C)

Anna from School A told us “Last week I got my report back from Ms Andersson. I normally have to rewrite my report because I have so many spelling mistakes. But I think I’m better [at spelling] now and Ms Andersson said it’s probably because I’ve worked with Spelling Bug so much.” (Anna, School A)

One of the boys spoke about how Spelling Bug made him consider the actual meaning of words and how words that sound the same may have different spelling depending upon the meaning of the word. The boy said, “I never thought about this before” (Albin, School A). It is a fascinating finding as one of the standard spelling activities in the classroom is to look up the meaning of words in dictionary, but Albin did not note this. The motivation of wanting to be rewarded in Spelling Bug seemed to be the trigger for learning in Albin’s case. I found that all students enjoyed working with Spelling Bug and they were keen to keep improving themselves. Part of the engagement was to build up their bugs’ world but I observed how the students were encouraged by the system to perform well as it was not too hard to be rewarded.

6.11 Summary

Teachers are using existing technologies such as word processing, emails and spreadsheets for documentation of student progress, lesson plans and communication with parents. If a teacher has access to Smart Boards, these are used as a replacement for a black/white board. The teachers however do not feel confident in how to integrate technologies in their teaching and they are unaware of the capability of technologies and how these can complement, support and be well integrated into their daily teaching.

After the first phase of introducing Spelling Bug, when students were starting to accumulate results, the teachers had a positive change of attitudes to using technology to support teaching and learning. The change of attitude was triggered when the teachers witnessed the benefits for their students’ engagement in learning spelling - particularly the engagement of the students who were considered low achievers.
The teachers are time poor and feel stressed. They view technology use to be for the benefits of students’ learning and they have not thought about the technology being useful for their teaching. However, if students are being engaged and working well with technology, the teachers see it as a positive activity. The teachers were surprised when they were introduced to the amounts of data Spelling Bug had collected about their students’ spelling activities. The teacher part triggered teachers’ attitudes to change and their restrictive approach to technology adoption was changed. The teacher part made the educators see new potentials with integrating technology in their teaching.

It was important for teachers to have computer software that was designed to fit with the already existing teaching and learning activities. A couple of teachers had searched for suitable software but not found any they were pleased with. All the participating teachers were happy with software that could be used for 10-15 minutes, to fit in with other ongoing spelling activities. Teachers found it stressful to not have access to IT support on a daily basis when computers were not working. Also, they would have liked to have access to the word database and to be able to prioritise the weekly spelling words so students would be tested on these.

All students engaged well with Spelling Bug. The short and intensive activity working on Spelling Bug was enough to have the students working through 60 spelling words in 10 minutes. The level of difficulty was well adjusted and the students were not discouraged when they were challenged with higher level of difficulty. As Ms Larsson pointed out, Spelling Bug managed to keep the students keen to continue but still there were challenges to make the spelling interesting. We suspect however that the short duration of active work, may pose problems for student models that are based on longer trends in a student’s performance and note shorter bursts of activity, sometimes influenced by the environment.

The teachers noticed a higher awareness among the students around spelling. The students were discussing spelling and how to approach a new
word to spell. The teachers also found the students encouraging each other to “have a go” at spelling when they were working on essay writing in class. Spelling Bug suited all the students, low to high achiever and students with disabilities. The students found a common ground to socialise with each other, even though students were working at different levels of difficulty. The screen looked the same for all students and they all worked with the aim of earning bugs for their collection.
7 Discussion and Conclusion

This thesis argues the importance of considering the complex nature of a classroom setting when designing useful technology to support both learning and teaching. As Grudin (1988) pointed out, a computer system must be accepted by its users for it to be useful.

To gain acceptability, as Grudin calls it, a holistic view of the context, users and the choice of technology collectively contribute to successful use in education. The results from this thesis demonstrate the importance of considering both teachers and students as stakeholders in a classroom environment as well as having well functioning learner-adaptive technology for successful use.

In this chapter I discuss the results in relation to formulated research questions, followed by a discussion of the positive responses from participating teachers and students. Future research studies are discussed before closing with concluding remarks.

7.1 Research question

The following hypothesis was made at the beginning of this thesis:

A lightweight learner-adaptive method as exemplified by the ‘Radial Basis Function’ technique functions at least as well as a student modelling technique as exemplified by Millán and Perez-de-la-Cruz (2002) in a classroom environment.

The results have shown there is not a statistically significant difference between the spelling results and progress of students who have been using either selection technique. The results nevertheless demonstrated that good adaptation of content is vital for the students’ engagement. As one of the teachers said, it is vital that the software challenges the students at the right level to keep them interested in working more, but not discouraged by having material that is too difficult. Unlike ITS systems such as PAT, Spelling Bug does not have a built-in tutor and the aim of Spelling Bug is to complement the already existing human teaching.
While observing and interviewing students and teachers I found other factors than the choice of selection algorithm may have an impact on the successful use of computer based spelling programs in a classroom environment. To answer the second research question, 

*How effectively does learner-adaptive application of student modelling and ‘Radial Basis Function’ techniques support teaching and learning in a collaborative classroom environment?*

I focused on studying Spelling Bug from a number of perspectives presented below.

**Effectiveness in supporting spelling achievement**

When I used traditional pen and paper tests for testing students’ spelling, the tests did not indicate any significant progress among the participants. But the triangulation between hand-written test results and the computer data logging, presented information to support a positive correlation between number of completed spelling activity and accuracy at the post-deployment spelling test. In the group which did not use the system for long, displayed a decline in spelling performance. The traditional method of testing students requires a longer time to pass between pre-test and post-test. The pen and paper test is also subject to students’ overall wellbeing (e.g. tired, not feeling well, unfocused) and the post-tests. The user study with Spelling Bug was made at the end of the school year. A computer-based record of everyday activities provides teachers with much more information on students’ progress and with the larger amount of data “bad” days will not be significant in the overall progress. Students clearly developed an improved awareness of methods to be used when spelling by working with Spelling Bug. The newfound awareness for spelling methods was applied in activities where spelling was used outside of the learner-adaptive system.

**Usefulness as a teaching aid**

At the start of the user study, teachers did not view Spelling Bug as a tool to support their teaching. When the teachers took interest in Spelling Bug it was triggered by them observing their students’ enthusiasm for working with the
system. At the very end of the user study the teachers’ attitudes to using technology in their classroom had matured and they realised the potential of the teacher part in Spelling Bug. Teachers who had not considered technology for their own benefits were now much more open to creative thinking around how learner-adaptive systems can be useful for their own benefits. I decided a gentle approach of letting the teachers seek out the potentials with Spelling Bug was preferred, even if it meant the usefulness of Spelling Bug as a teaching aid was not fully explored. The decision for this approach was based on experience from working with a classroom installation called Discovery Table in Boden, Dekker and Viller (2011). With Discovery Table we designed the interactions with the technology to suit the existing classroom activities, as well as to allow for teachers to explore the table in their own pace. This design and approach had a positive effect on otherwise technology anxious teachers.

**Effectiveness at adapting to individual learning needs**

In the six classes that participated in the user study, students were at varying levels of spelling ability, with different learning styles. Some students even had diagnosed and suspected disabilities. Spelling Bug was designed to suit visual, audio and tactile learning and all participating students successfully worked with Spelling Bug. The teachers particularly witnessed the improved efforts among their students who were considered lower achievers (Boden, Viller & Dole, 2010).

**Ability to offer an experience that is both engaging and enjoyable**

Students initially viewed learning to spell as a boring and a “must-do” activity. While most students complete the spelling tasks teachers give them, it becomes a strained chore that some of the weaker students try to avoid. A learner-adaptive system provides students with the right level of challenge to keep the students going. Also adding to the enjoyment, Spelling Bug had a reward system, imitating the popular trading cards that students in this age group enjoy on the school grounds. The trading system in itself did not seem to be the greatest attraction to the students but rather the fact that it was fairly
easy to earn a reward. It made the students feel confident and they viewed their bugs’ world more like having pets.

*Ease of use overall fit with existing teaching practice.*

For new technology to be accepted and well used, it is vital to ensure a suitable fit with on-going classroom activities. Teachers are pressured to offer individualised teaching and asked to teach a great amount of material. I note in Results that teachers (e.g. Ms Andersson and Ms Bengtsson) had not previously been able to find computer programs that satisfy their expectations and needs, to operate in tandem with classroom activities. With Spelling Bug they now expressed a satisfaction and enthusiasm for continuing to work with learner-adaptive systems. One reason for why Spelling Bug suited these teachers comes down to basic design principles such as a quick start, a short timeline for working, while still incorporating a substantial amount of spelling activities.

The classroom activities were often designed as 10-20 minute activities before students were moved on to another learning activity. By allowing students to work with Spelling Bug for 10 minutes, they still had 5 minutes extra for trading and a few minutes for changing rooms etc., before and after using the program. The practice of designing technology based learning activities around the existing classroom activities have proven to work well in other research studies, as seen in Boden, Dekker, Viller and Matthews (2013). Boden, Dekker, Viller and Matthews (2013) designed a classroom activity (“Save the Wild”) for teaching young children to learn about sustainability. Save the Wild was designed to have a non-invasive impact, and to complement already existing classroom activities.

### 7.2 Validity of results

The use of Spelling Bug resulted in positive feedback from both teachers and students. The high level of positive feedback can be explained by that only participants who volunteered were involved in the user study, but also by the nature of an iterative design process which engaged participants. The iterative design process allows for immediate changes and feedback to the users.
(Button and King, 1992) of the learner-adaptive system and the designs can change to ensure a successful fit with users and the context they work in. This meant that when problems occurred they were identified, evaluated and a solution could be applied to solve the issue. Spelling Bug is based on Magic Spell (Boden, 2004). Building upon the user study of Magic Spell, I re-designed the spelling program to Spelling Bug. Spelling Bug was user tested during one school term. A re-design of Spelling Bug was made based on observations of students and comments from teachers from the user testing. Another iteration of user testing and evaluating was done with the new features of Spelling Bug (see Figure 17).

![Figure 17: Illustration of iterative design process of Spelling Bug.](image)

Reseaching in real world contexts such as classrooms can be difficult and can for various reasons, as in this study, lead to participants who will not follow through the full study. The loss of School B was unfortunate as the results indicate that it is important to carry on activities and to have the technology at hand, for an extended period, for positive outcomes to be realised. I tried contacting the two teachers after their new school principal had decided to delay the school’s participation in the study. Unfortunately, the two teachers had left the school and I was unable to make renewed contact. It would have been good if I had secured a second channel of communication with the teachers as I had only email addresses, so I would have been able to trace the teachers.

The format of having a researcher take part of everyday activities meant that confidence and mutual respect were established between the researcher and the class teacher. Being sensitive and allowing for the teachers' needs (Kim, Kim, Lee, Spector and DeMeester, 2013) is important for successful integration of new technology. Teachers are very time-poor, exemplified by
days when I spent the whole day waiting for an opportunity to talk to a teacher. Even though I had arranged for a meeting time, parents who need to talk, students with injuries, students fighting at lunch break etc., tend to disrupt planned activities at school. By being patient and using this waiting time by helping out in the classroom with ongoing teaching activities, the teachers showed they appreciated my presence rather than feeling that I was watching them.

The teachers were made aware of the features in Spelling Bug that could be used for their planning and documenting of each student. While I demonstrated this to the teachers at the beginning of the user study, it took a long time before the teachers decided to make use of the feature. To not stress the teachers (Mumtaz, 2000), I took the approach of allowing teachers to decide themselves when they were ready to adopt the teacher features in Spelling Bug.

The recorded voice used in Spelling Bug consisted of three different variations of English (Irish, American and British). The students found the non-Australian pronunciations confusing at the start of using Spelling Bug. The Queensland literacy curriculum does state that students should be exposed to the diversity of the English language. The difficulty in understanding the various dialects may have affected the students’ performance during the first week of working with Spelling Bug, but I note that the children quickly got used to the range of voices, and had less problems after that. To avoid confusion, I would recommend finding funding to hire a native speaking Australian for recording the words included in a spelling system.

7.3 *A better design to suit the classroom*

I conclude the following design objectives from my study.

Short activities: Children become tired from intensive learning sessions (see 5.1.1. and 5.1.2.) so I recommend short activities for learning.
Fit in with the daily routines of the classroom: Consider the existing schedules and design educational technology to fit within these timeframes (see Ch. 5.5.2. and 5.6.4).

Provide simple teacher feedback: Build in feedback for the teachers so they can follow each of their students’ activities. Keep it simple with visualisations (see Ch. 5.5.2 and 6.6).

Right level of challenge: Keep the activities at the right level of challenge to keep the students engaged and motivated (Reeve, 2005; see Ch. 6.7).

Activities must be individualised: The range of abilities is great within a year level. Ensure that the individual student is working at their specific level of difficulty, so they are able to participate on equal terms (see Ch. 5.5 and 6.7).

A student-model does not benefit learning: For a simple and quick development of learner-adaptive educational software, there is no need to use a student-model. I failed to demonstrate any advantages to the much simpler principle of evolving education content (see Ch. 6.1).

Use simple interfaces: Teachers prefer when the interface is kept simple and without distractions (Boden, 2004; see Ch. 5.5.2).

7.4 Future work

The results from studying Spelling Bug and its use in classrooms are positive and encouraging so new questions have emerged and for future studies it would be interesting to investigate learner-adaptive systems and the teacher support in more detail. At the end of the Phase 2, teachers had a big change of attitude towards learner-adaptive systems. At this point they realised the potential of using such methodology for their own teaching and planning. A more longitudinal study where teachers plan for and use the teacher feature actively, would provide more insight into how technology could have an impact on future teaching methods.
Spelling Bug focused on the task of working with spelling, but the principle of learner-adaptive system easily transfers into different subject areas. Teachers typically build up short activities that are used for students to work through in groups for 15-20 minutes each week. These group activities are iterated every week. This is where I think the design of Spelling Bug fits in. Teachers use a similar method and structure for weekly activities in mathematics. A future study could investigate if the design rules I used for Spelling Bug generalise to a subject such as mathematics.

The handwritten pre- and post-deployment spelling tests were based on the Australian national tests for literacy. It was interesting to see how the students at School C performed so poorly on the post-test as this was exactly the same test as the pre-test. It was a surprising result and should need further investigation to why this occurred. The hand-written, “one-point-in-time” is the model schools now use for measuring students’ learning and progress, it would be of interest to research if technology could be part of the recording of assessment of progress for the individual students.

There is currently a push to promote STEM (Science, Technology, Engineering and Mathematics) in early schooling. Information and Communication Technology (ICT) capability is seen as a vital competency into the 21st century (ACARA, 2015). The new Australian Technologies Curriculum requires that digital technologies (e.g. robotics, coding) are integrated into teaching from foundation years and onwards. Schools are attempting to meet this need by adopting unsustainable stop-gap measures, for example, engaging visiting consultants who provide an introduction to emerging technologies. Together with a group of colleagues I am developing a research program to expand on the ideas discussed in this thesis.

The project will study how the introduction of Studio classrooms can support the development of teachers to be competent and confident to embracing new technologies and novel learning environments. Studio classrooms offer the means for delivering on this vision. Studio simultaneously refers to two closely related concepts: a physical space (studio settings) organised for the
collaborative design and prototyping of new technologies (e.g. an architectural studio) and the pedagogical approach that is adopted in constructive design disciplines (Schön, 1985). Studio settings are technology-integrated environments where place and pedagogy come together with possible solutions to wicked problems, developed collaboratively in an exploratory and iterative fashion. Wicked problems refer to open-ended problems that can have several solutions and be solved by using a number of methods. All work within the space is open to scrutiny by peers and tutors, with reflection and critique a natural component of this practice. The pedagogical approach typically involves open-ended exploration, peer collaboration, construction, iteration, presentation, critical reflection and critique.

The project will utilise pedagogies of group work, collaboration, problem solving and authentic contexts. Such pedagogies have been reported as essential for student participation and engagement in STEM subjects, particularly for girls (Tytler, et al., 2008). The project will adopt and adapt Schön’s principles of studio to build classroom communities in primary schools where teachers and learners collaborate, with the support of technologies, to identify, explore and build solutions to challenging, loosely defined, open-ended problems.

The study is planned to research three separate cohorts of students across 3 years and it will provide a design context for improving teaching and learning processes through iterative cycles of implementation evaluation reflection and replanning like the iterated design cycle of Spelling Bug. In this longitudinal design, we will explore the long-term effects of embedded digital technologies in the curriculum and seek evidence on the extent to in-classroom professional development supports a successful integration of technology in education. In particular, the pedagogical outcomes will be an important means of evaluating the fit between the technologies, their specific configurations, and the learning activities. The Studio Classroom Model is a ground-up and cascading approach to teacher professional development, that occurs on site, with strategically determined cohorts of teachers receiving individualised
coaching and mentoring within their classrooms, who then engage in peer-teaching to support the next cohort of teachers.

This new project will build on my previous research related to technology mediated teaching and learning across the curriculum, via digital technologies such as robotics (see Dole, Boden, Viller, Campbell, 2013) and the present work.

7.5 Conclusion

As technologies are emerging in our society, schools are also seeing new technologies designed for the educational purposes. With systems such as Intelligent Tutoring Systems to support individuals in their learning, students can work and learn in their own paces. ITS systems have well developed and tested technology (Conati et al., 2002; Koedinger et al., 1995; Aleven & Koedinger, 2002; Millán & Pérez-de-la-Cruez, 2002) to give as high level of support for learning as possible. These systems have proven to be highly useful among high school and university students and students learning without the support of a human tutor. While in primary school settings, young students naturally enjoy group activities and the presence of a human teacher. To support the classroom activity and the teachers who are not professionally trained in how to incorporate technology into their teaching and the students’ learning, this thesis have investigated which factors have an impact on the successful use of learner-adaptive systems (LAS). Spelling Bug, an example of a LAS, were designed to suit the already teaching and learning of spelling in a primary classroom. In an iterative process, Spelling Bug was tested with grade 4 primary school children and their teachers. Between the two iterations, the use was evaluated and changes made to Spelling Bug for a second user iteration. From the observations, interviews, hand-written spelling tests and computer data log I made a number of reflections that all together contributed to the successful use of a learner-adaptive system. The reflections I made are all related and depending on each other to varying degrees. To summarise the reflections make up a list factors that together contribute to the successful design of LAS. I recommend
the following reflections be considered when designing for the active primary classroom:

- **effectiveness in supporting spelling achievement**
- **ability to offer an experience that is both engaging and enjoyable**
- **effectiveness at adapting to individual learning needs**
- **usefulness as a teaching aid**
- **ease of use overall fit with existing teaching practice**

The imaginary educational system described in the introduction can be a reality in today’s classroom. The technology exists and designers now need to ensure the systems are designed to suit the contexts and its users. The challenge for designers is not to attract the students to use technology but rather to design the technology so it challenges the students at the right level of difficulty. The second challenge the designers face is to design the technology so that teachers feel ownership and can understand the benefits in terms of their teaching. Designing to support the teacher requires that the designer understands the learning context. While learning is a continuous activity, the classroom is challenged with interruptions such as extra curricular activities, social interactions, injuries, variations of learning abilities and special events. With learner-adaptation built into computer systems, the technology can support not only the individual learner but also the teacher. Learner-adaptive systems are interesting as they can be used well to support the teachers in their planning and decision-making. The teacher support can in its turn lead to improved teaching strategies.
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Appendices
Appendix 1: Article – Augmenting play and learning in the primary classroom

Augmenting play and learning in the primary classroom

Marie Boden
Andrew Dekker
Stephen Viller
Ben Matthews
School of Information Technology & Electrical Engineering
University of Queensland
Australia

marieb@itee.uq.edu.au
dekker@itee.uq.edu.au
viller@acm.org
matthews@uq.edu.au

ABSTRACT
In this article we present the design and study of Save the wild, a system designed to support augmented play and learning for children. Save the wild is an augmented reality (AR) based system with which children can interact by creating origami paper characters printed with fiducial markers that can be recognized via the webcam attached to the computer. The system aims to give students a level of awareness around problems with sustainability. As children make visible their origami creations to the camera, the system displays animated virtual characters that are attached to simple storylines that relate to sustainability and environmental consciousness.

We studied how Save the wild was used and interacted with by students in two environments: at a public exhibition and within a classroom. We found that the technologies that were used (fiducial markers) can be used to create environments that support multiple modes of interaction and different forms of engagement with educational content. The technology allows designers of these systems to augment physical play and activity without requiring new technologies to be introduced, rather using technologies already found within the classroom. We find that by using AR, it is possible to enhance play-based learning without it becoming focused on the technology – rather it augments and guides the learners’ own narrative. We conclude with a discussion on how AR/markar technology can enable technology to create a more exciting interactive and social experience for young students while they are learning.

Categories and Subject Descriptors
H5.m Information interfaces and presentation (e.g., HCI); Miscellaneous.

General Terms
Design, Human Factors.

Keywords
Interaction design, education, fiducial markers, augmented reality, physical computing, play.

1. INTRODUCTION
The use of technology in classrooms holds the promise of new interactions and experiences when learning. Emerging technologies offer teachers new possibilities to communicate with individual students, organize group activities, and monitor individual progress [1]. There have been a number of discussions about how best to use technology in classrooms that focus on content delivery, with the assumption being that schools will use technology in the classrooms to support the teaching of its content. There have been a number of innovative technological developments in the higher education and adult learning sectors that have been adopted on a large scale, e.g., MIT’s open courseware, massive online open courses (MOOCs), online publication platforms such as (Taylor’s and Academic Earth), open online learning institutions such as CodeAcademy and Khan Academy. However, technological initiatives designed for, and relevant to, primary school classrooms (some of which we will review in the next section) are still a long way from seeing a similar scale of widespread adoption. When we visit an Australian primary classroom today, we are not yet met by a seamless integration of technology as a tool for daily learning infrastructure (such as numbers of computers in the classroom and network connectivity) can vary widely from school to school, as can individual instructors’ familiarity with teaching with technology. For most publicly funded primary schools, the technological revolution is one still waiting to happen.

We are interested in how to design interactive technology so there will be new values added in learning and play. This study is a continuation of our previous work - Discovery Table [2], where we investigated the design of augmented artefacts to support learning in a preparatory classroom. In the original study, we found that students like to move back and forth between the activities in the classroom and that they like to bring something physical with them to show to teachers and friends, extending the learning process away from the installation. We also found that new technology itself can be intimidating; for teachers if they are not familiar with it. From our findings, we decided to explore the potential for the design of augmenting play that is already an integral part of the classroom through the use of existing technology already present in the environment (desktop computers). We focused on a specific activity (creating origami to learn about sustainability), which is a physical hands-on activity where students could keep their artefact, carry it with them to a computer and continue to play with it. We wanted to explore how we could augment this activity, to create a more intuitive and seamless use of technology in the learning context.

2. BACKGROUND
Our work is informed by previous studies that have deployed new technology within classroom environments, considering the microcosm of existing infrastructure within the classroom. In particular, we are interested in technologies that can enhance learning and discovery through the use of artefact detection and augmentation (Augmented Reality).
2.1 Classrooms and Technology
Technology has had an important impact on activities within the classroom, with the aim to support both teachers and learners within the learning context. Traditionally, technology that is used within the classroom consists of commercial off-the-shelf (COTS) systems (such as Desktop computers), which are deployed into the learning environment without a clear understanding of their purpose [3]. This can be attributed to a number of factors, in particular, the disconnect between the design of the technology and the learning activities that are already taking place [3].

Most often, these COTS technologies are poorly introduced to the students, and also poorly supported by teachers. This means that students are not only tasked with learning the practicalities of the technology, but also having to make the connection between the technology and the learning activities being presented by the teachers [4].

Bauman et al., [5], when developing the “Subtle Stone” - an affective technology which uses a child’s emotion - found that there are specific needs for technology to support the learning environment, and that there “is little prior work to draw requirements for the design of such technologies”. Hove et al. [6] explore the issues of developing and deploying technologies into the classroom to support the learning environment. The authors suggest that there are six areas that should be paid attention to when integrating technology into learning environments:

1) Resources
2) Institution
3) Subject culture
4) Attitudes and beliefs
5) Knowledge and skills
6) Assessment

These areas highlight that it is not the technology itself that is problematic in the classroom context, but the relationship between the technology and the context. This is not to suggest that the use of technologies in classrooms is uncommon, since teachers found that 99% of teachers surveyed had implemented some form of technology integration into learning, but rather that the technology is being used for skill-based learning, as opposed to supporting deeper levels of learning. This suggests that to improve the use of technology within classrooms, teachers should be educated on methods in which they can adapt existing technologies to support their learning structures purposefully, rather than in ad hoc technology, such as computers, into isolated activities.

Cox [7] found that teachers are more interested in technologies that help improve learning by making it more enjoyable for both the students and themselves. A popular way of achieving this is to use technology to support routines that are used to help teach subject matter, giving them real-world reference to more abstract knowledge. Ivers et al. [7] developed SAGE, a system that allows students to create their own stories within a configured space. The learning focus of this system is to support children in the exploration of identity and communication. Often work suggests that there are benefits to creating technologies that allow for multiple children to learn socially and use it collaboratively. KidPad and Klapn [10] are systems that have been explicitly designed to facilitate collaboration between students, without forcing a specific method of participation. “We introduce an approach to the design of shared interfaces that involves subtly encouraging children to explore the possibilities of collaborating, without forcing them to do so”:Billinghurst [11] suggests that by providing a common workspace, students have the ability to better collaborate: “In a classroom setting, students work together better if they are focused on a common workspace. Yet this is difficult to achieve in computer-based education”.

2.2 Augmented Learning
An approach to designing human-computer interaction that has become popular in the last decade is the concept of Augmented Reality (AR). Azuma [12] defined AR as “a variation of Virtual Environments (VE), or Virtual Reality as it is more commonly called. VE technologies completely immerse a user inside a synthetic environment. While immersed, the user cannot see the real world around him. In contrast, AR allows the user to see the real world, with virtual objects superimposed upon or composited with the real world. Therefore, AR supplements reality, rather than completely replacing it” Azuma [12]. This method of augmenting a physical environment is commonly used in settings in which the environment contains an existing purpose to support an activity – such as a classroom, museum, or airport.

Many studies have been conducted which explore the possibilities of augmenting artifacts to support learning [2,13,14,15,16]. By making the common or everyday objects more interactive and engaging by incorporating surprises or information, the students learn and are encouraged to continue their search for more and new information. Billinghurst [11] discusses the importance of physical objects within a classroom setting, in educational settings physical objects or props are commonly used to convey meaning. Physical objects support collaboration both by their appearance, the physical affordances they have, their use as semantic representations, their spatial relationships, and their ability to help focus attention.”

Augmented reality consists of two aspects - the physical object being interacted with (which may include a marker for recognition) and the technology, which detects the physical object and augments it through a combination of display and sound. We suggest that there are two primary methods of Augmented Reality: Situated AR – where the technology is situated in the space (such as projecting onto a wall), and Mobile AR - where the technology is portable, and held by the user (as shown by popular Augmented Reality smartphone applications such as Google Glass). The differences between these two methods are primarily based on how the user interacts with them. Do users carry physical artifacts to the technology? Or do users carry the technology with them and use them as a portal to the AR view?

<table>
<thead>
<tr>
<th>Method</th>
<th>Mobile AR</th>
<th>Situated AR</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Component</strong></td>
<td>Technology</td>
<td>Object</td>
</tr>
<tr>
<td><strong>Limiting Factor</strong></td>
<td>Concurrent users</td>
<td>Existing infrastructure</td>
</tr>
<tr>
<td><strong>Object Considerations</strong></td>
<td>Easier to design for if not portable – can assume its place within an environment</td>
<td>Must be portable and tangible</td>
</tr>
<tr>
<td><strong>Interactions</strong></td>
<td>User walks to the object of interest</td>
<td>User carries the object of interest into the augmented space</td>
</tr>
</tbody>
</table>
When designing AR within learning environments, an essential consideration is the existing infrastructure required. Mobile AR (where the technology is portable) does not have the same degree of reliance on the existing infrastructure embedded within the environment; however, there are likely to be issues of scaling in settings such as classrooms (the number of devices required, or wireless network bandwidth). A major limitation with Situated AR is that the design of augmented artifacts typically requires a different way to leverage off the shelf computer equipment to support AR. Desktop computers are now capable of performing object recognition out of the box (using a built-in web camera). Screen sizes on these computers, while not the size of projectors, are bootstraps large enough to provide a collaborative viewing experience.

While Situated AR has historically required custom-built infrastructure within the environment, there is now an opportunity to leverage off the shelf computer equipment to support AR. With AR, computers are now capable of performing object recognition out of the box (using built-in web cameras). Screen sizes on these computers, while not the size of projectors, are bootstraps large enough to provide a collaborative viewing experience.

A major consideration to consider for the method of Augmented Reality is the affordances provided by the objects themselves. In environments where physical objects are the primary interaction point, the affordances provided by the objects themselves can greatly influence the user experience. The use of physical objects provides additional context to the user experience, allowing for a more immersive and engaging interaction.

While Augmented Reality may first appear like a natural progression within classroom environments, there are considerations that should be taken into account. By its very nature, Augmented Reality can provide a rich and engaging learning experience, but it is important to ensure that the technology is used in a way that supports the learning objectives and engages the students in a meaningful way.

AR within classroom environments needs to be designed for the institutional context.
classroom, however, they also expressed insecurity and hesitation towards having to set up new technology they were unfamiliar with. Cuban [27] found that while teachers expressed a positive attitude to the usage of technologies for young students they seemed to only think of the technology as a supplemental activity.

Existing infrastructure in primary classrooms can be diverse across various schools. It is rare to find a one computer per student situation, and often there will only be one or two computers in a class of 25 students. Some schools have a robust internet infrastructure but many schools are still struggling with unreliable network access. Teachers can find it stressful having to troubleshoot technical issues when they have 25 primary students around them. Save the wild is a system designed with sensitivity to some of these issues. It can be used by several students at the same time, easily fitting within a classroom without requiring internet access, bespoke peripherals, or special equipment.

3. SAVE THE WILD

At the University of Queensland, a group of third year students designed and implemented the project Save the wild within an Interaction Design course. The objective of the project was to design and test a prototype that incorporates the theme of playfulness. Save the wild has been designed to suit the young primary school classroom with students between the ages of 5 and 8 years old. The project was designed to complement other ongoing classroom activities, where the children are working with a theme of sustainability. Specifically, the learning objectives that were in the study focused on learning about protecting nature by not throwing litter and rubbish on the ground.

3.1 Design

Save the wild is designed as a center activity in a primary classroom. In this corner a small table and a few chairs (see Figure 1) are placed with an off the shelf computer on top of the table.

Figure 1 Table with the desktop computer set up for Save the wild.

Below the computer table a play mat is on the floor, the students can sit on the mat and fold up a variety of origami designs. Students choose between eight animal figures (e.g. leoka, fox, owl, frog), three rubbish figures (plastic bag, old paint brush and a glass bottle) or two recycling figures (recycling bin and recycling van). Each of the origami templates contains a fiducial marker (a marker technology which is a variant of a QR code), which is pre-printed onto the back of the folded paper (see Figure 2). Students construct the origami using instructions located with the collections of templates.

Figure 2 Children folding origami figures. The fiducial marker is pre-printed on the paper.

When a student has finished folding the origami figure, he or she can hold the origami up in front of the computer and there will be an animation appearing on the screen. The computer reads the fiducial marker with the built-in camera, and then displays the animation/narrative associated with the marker.

The system has a large variety of narratives to be displayed, both for single code scanning and for multiple markers simultaneously. This means that students can play with Save the wild individually but also together in groups of students, and see the on-screen narratives interacting with each other.

The focus of these narratives is to show how animals move and live in nature. When a student holds up the origami animal in front of the computer e.g. a snake, an animation will be played showing how the snake is moving on the ground. When the student moves the origami animal away, the animal will disappear from the screen. When a rubbish origami fold is held up in front of the screen there is an animation representing the rubbish e.g. a glass bottle. If an origami of an animal is triggered the animal will move on the screen but also get injured by the glass bottle that breaks in the former animation. The rubbish can only be removed by one of the origami designs of a recycling bin or van. The recycling origami will initiate an animation of a recycling van moving over the screen and then the rubbish will disappear from it. This allows individualized stories to develop for each student as they show and hide origami, allowing for a playful and customized experience. The experience of a narrative, due to the physical nature of the origami, can be taken away by the student to reflect on later.

4. DATA AND METHODS

In order to understand how children interacted with Save the wild, and to evaluate the potential of the system to support regular classroom activities and convey ecological content, the prototype was independently deployed in two settings. Our methodological approach was factorial [25], we gave priority to collecting observations of children's interaction with the system without our intervention or instruction. This better enabled us to appreciate how well (or not) the system communicated its possibilities for interaction to target users, what affordances it provided, and what expectations of their own young users brought to it. Below we present results from our two observational studies of children interacting with the system.
interact with the system. As the children were playing with the paper figures, the camera would pick up some of the printed markers and trigger an animation on the computer screen. The children who were around 5-6 years of age soon became curious about the code on each origami figure. Most of the children discovered that the computer recognised the figures when they held them up to the computer. We found that once the children had seen someone holding up the origami figure in front of the computer, many more children wanted to join in and to see what happened when they held up their figure. At first the children did not see the connection with the printed code and the computer. They would just hold up the figure facing towards the computer (all codes were printed at the back of the figure) (see Figure 3).

Once the students had realised they needed to have the printed code towards the camera they became very aware of this and some overdid the positioning of the origami figure by putting it too close to the camera. Often parents or an adult pointed to where the camera was located. By watching other children most of the students realised that they did not need to put the origami figure close to the screen. It was only the youngest participants (2-3 year old) who struggled to understand how to position the figures.

Out of the 51 participants, the children from 8 years old and younger came back several times to play more with Save the Wild. The younger students also tended to stay for longer periods compared to the older participants.

Certain aspects of the system were not self-discovered by some children. For instance, many of the younger children (2-7 years old) did not discover on their own how to clean up the rubbish that had collected on the screen. These younger children learned how to ‘clean up’ the environment by watching the older students interact with Save the Wild. Once the younger ones had seen how the older students used the recycling origami figures, however, they had no problem copying the behaviour to remove the bottles and plastic bags from the scene. We found that this social learning allowed for a sense of understanding of the system as opposed to the difficulties encountered when adults attempted to explain the technology.

After only a short period of time of playing with the system, all the children were able to understand how to save the WIld by scanning fiducial markers. However, very few of the students realised that they could combine the origami figures to initiate more new activities on the screen. Many children tried to interact with the animals on the screen by touching and trying to make swipe gestures (see Figure 4) on the computer screen. A parent commented on how natural and intuitive it seems for the children to interact with the figures on the computer screen compared to how adults behave.

From our observations in the exhibition study, we found that the Save the Wild experience provided an interesting way to augment the physical activity of Origami. Our observations of the social learning (where children observed others using the system) gave us insight into how features of the system can be discovered and taught to others, without explicit adult intervention. As our principal interest was in augmenting learning in a classroom environment, our second study deployed Save the Wild within a classroom environment, to observe how primary school children explored the system in the course of a lesson.
4.1.2 In a classroom

For the second user test we set up *Save the wild* as part in an Australian grade one classroom. The computer was set up in one of the corners of the classroom. The set up consisted of one computer screen, origami paper, instructions on how to fold various origami animals and objects, and one small paper box consisting of already made up origami animals and objects. 22 children, 10 girls and 12 boys, aged 5 to 6 years old tested the system.

We sat on the floor close to where the children were playing with *Save the wild*. As the study progressed, we made observations using a mobile phone camera and taking notes. This second user study aimed to study how young students in a classroom interact with *Save the wild* without parental or adult instruction.

The teacher had given the students tasks to work on for the day. The first task was to individually organize their yearly portfolios and the second task was to do exercises from a Christmas workbook.

We intentionally did not introduce or explain *Save the wild* so that the children could freely play with the system, as they liked. The teacher had agreed to allow the students to play with *Save the wild* whenever they were interested.

Initially, the students stayed at their desks while working on the tasks their teacher had instructed. A few students passed curiously at the corner. A few other students got excited when they recognized that there was an origami activity. After only a few minutes, two girls came and asked why there was a computer in the corner. They asked us "what is it?" and we responded "Why don't you go and have a look to see what it is. You're allowed to have a play." The two girls walked over and sat down in front of the computer. They discovered the populated forest and then they picked up one origami animal each. The girls did not know how the two worked together but soon they played with the animals in front of the screen. Suddenly, one of the girls called out, "Look, did you see something moving?" "How did that get there?" The other girl was quiet with a fascinated expression on her face. The first girls continued, "Do you think it was this (holding up her origami animal)?" The girl holds up her animal but nothing happens.

The girls continue playing with their animals and suddenly there's movement on the screen again. "Look!" The girl is pointing to the screen. "Lift up your animal again." The girl figures out that the origami folds are making things appear on the screen and they get very excited. The girls giggle and try different animal folds and they are fascinated about the screen appearances. After around 10 minutes of play the girls discover how the animals will disappear from the screen when they click on the origami animal but also how plastic bags and glass bottles fall and break at the bottom of the screen. One of the girls discovers how the recycling bin is sweeping away some of the bottles left on the screen. She says, "Oh look, it's sweeping the bottle off." The other girls says, "The animals get hurt, see they're bleeding." A third girl has joined the other two girls and she says, "It's fun smashing bottles." The second girl calls out, "Clean up!" The students tend to test out the "bad" origami folds but as they play continued they seemed to not want to make the animals injured and therefore avoided the plastic bags and glass bottles. One boy discovers how the objects are hurting the animals and calls out, "the birds are dying. Get the recycling bin because the birds are eating the plastic bags." Almost all students have a short learning curve before they discover how the animations are triggered on the screen. When the animations are not happening, the students try to put the animal fold closer to the screen or they try to swipe or flick the animal quickly in front of the screen. When one of the students does not know how to make their origami animal appear on the screen, other students kindly offer their help and explain how to hold the tutorials towards the screen. One boy is keen to help other students hold up the origami animals so the computer screen will recognize the mark. When another student struggles to get his origami fold recognized, the boy points to the camera whole on the screen and says, "The sensor is up there!" The student straight away tries to put the animal close to the camera and this does not work either so he picks up another animal. Only this one boy has difficulty making his animal appear on the screen. But he does not seem concerned about his animal's lack of appearance on the screen and he happily participates in the playing with the paper animals.

The children play together with *Save the wild*. On the occasions when two or more students are sitting and playing in front of the screen, the animations start interacting with each other. "Oh, the animals are kissing!" a boy exclaims out loud. The other children look up and they all giggle. "Try the wolf now," another boy says. The boys have discovered how the animals can interact with each other when several animals are held up together. "Oh, yeah!" (The children see a mole being carried away by one of the birds.)

After the children have finished playing with *Save the wild* they take their origami folds back to their desks. During the day we notice how many of the students continue playing with their origami folds and they make up little stories around their play. Two of the boys stop us and asks us to watch their new story. "Look, we have made a story about the unimaginable: a snake makes best friend with a fox."

5. DISCUSSION

There are a number of discussion points we have drawn out of our observations with *Save the wild*. While the case material we have presented does not warrant broad generalizations, there are several design relevant observations that have helped us build an understanding of how the system worked in these two contexts. Specifically, systems like *Save the wild* (a) support 'passive' augmentation (b) leverage everyday skills over digital literacy (c) allow for 'walk away' interaction and support the construction of user-generated narratives and (d) make small demands on existing infrastructures. They also may (e) create false or misleading
expectations for interaction. Our discussion is organized around these observations.

Support *passive* augmentation. In both the Math Trail and Discovery Table examples, the emphasis of the activity was tied to interacting with the digital on-screen environment. While the artifacts of interaction were physical, the activity relied on active engagement in a digital environment. In contrast, the activity and interaction for *Save the wild*’s origami activity is augmented by the digital environment, and the play (and learning to an extent) could take place within or outside of the digital scene. The physical origami figure is not only a means of manipulating digital interactions, so play with the physical artifact is enhanced, but not dictated through, what has been digitally augmented. This is what we refer to as “passive” (i.e. take-it-or-leave-it) augmentation, in an important respect, the digital experience is optional. Instead this is an example of education through experience and open-ended play, rather than through navigating information environments. *Save the wild* creates a digital experience by passively augmenting physical play. In this respect, fiducial markers were an excellent technology to support the embedded nature of this physical/digital interaction. Due to the passive nature of the markers they could be effortlessly attached to artifacts that carry pre-existing meanings and possibilities for interaction (other than as a means of interacting with the system).

Leverage everyday skills over digital literacy. The origami exercise itself was half the success of *Save the wild*. Children sat down and folded their own characters and objects. By the time the origami figures were successfully used to trigger animations on the screen, the children already had something invested in those characters. The ordinary skills required to understand instructions, follow fold paper and recognize animal figures were the only prerequisites for play. Most of the children discovered the possibilities of the marker technology without needing a particular (right or wrong) concept of that technology or a theory of how the computer could recognize the figures. Through the *Save the wild*’s focus on physical artifact construction allowed for a walk away interaction, where the learned experience at the installation lived on in the artwork away from the digital scene on the screen. This was observed in how the children continued playing with the figures throughout the day, and created their own stories after leaving the computer. While *Save the wild*’s inspiration embodied the ecological theme, it did not impose one on subsequent interactions, permitting a degree of playful latitude in the construction of new narratives around the origami figures.

Make small demands on existing infrastructure. We noted early in the paper that a central challenge in introducing technology to primary schools relates to the fact that the existing infrastructure in classrooms is just not dependable. While there are a number of systems that have been thoughtfully crafted for the learning goals of a primary education context, they often require more technology than one can be certain to find already in the classroom. Equally, teachers have different levels of confidence in, and competence with, involving new technologies in their curricular. In these respects, *Save the wild* made small(ish) demands on existing infrastructure and technology, requiring only a desktop computer with a webcam, and no internet connectivity. (Overall we are encouraged by the potential of fiducial AR (when the technology belongs to the setting) for the possibilities it presents for leveraging existing infrastructure. Participating teachers felt comfortable with the technology as they only needed to start up the software and then they could leave the children to explore.

Create false expectations. On a more critical note, the technologies meshed up in *Save the wild* (webcam, fiducial markers, animations) created some expectations for system behavior that were not realized in the interaction. For example, we found that when children were explicitly guided on how the technology worked (being prompted by an adult “here is where the camera is”), they tended to incorrectly place the markers too close to, or directly on, the lens. However when students experimented unaided with the system, they were able to observe how and where the scene became interactive, progressively exploring the system in general, explanations of the system in terms of its technology (“this is the camera” or “this is the marker”) fueled false expectations that disrupted interaction [23]. We also noticed another tacit expectation emerge in interaction, to do with multiple artifacts being used to trigger animations at the same time. When they “knew” how the system worked, the students tended to take turns holding markers to the screen. They rarely experimented with holding up multiple markers at the same time (a form of interaction the system actually supported). We fail that while fiducial markers (and other marker technologies) do support simultaneous markers, this was not behavior that was exported of the system. If we were talking about adult user behavior, we might be tempted to suggest that their expectations of system behavior were “imported” from elsewhere, i.e. from the behavior of other forms of technology such as swipe card readers, RFID, ticket machines, multiple烧 questionable only support a single input at a time. With respect to the junior age groups of users we are considering here, however, we are still looking for other explanations. However, false expectations were not always a detriment. The emergence of interactive difficulties also had a consequence of providing opportunities for peer learning. Students were able to learn from others how the system worked by observing and being shown how the figures created animations on the screen.

6. CONCLUSIONS AND FUTURE WORK

This study was to examine how existing playful activities could be augmented through the use of marker technologies. We found that the use of fiducial markers created an intuitive experience, without making heavy demands on the infrastructure already embedded within the classroom environment.

More studies of systems like *Save the wild* in real classroom settings are needed to determine the success of augmenting play to enhance learning, and the degree to which the discussion points we have identified carry over to other systems, other context and other classroom contexts. Careful attention to the existing infrastructure in classrooms can lead to the introduction of new technology that is not intrusive but supports and enhances existing classroom and learning activities. Through the use of the markers, physical activities (such as the origami) can be extended and raised to help reinforce the learning objectives, passively
augmented by technology. We are planning further studies in the area of seamless interaction through the use of tablets and augmented reality. We are continuing more studies in how walk-away interactions with technology can create more engaging, collaborative experiences in the classroom. While we wait for the large-scale introduction of technologies into classrooms, we can leverage existing infrastructure to creatively augment learning experiences in pedagogically meaningful ways.

7. ACKNOWLEDGEMENTS

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8. REFERENCES


Appendix 2: Article – Discovery Table

Discovery Table
Exploring the design of tangible and ubiquitous technology for learning in preparatory classrooms

Marie Bodén
School of Information Technology & Electrical Engineering, University of Queensland, Australia
marie.boden@uqconnect.edu.au

Andrew Dekker
a.dekker@uq.edu.au

Stephen Viller
viller@acm.org

ABSTRACT
In this paper we investigate how technologies can be designed to augment existing learning objects. By following an iterative interaction design process of working with teachers and children in a classroom environment, we can better design technologies through the augmentation (rather than replacement) of existing learning activities. Our case study – the Discovery Table – uses a variety of technologies to allow everyday plastic symbols of letters and numbers to be placed on a technology augmented table in order to provide visual, audible and tangible feedback to the children. Discovery Table demonstrates a first step towards more fundamental work towards successful design for tangible learning.

Author Keywords
Interaction Design, education, tangible, ubiquitous technology, inter-disciplinary, playful, in-situ evaluation.

ACM Classification Keywords
H.5.2 USER-INTERFACES (User-centred design, Prototyping, Interaction styles, Evaluation/methodology)
J.3.1 COMPUTERS AND EDUCATION: Computer uses in Education.

INTRODUCTION
With the ever-increasing availability of technology for use in learning environments, there are many opportunities for new classroom experiences. In Queensland, preparatory classrooms have been a part of the primary school system since 2007. These preparatory classes aim to prepare the young students for the start of year one of primary school. The classrooms are designed so that children will be inspired and supported in a playful and open-ended environment for learning and understanding the world. While there have been a number of technologies brought into these classrooms, current systems often require staff and students to be educated on how the technology can be used and supported. At the University of Queensland, groups of third year Interaction Design students were asked to design physical computing systems for ‘everyday interaction’. In this paper we present The Discovery Table as a case study to illustrate how physical computing technologies and in-situ study of the problem context have been combined in the design of Permission to make digital or hard copies of all or part of this work for personal or classroom use is granted without fee provided that copies are not made or distributed for profit or commercial advantage and that copies bear this notice and the full citation on the first page. To copy otherwise, to republish, to post on servers or to redistribute to lists, requires specific permission and/or a fee.

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a tangible learning environment, to support active learning in the preparatory classroom. By augmenting everyday artefacts which are both familiar to students and teachers and also fit with existing approaches to teaching and learning, technologies to support independent learning can be designed without the overhead of requiring teachers or students to be trained in their use.

The Discovery Table is an interactive system that enables individual children to learn independently about basic numeracy and literacy by displaying interactive animations related to the letters and numbers placed on the table. The target audience for this system is children (within the age range of 4 to 5 years old).

LEARNING IN PREPARATORY CLASSROOMS
Preparatory students are starting to play with and learn about letters and numbers to prepare them for grade one in primary school when they are introduced to reading and writing. In preparatory classrooms teachers read stories and there are several games to play involving learning, but these require the involvement of someone who already knows the letters and numbers to play along.

It is important to recognise the various learning styles: visual, auditory, and tactile (Flemming, 2001), so that the children have best possible environment to see their individual learning style. Auditory learning styles are particularly important for early stage learning of language, where phonics or letter sounds are one of the important aspects in learning how to read. Phoneme awareness is one cause of success in learning to read and thus Hulme and Snowling (2005) believe that lettersound knowledge is an important basic foundation to have as it develops rapidly and in tandem with the growth of phoneme awareness. The Jolly Phonics is a systematic phonics program designed to teach children English by learning the 42 sounds of the language to facilitate word formation (Lloyd, 1992).

Piaget (1972) observed that when children explore and interact with objects in their surroundings, they create a better understanding when they learn. On this basis, discovery learning is recommended and teachers are encouraged to use a wide variety of concrete experiences like the use of manipulative objects or going on field trips to help children learn. From a human centred design perspective, Norman (1999) concludes that people interact better with technology when they can control the technology through physical objects. Both Piaget and Norman’s theories originate in different fields, but both identify the importance of tangible interaction, particularly in support of learning situations.
In seeking inspiration for the design of Discovery Table, we examined a number of tangible interaction technologies which harness visual, audible and tangible interactions, to cater for the three identified learning styles in children.

RELATED WORK
Stoyrent (Stanton, O’Malley, Ng, Fraser and Benford, 2003) is an educational project aimed at creating an immersive environment to facilitate children’s learning in collaboration with adults. RFID tags were attached to clues, which are pieces of paper that trigger video clips with corresponding scenes projected onto the surface of a tent. It uses a physical interface like paper, acting as glue to bridge between the physical world and digital content. Stoyrent is based on the idea of supporting children learning while interacting with adults.

Toddy’s Life (Kanoh and Chakamori, 2001) is an installation artwork which allowed interaction by touching a collection of steel objects stuck onto a table’s surface. The objects are illuminated by light from a projector such that they cast a strong shadow onto the table top. When an object is touched, its shadow becomes animated to reveal characteristics of the object touched, or to change its shape entirely. Those attributes of physical objects are augmented in a number of works within this space, commonly with shadows (Worthington, 2005) or with the placing of everyday objects (Takahashi and Basadi, 2005).

In contrast to the above projected displays, the Drift Table (2004) by Gaver et al., uses a standard display built into the surface of a table, but restricts the view of the aerial photographic images to a circular view in the centre of the table. The portion of image viewed is then controlled by the placing of objects onto the table top, so that the image drifts in the direction of the objects, as determined by force sensors built into the table. This is an excellent example of how everyday objects can be augmented with technology to enhance and create a ludic design (Gaver, 2002), without destroying the existing form and function of the object. Rather than forcing a particular use for the Drift Table, users are left to explore (and discover) how the technology can be interacted with. “By avoiding suggestions of what people should do with the Drift Table, we created a situation in which they could play around with what they could do.” (Gaver et al, 2004)

Siftables (Merrill, Kalanzahi and Maes, 2007) are digital tiles that have the ability to display graphical symbols, as well as sense their orientation and proximity of other tiles. The emphasis on simple interactivity of these tiles (with their embedded technology) has the potential to facilitate both an engaging and pick up and play method of learning for preparatory age children. While Siftables appear to be an appropriate (and exciting) upcoming technology for use in these classrooms, the focus of this technology is for new activities within the classroom, rather than augmenting existing activities.

CLASSROOM INVESTIGATION
The design team working on Discovery Table made several visits to an inner city suburban school in Queensland. The two preparatory classrooms have an open setting with several doors between the rooms. Students from both classes can easily move in between the two classes. Each classroom is divided into several areas where the students can participate in various activities, e.g. reading corner, painting area, technical area, cushion corner, home play corner, discovery corner. The students are encouraged to play and learn both together and independently. There are three teachers teaching in the two classes and the teachers move between the classrooms depending on activity.

At a first visit to the school, teachers guided us through the classrooms. One teacher told the research students about “discovery corner”, which they were “particularly proud of”. The discovery corner is a place where students can play individually or together around a table which is set up by the teachers. The discovery corner features a theme that is being currently studied by the children. When we saw the discovery corner the theme at the time was seeds and plants. In the corner students could observe and investigate how seeds were growing. Students could examine existing potted plants, dried leaves and seeds. The idea was for the students to make drawings of their observations. In the discovery corner, students are encouraged to play and learn together, independently of each other. The enthusiasm of both teachers and students for this space inspired the research team to extend the idea of the Discovery Table towards a similar exploratory experience, but augmented with technology.

The design team continued to visit the school to conduct further exploration throughout the design process. This iterative process was invaluable in providing the design team with insights into realistic scenarios of use for the Discovery Table.

DISCOVERY TABLE
The objective of The Discovery Table was to design and test a prototype that incorporates physical computing technology that can be used effectively for everyday learning in preparatory classrooms. Discovery Table is an interactive table for primary school children between the ages of 4-5 years old, for them to use as a tool to learn the sounds and form of the alphabet and numbers from 0-9. The table is meant to function as a stand-alone activity that can be deployed and evaluated in situ - situated in a corner of the classroom environment for children to explore in their own time. The prototype was designed in a way that children could effectively operate the table without requiring teacher intervention for setup or supporting the child’s interaction.

DESIGN
The Discovery Table consists of a children’s size table (1.5m by 1m), which is augmented with a variety of technologies. At the front-facing corners of the table, RFID readers are placed underneath the table (see Figure 1) with coloured stickers on top of the table to indicate the extent of the sensor area for where objects should be placed. The rear side of the table is attached to a shelf system that holds above the table a projector, speaker and laptop enclosure. The projector is configured along with a mirror set at a 45 degree angle in a way that the projected
image covers the top surface of the table. To make the Discovery Table more attractive and to fit into the pre-classroom, the shelf system was decorated with curtains, colourful ribbons and stickers (see Figure 2).

Traditional plastic letters and numbers were purchased from a toy store - each of which represents a single letter or number. These symbolic objects are used as the physical interaction objects for the system, and are placed by users on the table (in the indicated regions). An RFID tag is attached to each object, which is read by the RFID readers and sent to the software. The software application is written in Adobe Flash, and presents animated visual and audio feedback based on the RFID tagged objects, which is projected directly onto the table.

Figure 1. Technical setup
Figure 2. In-situ setup

There are a number of visualizations, which are projected onto the table depending on which objects have been placed on top of the sensors. As a letter or number is placed, an animation occurs which represents the object. For example, when the letter B is placed on the table, a bat will fly in. If A is then placed on the table, the bat will fly off with an animated apple. As the visuals appear the table produces an auditory representation of the visual. Table 1 below explains the various kinds of interaction that the table reacts to in more detail.

<table>
<thead>
<tr>
<th>Type</th>
<th>Icons</th>
<th>Visual</th>
<th>Audio</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 Letter</td>
<td>A</td>
<td>Apple Animation</td>
<td><em>Apple</em></td>
</tr>
<tr>
<td>2 Letters</td>
<td>B</td>
<td>Bat eating an Apple</td>
<td><em>Bat</em>, <em>Apple</em></td>
</tr>
<tr>
<td>1 Number</td>
<td>5</td>
<td>5 bubbles appear</td>
<td><em>Five</em></td>
</tr>
<tr>
<td>2 Numbers</td>
<td>2, 3</td>
<td>2 bubbles and 3 bubbles appear, and float towards each other</td>
<td><em>Two and three</em>, <em>Five</em></td>
</tr>
<tr>
<td>Letter A</td>
<td>C</td>
<td>5 cats Animation</td>
<td><em>Five Cats</em></td>
</tr>
</tbody>
</table>

Table 1. Interaction types

Through this simple physical interaction of placing two plastic numbers/letters onto marked areas of the table (see Figure 3), children are able to see and hear how these letters/numbers are used to represent real world objects (such as an Apple). The animations presented by the system are styled as cartoons, use bright and vivid colours and exaggerated animations. The audio recordings are delivered in a similar way to children’s TV shows, where the voice is spoken with a child’s voice. The system is also designed to take into account the exploratory nature of the interaction, and will automatically reveal visualisations as children switch letters/numbers. Additionally, interaction problems with placing letters or numbers upside down are avoided due to the RFID technology (in that the physical objects simply need to be in range rather than placed precisely). The on-screen visuals of the letters in use in words also assists children in understanding the correct orientation for the symbols.

Figure 3. The Discovery Table in use

STUDY

Discovery Table was installed in a preparatory classroom. Children from two classes (40 mixed gender students) were invited (on a voluntary basis) during two school days to play at the Discovery Table. The student design team decided together with teachers to spend one day ahead of the testing in the classes so the preparatory students would be acquainted with the new adults. A video camera was set up to record activities at the table and researchers stayed close to the table so children could ask for help if needed. During the tests, one of the designers made observations and took notes of the activation that occurred. After testing, we interviewed the teachers about their thoughts on how Discovery Table worked with the preparatory students. The interview was set up as a semi-formal discussion with all teachers.

The preparatory students were very curious and interested to learn what we were doing when we first started setting up the Discovery Table. At first the children would try to press the part of the table where the RFID reader was placed (on the surface you can see arrows pointing to this part), when this did not work the children then tried placing the letters and numbers there. Quickly the children discovered that animations occurred on the table when they placed a letter in a particular part of the table.

On occasion, some children would place a letter or number upside down on the table. However (due to the nature of RFID), on seeing the animation with the letter or number the right way up, the student would then correct the orientation of the physical letter. We found that it was unusual for one child to play at the table alone. If one child would start playing with Discovery Table, then very soon a second child would join in with the first, and they played together at the table with the numbers and letters in much the same way as when they played with other resources in the classroom.

When using the numbers children started to say the numbers aloud after the related audio was played on the
speakers, or they would point to the bubbles that appeared on the table to count them. The students enjoyed playing with the Discovery Table and they started to come back telling us “I like this one” and asking, “Can I play more?” One of the children tried Discovery Table and she came back for a new play with the table, only this time the girl had brought a paper and pen with her (Figure 3). When she played with the table she started tracing drawings of the animations and copying the words that appeared on the table. Afterwards we found the girl sitting with a group of other friends in the cushion area and they were reading to each other from the papers they had written at Discovery Table.

Teachers observed how the students enjoyed playing with Discovery Table. In the interview with teachers after the trials, all teachers were enthusiastic about the Discovery Table corner. Teachers discussed how the table suited the classroom activities and that it was good that students could learn independently without the teachers sitting next to them. “It’s (Discovery Table) useful to support us in teaching the kids about alphabet and numbers,” one of the preparatory teachers said. The teacher explained how they normally have to physically participate in games with letters so the students can be taught the right sounds to match each individual letter. With Discovery Table all teachers said they felt the students could work on their own and teachers had time to focus on other activities. Teachers also pointed out how well the Discovery Table matched the learning activities they normally run in the preparatory classrooms.

DISCUSSION
The teachers were initially nervous about bringing the technology into the classroom, as they did not feel comfortable operating the technology. Discovery Table was designed to suit the existing classroom environment so that the table could be used without children or teachers having to learn how to operate it. The table suited staff that had little experience of using technology, as they did not need special training. Once the teachers discovered the children interacted with the technology without any teacher instruction they became more relaxed about it. The teachers were much more positive about Discovery Table and they started discussing ideas of a more advanced table where the students could play around with letters to form words.

Discovery Table was intentionally designed to support all three learning styles that exist in a classroom, with tangible letters and numbers, audio, and visual activities. The audio from the speakers is an important part of the learning and significantly performs a role usually played by the teacher in providing the students with the appropriate sounds for the letters and numbers.

Once the children began tracing the cartoons from the table, the drawings formed a bridge between the Discovery Table and other classroom locations and activities. Compared to the existing “discovery corner”, the technology used in Discovery Table provided instant feedback to the students to support their learning.

CONCLUSION
By designing to match already established learning in a preparatory classroom, Discovery Table proved to be a successful installation. The interaction design process followed was important in ensuring that the technology designed for the classroom was creative and innovative but at the same time also considered the context and the learning theories that already operated there. Discovery Table is the start of a longer term investigation into the use of tangible artefacts in collaborative settings for teaching and learning together with education researchers.

ACKNOWLEDGEMENTS
Thank you to Lufta Thameen, Diem Nguyen, Melody Co, Hoomie Hung. Zaire Zannirian, interaction design students at The University of Queensland. Thank you also to participating preparatory students and teachers.

REFERENCES
Huie, C., Snowling, M., Caravolas, M., Carroll, J. (2005) Phonological Skills Are (Probably) One Cause of Success in Learning to Read: A Comment on Castles and Coltheart. Scientific Studies of Reading, 9 (4), 351
Appendix 3: Participant Information Sheet (Parent/Guardian)

Spelling Bug
Spell training with adaptive software.

Parent/Guardian Information Sheet
Your child is being invited to take part in a research study. The Principal and participating classroom teachers have agreed to allow this research to take place at your school. Before you decide if you would like your child to participate, it is important for you to understand why the research is being done and what it will involve. Please take the time to read the following information carefully and discuss it with your child’s teacher if you wish. Ask us if there is anything that is not clear or if you would like more information.

The Spelling Bug research project is exploring how intelligent software can be designed to suit a classroom environment. Intelligent software can be used for individualising tasks to suit every student. The purpose of individualising tasks for the students is to ensure the child is challenged with suitable tasks depending upon their ability and level, at the same time students feel like they are working on the same task as their classmates. Our aim is to investigate how the underlying technology may be designed to best suit a classroom environment and also to find suitable modern technology to complement traditional teaching for maximized learning.

In this study we would like to invite your child to work with a spelling software system during term 4. The activity will be initiated by the teacher and the children will be working with the software for about ½ hour per week as a complement to ordinary spelling activities. The software is designed so it appears as a computer game for the students and it should be an enjoyable experience for the children.

All data collected will be encrypted so your child’s identity will not be recognized in the study. We will keep a data log of the students use and progress over time and the teacher will have access to this data as it may be beneficial to the student’s learning. After the test period some students may be invited to an interview where we will ask questions on the children’s experience interacting with the “spelling game” and what suggestions they might have for improvements.

By taking part in this study, you and your child are contributing valuable input to the development of educational software. The classroom teacher has agreed to use Spelling Bug software as part of their program for teaching spelling and we ask for your consent to log your child’s activities and to interview your child for 15 minutes after the test period. Participation is voluntary and your child may withdraw and leave the study at any time. If you no longer wish for your child to be involved, you may contact the researchers or your child’s teacher and your child will be withdrawn from the study. During the test period, only children who have been given permission will be included in the research. Children, who are choosing not to participate in the study, may still work with Spelling Bug but there will be no collection of their activities and they will not be included in the research study.

All information collected during the research will be kept strictly confidential, in an encrypted format stored in a secure location. On completion of the evaluation, an analysis of the results will be forwarded to the Principal and will be available to all interested participants and parents.

Please feel free to contact us if you have any questions, concerns or feedback about participation in this study.

Marie Boden, Dr Stephen Villier & Dr Shelley Dole
School of Information Technology & Electrical Engineering
University of Queensland
marieb@itee.uq.edu.au & villier@itee.uq.edu.au & s.dole@uq.edu.au

This study has been cleared by one of the human ethics committees of the University of Queensland in accordance with the National Health and Medical Research Council’s guidelines. This study is approved by Education Queensland and your school’s principal. You are of course, free to discuss your participation in this study with project staff (Marie Boden is contactable on 3365 1677). If you would like to speak to an officer of the University, you may contact the Ethics Officer on 3365 3924.

Researchers associated with the study have been in touch with a Working with Children suitability card (Blue Card).
Appendix 4: Consent Forms (Parental/Guardian and Teacher)

Spelling Bug
Spell training with adaptive software.

Parental/Guardian Consent Form

✓ I have read and understand the information sheet detailing this project.
✓ I acknowledge that my child may withdraw from the project at any time without consequence.
✓ I understand that this project is not grading or examining my child.
✓ I understand that all information collected during the research will be strictly confidential.
✓ I understand that all data related to my child may be published for research purposes only and that this data will be de-identified.

I, ____________________________, allow my child, ____________________________, to participate in this project.

Signature of Parent or Guardian*: ____________________________

Date: ____________________________

Guardian has legal authority to give permission on behalf of the child.
Address of Guardian: ____________________________
Witness to Guardian Signature: ____________________________

Participant (student) Consent Form

I agree to participate in this project:

Name: ____________________________ Grade: ____________________________

Signature: ____________________________

Date: ____________________________

This study has been cleared by one of the human ethics committees of the University of Queensland in accordance with the National Health and Medical Research Council’s guidelines. This study is approved by Education Queensland and your school’s principal. You are of course, free to discuss your participation in this study with project staff (Marie Boden is contactable on 3365 1657). If you would like to speak to an officer of the University, you may contact the Ethics Officer on 3365 3924. Researchers associated with the study have been issued with a Working with Children suitability card (Blue Card).
Appendix 5: Consent Forms (Parental/Guardian and Teacher)

Spelling Bug
Spell training with adaptive software.

Teacher Consent Form

☑️ I have read and understand the information sheet detailing this project.
☑️ I understand that I may withdraw from the project at anytime.
☑️ I am aware that all information I provide is confidential and will not be reproduced without my permission.
☑️ I am aware the data collected may be published for research purposes only. This data will be de-identified.

I agree to participate in this project:

Signed: ___________________________ Date: ___________________________

Printed Name: ___________________________ Date: ___________________________

This study has been cleared by one of the human ethics committees of the University of Queensland in accordance with the National Health and Medical Research Council’s guidelines. This study is approved by Education Queensland and your school’s principal. You are of course, free to discuss your participation in this study with project staff. (Marie Boden is contactable on 3361 4277, if you would like to speak to an officer of the University, you may contact the Ethics Officer on 3365 3924. Researchers associated with the study have been issued with a Working with Children suitability card (Blue Card).
Appendix 6: Pre-Interview Questions for Teachers

Interview form for primary school teachers (Pre)

Background information
How long have you been teaching?
What grades have you been teaching?
What type of classes have you been teaching? Mixed genders, mixed ages etc.
What types of documents or information are you given beforehand on what government policies you have to follow when teaching spelling?
What instructions are you given from your principal on how to teach spelling?

Teaching spelling in grade four procedures
Can you tell me how you normally proceed when teaching spelling for a class in grade four?

Does the teacher separate between teaching spelling and assessing spelling?

Can you as a teacher see what different learning strategies different students are using when learning to spell? Explain and try to exemplify what you mean.

Quality control
How do you keep record on how the teaching is progressing within the class?
How do you keep record on each individual student’s spelling progress?

Can you think of anything that would be a useful help for you as a teacher when working with spelling? Can you please explain your thoughts?
Appendix 7: Pre Interview Questions for Students

Marie Boden

Spelling Bug

Interview with students about spelling
(A group of 4 or 5 students will be interviewed together. One student will choose a group of friends and the interviewer will initiate a chat around spelling.)

No of boys:
No of girls:
Ages:

  - Can you remember when you first started learning spelling?
    Was it hard or easy?
    How did you feel about it?

  - How do you feel about learning spelling now?

  - Can you please tell me what activities you do at school when learning to spell?
    Which exercises do you like the most?
    Which exercises do you like the least?

  - Do you think there are any other activities of working with spelling?

  - Can you think of any suggestions of activities for working with spelling?

  - Do you ever work with spelling outside of school? Eg at home.
    What activities do you work with then?
    Do you like these activities?

  - Have any of you worked with a computer program that trains spelling?
Appendix 8: Post Interview Questions for Teachers

Qualitative interview with teachers who have used Spelling Bug

1. How do you feel Spelling Bug has worked with your Students? Please explain why?

2. Do you feel that Spelling Bug has helped improve the students spelling ability? Why?

3. Which particular students have improved as a result of using Spelling Bug (if any)? How can you tell?

4. Would you consider using Spelling Bug as an integral part of your spelling program after this study? Please elaborate.

5. How frequently do you believe the students need to work with Spelling Bug for best learning outcomes?

6. Did you find that your students enjoyed working with Spelling Bug? Could you please give me examples of why you got this impression?

7. Were there any of your students who you found Spelling Bug was not suitable for them? Why?

8. Do you think Spelling Bug is appropriate computer software for grade three/four students? Why? Would it be appropriate for other grades? Please elaborate.

9. What do you think about the user interface of Spelling Bug? Colours? Is it easy or difficult to work with for the students?
Appendix 9: Post Interview Questions for Students

Questions

- Do you think there is anything you can do to improve your spelling?
- Do you know exactly what parts of your spelling you need to work harder on?
- Do you think you became a better speller after using the Magic Spell?
- Was it hard to win beans and wands?
- Was it difficult or easy to spell in Magic Spell?
- Did you find it got harder or easier to spell after a while?
- Did you like to trade wands with other students?
- Was it easy or difficult to understand how to work with the Magic Spell?
- Was there something that you found tricky when you started working with the magic Spell?
- Was it difficult to know where to click when you wanted to do something in the Magic Spell?
- When you did something wrong in the Magic Spell, did you understand what you had done wrong? Did the software indicate what you need to do to correct?
- Do you think it is useful to see the statistics on how you are progressing with the spelling in Magic Spell?
- Did you think more about the spelling rules that the statistics had shown you needed to work on when you continued playing Magic Spell?
- Was Magic Spell a fun or boring game?
- Do you think that Magic Spell is a good complement to other spelling exercises?
## Appendix 10: Spelling features

<table>
<thead>
<tr>
<th>Regular expression</th>
<th>Descriptor</th>
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<td>2-vow</td>
</tr>
<tr>
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<td>2-eo</td>
</tr>
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<td>bb</td>
</tr>
<tr>
<td>*[nn].<em>.</em></td>
<td>nn</td>
</tr>
<tr>
<td>*[mm].<em>.</em></td>
<td>mm</td>
</tr>
<tr>
<td>*[cc].<em>.</em></td>
<td>cc</td>
</tr>
<tr>
<td>*[ck].<em>.</em></td>
<td>ck</td>
</tr>
<tr>
<td>*[pbdw]t].*</td>
<td>-t</td>
</tr>
<tr>
<td>*[bt].<em>.</em></td>
<td>bt</td>
</tr>
<tr>
<td>*[pt].<em>.</em></td>
<td>pt</td>
</tr>
<tr>
<td>*[ct].<em>.</em></td>
<td>ct</td>
</tr>
<tr>
<td>*[wrtpgcs]h.*</td>
<td>-h</td>
</tr>
<tr>
<td>*[wh].<em>.</em></td>
<td>wh</td>
</tr>
<tr>
<td>*[st]?ch.*</td>
<td>ch</td>
</tr>
<tr>
<td>*[sh].<em>.</em></td>
<td>sh</td>
</tr>
<tr>
<td>*[gh].<em>.</em></td>
<td>gh</td>
</tr>
<tr>
<td>*[+th]+*</td>
<td>th</td>
</tr>
<tr>
<td>*th].<em>.</em></td>
<td>th</td>
</tr>
<tr>
<td>*kn].<em>.</em></td>
<td>kn</td>
</tr>
</tbody>
</table>
.*th$  th|
.*xc*.  xc
.*[sz].*|[aeiouyx][aeiouy].*

vow-c-vow
.*z.*  z
.*sc[aeiouy].*  sc
c
g[aeoui].*  g
c[aou].*  hard-c
g[aou].*  hard-g
c[ei].*  soft-c
g[ei].*  soft-g
*[iov]?e?es$  plur
*[io]?e$  sing
*[rtphgfdskvbnm]y$  con-y
*[euoia]y$  vow-y
*[st]ion.*  -ion
*[dbgkcp]e[sd]?$  -le
.*ing$  ing|
.*ng.*  ng
.*age$  age|
.*sed$  sed|
.*w$  w|
Appendix 11: Pre- and post deployment spelling test (Year 3 students)

<table>
<thead>
<tr>
<th>Spelling Bug - Spelling Test</th>
</tr>
</thead>
<tbody>
<tr>
<td>The spelling mistakes in these sentences have been circled. Write the correct spelling for each circled word in the box.</td>
</tr>
</tbody>
</table>

1. Sarah **lik** playing tennis.

2. The rose is a pretty **flouer**.

3. Anna's pet is a **spida**.

4. We are baking **bred**.

5. My best **frend** is coming for a sleepover.

6. Dad bought a new jeans **jaket**.

7. The teacher was **hapily** singing to the class.

8. John ate an red apple at fruit **brake**.

9. Mum **parkt** the car in the garage.

10. When it is **sommer** we swim a lot in the pool.
### Spelling Bug - Spelling Test

The spelling mistakes on these labels have been circled. Write the correct spelling for each circled word in the box.

<table>
<thead>
<tr>
<th>hand</th>
<th>brejk</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>driver</th>
<th>seet</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>petroll</th>
<th>tank</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>front</th>
<th>wheal</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
</tr>
</tbody>
</table>

### Read the text about *Pets.*

Each line has one word that is incorrect. Write the correct spelling of the word in the box.

Alex had allways wanted a pet,

a littel kitten of his own was his favourite.

Mum had promised Alex a pet for his bithday,

if he worked prooley with his homework.
Read the text about *Emma*.
Each line has one word that is incorrect.
Write the correct spelling of the word in the box.

<table>
<thead>
<tr>
<th>Emma knew she shoud do the</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>homework, so she was very happy when her</td>
<td></td>
</tr>
<tr>
<td>mum sugested to invite Wendy over.</td>
<td></td>
</tr>
<tr>
<td>Now the girls can help each other with the sience homework.</td>
<td></td>
</tr>
</tbody>
</table>

Read the text about *Tennis*.
Each line has one word that is incorrect.
Write the correct spelling of the word in the box.

| I played a tenins gam on Saturday. |  |
| I was very nervous as many of my frends |  |
| came to see me, even my tetcher came. |  |
| It was an easy game and it ended for to one. |  |
| I was the winer. |  |
Appendix 12: Pre- and post deployment spelling test (Year 4&5 students)

**Spelling Bug - Spelling Test**
The spelling mistakes in these sentences have been circled. Write the correct spelling for each circled word in the box.

<p>| | | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Many horses are good at runing.</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>The airplane flew ova Brisbane.</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>I ate a big pice of the cake.</td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>We are baking bred.</td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>My mum compeated in the Olympic Games.</td>
<td></td>
</tr>
<tr>
<td>6</td>
<td>Mr Dole wears a black leatha jacket.</td>
<td></td>
</tr>
<tr>
<td>7</td>
<td>The gorila is my favourite animal.</td>
<td></td>
</tr>
<tr>
<td>8</td>
<td>John ate a red appel at fruit break.</td>
<td></td>
</tr>
<tr>
<td>9</td>
<td>In atumn the leaves on the trees turn yellow.</td>
<td></td>
</tr>
<tr>
<td>10</td>
<td>I have an apointment at the dentist on Monday.</td>
<td></td>
</tr>
</tbody>
</table>
## Spelling Bug - Spelling Test

The spelling mistakes on these labels have been circled. Write the correct spelling for each circled word in the box.

<table>
<thead>
<tr>
<th>Word</th>
<th>Correct Spelling</th>
</tr>
</thead>
<tbody>
<tr>
<td>hand</td>
<td></td>
</tr>
<tr>
<td>brejk</td>
<td></td>
</tr>
<tr>
<td>driver</td>
<td></td>
</tr>
<tr>
<td>seet</td>
<td></td>
</tr>
<tr>
<td>petroll</td>
<td></td>
</tr>
<tr>
<td>tank</td>
<td></td>
</tr>
<tr>
<td>front</td>
<td></td>
</tr>
<tr>
<td>wheal</td>
<td></td>
</tr>
</tbody>
</table>

## Read the text about Cyclops.

Each line has one word that is incorrect. Write the correct spelling of the word in the box.

Normally everyone can see too eyes
when they look at themselves in the miror.

Cyclops though hav one big eye.

When we go diving we happyli use a cyclop
to protect our eyes.
<p>| | | | | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Spelling Bug - Spelling Test</strong></td>
<td>Each sentence has one word that is incorrect. Write the correct spelling of the word in the box.</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>18</td>
<td>Many stars can be seen in spase.</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>19</td>
<td>The line slowly moved forwerd.</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>20</td>
<td>I can count to nummer 1000.</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>21</td>
<td>I really hait the taste of sprouts.</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>22</td>
<td>The neighbour's have a vicshious dog.</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>23</td>
<td>Mr Bray is training to run in a marothan.</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>24</td>
<td>Sofia enjoys taking photos with her new cammera.</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>25</td>
<td>The bus stoped outside the school.</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>