Enhanced Classroom Learning using Wireless-enabled Mobile Devices

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Abstract – Context: Recent developments in technology have made it feasible to integrate mobile devices into classroom teaching, allowing students to interact with learning materials and teachers. This study aims to investigate the introduction of wireless-enabled mobile devices and observe the impact they have on traditional pedagogical techniques.

Aims: To observe and evaluate the impact of Technology Enhanced Learning (TEL) on students’ performance, this includes: addressing student participation; improving student concentration; providing information on the reception of learning material leading to an improvement in the overall academic performance of students.

Method: Software was developed and deployed on wireless-enabled mobile devices, so that students may be provided with Personal Digital Assistants (PDAs) during lectures, allowing them to interactively participate with the teacher and learning materials.

Several experiments were carried out to gauge the effectiveness of the TEL software, collecting quantitative data on the retention of information and academic success of students during lectures. Additionally, qualitative data was collected from students on their experiences with the technology.

Results: Having conducted several experiments using the TEL software it became clear that the functional requirements developed to enhance the traditional pedagogical paradigm were effective, however the intermittent nature of wireless-enabled mobile devices often interrupted classes.

Conclusions: The benefits offered by TEL are often overshadowed by failures in the technology infrastructure used. Before these benefits are explored further, and new methods of enhancing the traditional pedagogical paradigm are designed, a stable and reliable platform must be developed. This may become achievable through advancements in wireless networking, new mobile technologies and dependable programming techniques.

Keywords – Technology Enhanced Learning (TEL), Classroom Interaction, Pedagogical Techniques, Mobile Devices, Mobile Software.

I. INTRODUCTION

Technology Enhanced Learning (TEL) is the term used to describe the application of technology and electronic devices to assist and improve education. In addition to classroom teaching, technology is able to support students in the library, at home and in many other environments outside of the school. Thanks to modern distributed networks, such as Metropolitan Area Networks (MANs) and the Internet, TEL promises to greatly increase the availability and flexibility of education (Hewitt-Taylor, 2003).

TEL is a relatively modern emerging field of education and computer science, which has many themes. These include: technology assisted long-distance learning; classroom interaction; interactive learning materials and supporting homework (such as CD-ROM based encyclopaedias).

The majority of existing research and development in this field has been focused on Distance Learning, attempting to replace face-to-face human interaction with technology. This highly contrasts with traditional teaching methods, in which teachers have face-to-face contact with large classes and are supported by little or no technology (Zhang, Perris, & Yeung, 2005). This project, however, will address the more traditional Higher Education
teaching paradigm; a single lecturer addressing increasingly large audiences of students, with little, or no, time for one-on-one interaction in lectures.

This project proposes to bridge the gap between these two ends of the teaching spectrum by introducing TEL into the classroom. This methodology combines new technology based enhancements with the traditional pedagogical techniques utilised by teachers.

To accommodate the increasing range of technology supporting modern education, the emphasis has shifted from teaching to the ‘learning and development’ of students. Instead of primarily teaching, teachers are required to adopt a coaching and support role (Geisel & Meijers, 2005). In their investigation of educational change, Geisel and Meijers, observed that technology enhanced learning is only possible within ‘strong learning environments’. Since Durham University has been awarded the only Centre of Excellence in Teaching and Learning (CETL) for Computer Science in the United Kingdom, the department’s Advanced Learning in Computing (ALiC) initiative will provide a suitable test-bed for this project.

A. Motivations for Project

The aim of TEL is to improve the academic performance of students, whilst maintaining the value of traditional pedagogical techniques used by teachers.

Shortly before leaving office, Tony Blair set a 2010 deadline for “50% of all 18 to 30-year-olds to participate in higher education” (Andalo, 2007). An implication of this is the increasing ratio of students-to-teachers, which can be observed in a recent addition to the Durham University campus. The Calman Learning Centre, a state-of-the-art custom-built teaching facility finished in 2007, houses the university’s largest ever lecture theatre with a 400-person capacity. It is hoped that by introducing TEL the quality of teaching may be preserved despite the larger scale of classroom teaching.

This increasing ratio could further exacerbate the problem faced in smaller applications of the traditional higher education (HE) teaching paradigm, in which the common means for a teacher to encourage students to participate is to ask open questions of their audience. However, there are substantial drawbacks to this technique. It was observed by Wit that students are often uncomfortable interacting with teachers in front of their peers, noting that ‘no matter how much a lecturer stresses that making mistakes is encouraged, public humiliation seems a deeply rooted anxiety’ (Wit, 2003). A student in Zhang’s experiment commented, “I have to prepare beforehand in order to comment… I don’t want to ask silly questions” (Zhang, Perris, & Yeung, 2005).

There have been a large number of studies over several decades that have investigated the attention spans of HE students. Bligh noted that the first lapse in the concentration of students in a HE lecture is likely to occur between 10 and 18 minutes. This is a significant threat to the performance of HE students, as a typical lecture lasts between 50 and 60 minutes. To counteract this problem, Bligh noted that a 25 second rest period would increase a student’s level of concentration for up to 30 minutes following the break. He continues to suggest that ‘a change is nearly as good as a rest’, which suggests that by interspersing lessons with TEL-based activities, the concentration and attention spans of students could be improved (Bligh, 2000).

Traditionally, teachers have used homework questions and classroom tests to assess the level to which students understand the learning material covered in classes. These results often identify common weaknesses, allowing teachers to redeliver learning material in greater detail to clarify these weaker areas. Due to the large time overhead of marking an entire
class’ work, the redelivered content is often given several weeks, if not months, after the original content was delivered. Pedagogical studies have shown that, to provide the greatest benefit, any corrections and clarifications to the original learning material covered should be delivered as soon as possible after the original material has been delivered.

Utilising TEL to provide “live” (or synchronous) feedback on the reception of learning material delivered would allow teachers to identify areas that may require further clarification. Furthermore, it is feasible to utilize this information to provide students with targeted learning materials outside of the classroom (asynchronously) to further assist their learning.

B. Keys to Success

A solution that addresses the issues highlighted as motivations for this project would not guarantee its success. Well-produced TEL software may be undermined if it has a detrimental impact on the traditional pedagogical techniques of teachers, leading to a net loss in teaching quality.

The TEL software produced should not require teachers to make substantial changes to the learning material they wish to deliver. Instead, it should be feasible to introduce TEL software that has a minimal impact on the content of classroom teaching.

The majority of HE courses are restricted by the number of contact-hours teachers have with students. At Durham University, a typical module has two classroom hours per week over a course of 20 weeks. It is important that this limited resource is not further constrained by the introduction of TEL into the classroom. Wit noted some of these drawbacks in his study ‘setting-up the system takes time and there have been occasional problems with the projector; the “glamour” of the system can distract from the learning aspect or, worse, leads to asking questions just for the sake of it’ (Wit, 2003).

Furthermore, TEL software must be robust and reliable enough to be available whenever students are required to interact with technology. However, at the same time, the software should be non-intrusive, ensuring that during periods when it is not required, students are not distracted by it. As noted by Dawabi; traditional teaching causes ‘almost no noise or other distraction’; this should be an additional objective of TEL (Dawabi, Wessner, & Neuhold, 2004).

II. RELATED WORK

Due to the emerging nature of the TEL field the research into such methods are in an infantile stage. This chapter considers relevant studies conducted in both the educational and software engineering fields.

A. Investigation of Benefits

As outlined in the Motivations for Project there are several benefits expected from a successful implementation of TEL, leading to an overall increase in academic performance.

1) Acquisition of Knowledge

When considering personal study skills, McFadzean (2001) suggested that to be most effective, students should be proactive whilst attempting to acquire information. McFadzean
also suggested that it is the responsibility of the teacher to interact with students to encourage such involvement. Whereas, Dornisch and Sperling (2006) suggest that large blocks of information should be modified to include rich content such as diagrams, tables, illustrations, animations, etc. It is believed that this representation of information will ‘aid learner selection and attention to important information’ and ‘help organisation and integration with prior knowledge’.

Dornisch and Sperling extensively documented the effects of prompted Elaborative Interrogation (EI); this manipulation ‘supports learner knowledge construction by requiring learners to answer self-generated or “why” questions that are provided so that students make connections with prior knowledge to promote deeper processing’. During their investigation they experimented by putting EI questions in the margins beside passages of text, allowing students to consult the text when answering the question. The study showed that the EI process was more effective for immediate and delayed factual recognition than the traditional Repetition Control (RC) learning (Dornisch & Sperling, 2006).

By interspersing classes with “rich” materials delivered through TEL, this project should be able to introduce such benefits to the classroom. Developing a generic platform permits the software to deliver a diverse range of content, including audio, video and other multimedia.

2) Student Participation

During their investigation, Zhang et Al. (2005) found that students are often apprehensive about actively participating in large groups, noting that students are not enthusiastic about contributing publicly. One student commented, ‘I have to prepare beforehand in order to comment… I don’t want to ask silly questions’. This point has been further emphasised by Wit (2003), who noted that ‘no matter how much a lecturer stresses that making mistakes is encouraged, public humiliation seems a deeply rooted anxiety’.

By providing an anonymous-feedback platform, this project should allow students to be less apprehensive about contributing. Students who are encouraged to contribute will make a psychological investment in their responses. Wit identifies this may be useful for initiating discussion as it converts a student ‘from a passive attendee into an active participant for whom the outcome has some emotional value’; this is an example of how TEL may be used to encourage and contribute to traditional pedagogical techniques.

Furthermore, Scheele (2005) proposes that because lessons do not contribute to any formative assessment, students lack motivation to actively take part. However, if a form of assessment could be added to lessons an extrinsic motivation could be introduced, encouraging students to pay attention and participate through fear of failure if they do not.

3) Feedback on Reception of Learning Materials

Whilst considering the traditional HE paradigm, Bligh (2000) notes that ‘one of the most serious criticisms of the lecture method is that the lecturer has no feedback on his performance’. Investigating the possible improvements that TEL can contribute to traditional pedagogical techniques, Wit (2003) noted that it is possible for TEL to ‘provide useful feedback for the lecturers on the reception of their lectures’. Using TEL to test the knowledge of students gives teachers ‘the opportunity to adapt the lectures to the perceived difficulties of the class in front of them’ (Wit, 2003). This further emphasises the value of encouraging student participation (as highlighted above).
4) Improving Concentration

Bligh noted that the decrement in attention during traditional HE lessons has a ‘consequent need of variation in teaching methods’ in order to restore concentration to a productive level (Bligh, 2000).

This, therefore, suggests that in addition to the direct benefits highlighted above, the introduction of TEL into the classroom may have a secondary effect on students’ perceptiveness to traditional pedagogical techniques. Figure 2 demonstrates the impact of this varying stimulation on the attention of students.

![Attention of students in a lecture measured through heartbeats per minute (Bligh, 2000)](image)

This argument was supported by Gage & Berliner (1993), who introduced 10 methods for teachers to maintain the attention of students for longer periods of time. The most notable of these, in the context of this project, are: varying the stimuli; changing communication channels; introducing physical activity; asking questions; student self-questioning.

5) Tailored Learning

The increasing ratio of students to teachers in the HE classroom (as described in Section I.A – Motivations for Project) risks further depersonalising the HE teaching paradigm. The constraints of such large class sizes prevent teachers from tailoring learning to each and every student. Formative assessments are often used to gauge a class’ level of understanding, however there is little use of the individual student data produced by this exercise.

Using this TEL project to provide classroom-based formative assessment will allow
students who are particularly weak to be flagged for attention, and perhaps one-on-one tuition. However, this may prove to be impractical for large class sizes.

To solve this problem, the TEL system should automatically refer students who are struggling with concepts (as identified by incorrect answers) to relevant sources of information. This will allow students to be automatically set homework on their weak areas by assessing their in-class performance.

B. Related Technologies

Notable parallels can be drawn between the objectives of this project and two other classroom-based TEL systems: Personal Response Systems (PRSs) and the Wireless Interactive Lectures MAnheim project (WIL/MA). Before the project requirements were defined, these systems were subject to an in-depth domain analysis, highlighting the important features, benefits and drawbacks of each system.

These TEL systems allow students to answer questions asked by the teacher using electronic devices. Feedback from the responses of students is then shown to the teacher, allowing them to gauge the reception of learning materials.

1) Personal Response Systems

Personal Response Systems (PRSs) require each student to be given a hand-held device, known as a ‘clicker’, which has a number of labelled buttons. The teacher asks a question (often displayed on an overhead projector) and gives students a number of possible answers. Students are required to point their ‘clicker’ at a receiver (required for infra-red connectivity) and press the button that best represents their answer. This information is collected by the receiver and displayed to the teacher.

The PRS system is not required to be aware of the question asked, it simply collects the number of students that have elected each option. This allows teachers to spontaneously add new questions to their TEL experience during class time.

A major drawback of PRSs is the limited range of answers that students are able to give. Wit noted that ‘multiple-choice questions are sometimes seen as restrictive and assessing only a certain type of knowledge’. This type of question, however, is useful if the teacher wishes to canvas the opinions of students (i.e. questions that do not necessarily have a correct or incorrect answer), which may lead to the initiation of a discussion or debate on the possible answers.

2) WIL/MA

The Wireless Interactive Lectures / MAnheim (WIL/MA) project is a PDA-based application that allows students to interact with their teachers in two ways: by creating free-hand drawings/writing that is visible to teachers and by answering pre-defined multiple-choice questions (MCQs).

Although the MCQ functionality of this software does not offer any significant benefits over the earlier PRS technology the ability for students to make free-hand contributions is somewhat unique. A significant drawback to their free-hand approach is the demands on teachers’ time to monitor the input of students and take action as necessary. During an observation of an experiment with WIL/MA this was such a significant time overhead that a second teacher was required to monitor the students’ input (whilst the primary teacher taught the class using traditional pedagogical techniques).
The PDA-based software interacts with the teacher’s central computer using a wireless network. The significant technological advancement between the infrared (used by PRS) and wireless networking often means that WIL/MA is less reliable than PRS due to the intermittent nature of wireless-enabled mobile devices.

C. Summary of Related Work

It is widely recognised in the pedagogical field that there are several pitfalls to the traditional HE teaching paradigm. Laurillard (2006) notes that if we were to create a new paradigm for HE teaching, the dominant method would not be lectures. It is the objective of this project to reduce these inefficiencies in the current HE teaching paradigm in an attempt to create a more suitable method of teaching.

Related work suggests that to achieve this we must convert students from a passive audience to active participants, as ‘the construction of personal knowledge is a personal activity’ (Gibbs, 1981). Low (2008) outlines the five key benefits of this approach: permitting deeper learning; increasing student attention; maintaining motivation; enabling closer working relationships between teachers and students and appealing to the ‘majority of learning styles’.

Laurillard (2006) suggests that these key benefits are achievable if a “conversation” can be established between students and lecturers. This conversation allows teachers to convey information to their audience and judge how well it has been received via some method of feedback. She suggests that the most effective means of achieving this is through the lecturer asking the students questions, this continues until the students’ responses indicate that they understand the information put across.

If such a question/answer-based platform were provided, it should serve to mitigate the problems identified by Scheele (2005), who notes a ‘lack of communication causes lecturers to rely upon other unreliable sources to judge if students understand/understood what was being said in the lecture’.

III. Solution

A. Proposed Solution

This project intended to address the weaknesses in traditional pedagogical techniques (identified in Section I.A – Motivations for Project) and to improve upon the work already undertaken in this area (investigated in Section II.B – Related Technologies).

The aim of this project was to create a TEL system, named TEL Teacher, which enhanced students learning both inside and outside of the classroom using wireless-enabled mobile devices.

Inside class time (the synchronous case), teachers are able to present (pre-designed and spontaneous) questions to the students via the mobile devices. Each student is then able to answer the given question via the GUI on the mobile device. Once an answer is specified, the student is shown whether their response was correct or incorrect. If the student has provided an incorrect answer, they are given the option to view the correct answer. Statistics on the number of correct answers given is available in “real time” to the teacher. This allows the teacher to gain synchronous feedback on the reception of the learning material presented.

The data collected on the number of questions answered correctly is also utilised outside
of class time, the asynchronous case. This allows the TEL system to be used to download student-specific learning materials to the mobile device to assist the students learning in weak areas. Additionally, if a student is having major problems they are flagged for the teacher’s attention, so that one-on-one, targeted tutoring can be arranged.

B. Proposed Solution Architecture

The TEL system was split into three different applications: a mobile device application (for students); a desktop application (for teachers) and a server application (as a central point of information). This arrangement (illustrated in Figure 2.) of one server with a set of clients is defined as a two-tier client-server architecture (Sommerville, 2006).

1) Mobile Application

Each student is required to use one mobile device, which must be connected to a network to download content from the TEL System. To allow greater portability (and to prevent being constrained to physical network access points), these devices should be able to wirelessly connect to the TEL System.

Personal Digital Assistants (PDAs) were selected as a suitable hardware platform for the mobile TEL application due to their conformance to the above constraints. Furthermore, their stylus-based input gives scope for a wide-range of “rich” input methods, including free-hand drawings and handwritten text.

2) Desktop Application

The teacher is required to use a desktop application to monitor their classes and students. This application should be able to execute in their office (for the asynchronous use-case) and in classrooms (for the synchronous use-case). To allow portability, it is reasonable to assume that this application should be executable on a laptop computer.

3) Server Application

To allow multiple Mobile Applications and the Desktop Application to access a single, consistent data source, a central point of information is required. It is appropriate that this application is executed on a server that is out of sight. Executing this application on a high-powered server would provide the computational power required to give the system greater scalability.
C. Software Use-Cases

The TEL system produced by this project has two applications; inside the classroom (the synchronous use-case) and outside of the classroom (the asynchronous use-case).

1) Synchronous Use-case

The synchronous use-case considers the “live” use of the TEL software inside the classroom during lessons.

During the synchronous use-case, the Mobile Application is required to display questions to the user. The rich-output provided by the PDA is utilised to show in-depth information so that high-detail context may be provided for each question. Once the user has used the touch-screen to input their answer to the question, their answer is marked and they are given the option to view the model answer (pre-defined by the teacher). The response entered by the student is transmitted to the Sever Application.

The Desktop Application is responsible for allowing the teacher to release pre-designed questions to the Mobile Application and allowing new questions to be added (and released) spontaneously. Once a question is released statistics on the responses from students is made available via several graphs on the GUI. This will allow teachers to observe how well the class has received the learning material presented.

2) Asynchronous Use-case

The asynchronous use-case takes place outside the classroom; students are able to complete homework using the Mobile Application and teachers are able to monitor and review student performance using the Desktop Application.

Based on the responses to the questions given in lessons, the Mobile Application downloads student-specific learning material based on perceived weak areas in their knowledge. The rich-output display of the PDA is able to provide students with audio, video and web pages.

The Desktop Application automatically flags students who have frequently had poor performance during the synchronous use-case. The teacher is able to further investigate these students by reviewing their answers to questions (in the synchronous use-case) and observe whether students are completing their automatically set homework (in the asynchronous use-case).

D. Solution Design

A range of good software engineering and design principles were implemented in this project resulting in the delivery of a high quality software product. The following approaches were taken to ensure good application design in respect to the pedagogical objectives of this project.

1) Layered Architecture

A layered architecture defines several distinct groups of functionality within a software system, which have well-defined interfaces. This encapsulation of functionality allows the
implementation of given layers to be radically changed without affecting other layers of the application (as long as the interfaces are abided by).

The division of functionality into layers is often logically apparent, either defined by functional requirements or grouped by similar properties of functions. Traditional software applications are grouped into a presentation layer, application processing layer and data management layer (Sommerville, 2006). This is illustrated in Figure 3.

![Figure 3. Application Layers (Sommerville, 2006)](image)

This traditional layered application model was adopted in this project; the specific breakdown of this approach is shown in Figure 4.

![Figure 4. TEL Teacher Application Layers](image)

By encapsulating each layer’s functionality existing components can be identified and appraised for re-use. For example, the data management layer of the Desktop Application was provided as part of the Microsoft .NET Framework. This utilisation of Component Reuse lowers software development and maintenance costs; and increases delivery speeds (especially important in a rapid prototyping project) (Sommerville, 2006).

2) **Rapid Prototyping**

The Layered Architecture model allowed an iterative approach to be utilised during the development process. The functional encapsulation of each layer, enabled by well-defined interfaces, allowed rapid prototyping to test and verify iterative developments in a quick and relatively low-cost manner.

The use of evolutionary prototyping allowed good design and implementation to be retained in the application, whilst unreliable code could be removed in favour of better alternatives.

The pace of prototyping was restricted due to the complexities of testing the distributed
systems. This prevented the development of automated testing, requiring each prototype to be extensively tested by hand.

3) Critical Processes & Fault Tolerance

The importance placed on the robustness of the Mobile Application required its data management layer to consider fault tolerance around its critical processes. Fault tolerance is defined as a system consideration which ‘is designed so that faults or unexpected system behaviour during execution are detected and managed in such a way that system failure does not occur’ (Sommerville, 2006).

To achieve this, the Mobile Application “wrapped” the data management component provided by the Microsoft .NET Framework with fault tolerant assessors. Should the, often intermittent, wireless network be unavailable during a request from the Mobile Application, the fault was classified as either significant or tolerable.

Tolerable faults categorise events when a non-critical request (usually to retrieve data from the Server Application) has failed. These requests are repeatable, which allows the application to automatically re-attempt the operation later (after a few seconds delay). Upon encountering a tolerable fault the Mobile Application displays an icon on the toolbar, allowing the user to investigate the fault if they wish (Figure 5).

Significant faults, on the other hand, consider requests that are typically unrepeatable (usually an attempt to submit data to the Server Application). In this case the user is alerted as a priority using a message dialog (Figure 5). This message warns the user of the problem, and advises them of any corrective steps that may be taken.

![Error Alert Icon](image1.png)

![Error Dialog](image2.png)

**Figure 5.** Mobile Application Screenshot – Significant vs. Tolerable Faults

The use of rapid prototyping encouraged frequent quality of service (QoS) reviews of this critical data management layer, ensuring that the implementation provided the level of fault tolerance required.

4) Component Based Software

Component Based Software (CBS) encourages sound design principles, by specifying standardised, independent interfaces to which all implementing components must adhere. This allows developers to include any software element that ‘conforms to [the] component model and can be independently deployed and composed without modification according to a composition standard’ (Sommerville, 2006). This enables other developers and third parties...
to create plug-in components that may be added to an application to increase functionality.

CBS was taken into consideration whilst designing the delivery of content to the Mobile Application. Creating a generic platform for questions (in the synchronous use-case) and homework (in the asynchronous use-case) will allow new forms of interaction to be incorporated as advances in PDA technology allows.

The interface that standardises the implementation of question types allows the Mobile Application to download generic XML from the Server Application and dynamically create an instance using reflection. Once a question plug-in id instantiated, the process of displaying, receiving input (for answers) and marking the question is fully encapsulated. This inversion of control allows the Mobile Application to delegate all question-type-specific actions to the plug-in itself (Figure 6).

![Generic Platform Design](image)

**Figure 6.** Generic Platform Design

5) **Human Computer Interface**

As specified in the Keys to Success, TEL Teacher was required to be easy and intuitive to use. This will prevent the software from introducing an added level of complexity, which may distract students during lessons. The research conducted by Molich & Neilson (1990) has formed the basis of the majority of modern-day GUI design. Although the heuristic framework developed was not intended for mobile applications, the majority of the design principals still stand. The most important guidelines in the context of this project were to Provide Feedback, Error Prevention and Good Error Messages.

Provide Feedback advises GUI designers to ensure users are made aware of actions that are being carried out by the software. Whilst researching related technologies (Section II.B – Related Technologies) it was identified that a significant drawback of WIL/MA was a lack of feedback, leaving the user staring at blank screens, unaware if the software had crashed. To avoid this situation the Mobile Application GUI provided users with constant feedback, especially when waiting for questions from the teacher.

The Error Prevention principal encourages application designers to prevent errors from happening. However, if errors do occur Provide Good Error Messages suggests that the user should be provided with error messages, which identify causes of problems and suggest actions for the user to take. This was also identified as a weakness in the WIL/MA software, which often exits without warning or shows JAVA exception on-screen. In-depth discussion of the techniques used to counteract and mitigate network connectivity problems may be found in section III.D.3 – Critical Processes & Fault Tolerance. Figure 5 shows an example of the types of error messages shown by the Mobile Device.

6) **Preattentive Processing**

Another important Human Computer Interface (HCI) consideration to be taken into
consideration addressed the amount of time teachers were required to interact with the software during lessons.

As highlighted in Keys to Success, there is very little spare time in lectures to dedicate to TEL. It was noticed whilst researching WIL/MA (a related technology) that a lot of time, if not several teachers, were required to gain feedback from the group. To avoid this situation, the software implemented Preattentive Processing, i.e. the teacher is able to perform cognitive operations prior to focusing attention.

Figure 7 demonstrates the Desktop Application GUI during a lesson. The bottom-right corner of the screen displays a pie chart based on the class’ performance.

![Desktop Application Screenshot: “Live Lesson”](image)

Boundary detection, the ability to distinguish between two different groups of data, is facilitated by using contrasting colours to highlight the difference between correct (green) and incorrect (red) answers. This informs preattentive counting and estimation, allowing users to gauge the number of responses in each category by observing the size / proportion of each segment of the pie (Healey, 2007).

7) **Component Reuse**

By reusing existing components it is possible to build-in dependability into an application. This is achieved by introducing well-tested and verified components that have been developed by specialists.

Component Reuse was used as the basis of the Server Application by deploying the Microsoft .Net Framework’s web service functionality. This Service Oriented Architecture (SOA) allowed the project to take advantage of the well-defined and established framework for communication between the Server Application, the Desktop Application and Mobile Application clients.

Additional components were reused in the development of the Desktop Application GUI to provide graphs and charts on student feedback (Figure 7).

Furthermore, the use of existing components assists with the acceleration of the implementation process, reducing the cost of development and maintenance. This emphasises the rapid prototyping approach adopted in section III.D.2 – Rapid Prototyping.
IV. RESULTS

A. Synchronous Use-Case Experiments

To evaluate the impact of this project in the classroom (the synchronous use-case), an experiment was scheduled to observe the software produced introduced into a genuine HE lesson. This experiment was based on the following hypothesis: "Students who are supported by the TEL software shall be able to obtain and retain information presented during lessons with a greater accuracy than those who do not have access to TEL”.

To test this hypothesis a parallel experiment was designed, which assigned students in the experiment lesson into two groups: the experiment group (who were issued PDAs) and the control group (who were not given PDAs). Throughout the lesson, students who were in the experiment group were given questions to answer via the PDAs, whilst control group students did not receive any intervention and were only interacted with using traditional pedagogical techniques. The students assigned to these groups were probabilistically allocated.

After the lesson all students were given a questionnaire, which asked them several short questions to gauge how well they had understood the material presented during the lesson, as well as obtaining some qualitative feedback on their experiences.

The responses to the post-lesson questionnaire were marked either correct or incorrect, indicating if the student had understood the learning material covered. This allowed the performance of the control group to be contrasted with that of the experiment group.

Additionally, these experiments were observed by an impartial expert who had experience with other TEL systems (namely WIL/MA), who could give an accurate comparison between this project and other TEL systems.

1) First Experiment

The first experiment was scheduled to take place in a second year computer science lesson on Software Engineering. During this experiment 15 students were issued PDAs and 15 students were allocated into the control group.

This experiment was halted shortly after it began due to problems with the infrastructure of the equipment used. The PDAs used suffered issues that interrupted the connection between the Mobile Application and Server Application.

Although this prevented quantitative data being collected, to test the hypothesis highlighted, it was possible to observe the project software operating under realistic circumstances. After this initial experiment it was decided that the implementation (specifically the robustness) of the software must be revised to accommodate the circumstances experienced in the original experiment.

2) Second Experiment

The second experiment conducted intended to test the same hypothesis as the original experiment. This experiment was conducted with third year software engineering students in a lesson on project management.

The software performed well for the first half of the lesson, however problems were encountered with the SOA infrastructure provided by the .NET Framework during the second half of the experiment.
The results yielded from the first half of the second evaluation session suggested that the hypothesis was true, the experiment group had obtained and retained the information presented with greater accuracy than the control group (by a margin of 32.5%). However, because the amount of data collected was limited, due to the failure of the software, the lack of quantitative data undermined the credibility of such statistics.

The qualitative experiences of the experiment group during the first half of the experiment could still be collected, allowing conclusions to be drawn from the impressions of genuine users.

The students who participated had notable support for the application of TEL in the HE teaching paradigm, with the vast majority of students commenting that such a system would improve their motivation, help them concentrate and make them more likely to attend lectures.

However, a large number of students indicated they had concerns regarding being distracted from the teacher and lesson due to the presence of PDAs, especially when the system failed. One student noted that they had experience with a simple PRS system and found this to be much more beneficial than a “richer” PDA solution that was intermittent.

3) **Expert Observation**

Janet Lavery, CETL Teaching Fellow at the University of Durham, conducted an expert observation during the second experiment. Ms. Lavery has extensive experience in attempting to integrate WIL/MA (a related technology highlighted in section II.B – Related Technology) and was invited to observe the relative merits and drawbacks of the software produced. Ms. Lavery was asked to remain in a purely observational role, so that she could complete an in-depth ethnographical study, rather than participating in the intervention method.

Ms. Lavery made notable comments regarding: the impact of the software on students’ receptiveness to traditional pedagogical techniques; requirements on lecturers to adapt their teaching style; the time-impact of the system on lectures; reliability of the software.

Ms. Lavery noted that the system distracted students from the traditional pedagogical techniques used during the experiment, however, this is expected when a one-off introduction of TEL is used. She noted that, from experience, when TEL is introduced as a long-term learning aid, rather than a ‘treat’, students are significantly less distracted once the novelty of the technology has worn off (usually after the first lesson).

Ms. Lavery also observed how the pedagogy was ‘driving how the technology was used’, rather than the technology constraining the teacher to a specific way of teaching. She noted that in certain cases that the range of question types available may restrict the effectiveness of the technology, but in these cases traditional pedagogical techniques, such as open discussions, are still possible.

Regarding the time-impact of the TEL software, Ms. Lavery noted that the software produced did not have a greater impact than any other TEL solution she has had experience with. She noted that ‘If everyone brought the technology with them or were used to grabbing the PDAs the minute they walked into the room (like the handouts) I don’t think it would take too much time’. Instead it is the ‘strangeness of the experience’ and unreliability of such systems that consume a large amount of time during TEL lessons.

Ms. Lavery’s comments on the limitation of question types restricting its use to certain topics may be negated by noting the plug-in structure incorporated into the TEL Teacher software, as described in Section III.D.4 – Component Based Software. This will allow more
advanced and broader styles of questions to be introduced as PDA technological advances make them feasible.

Additionally comments on the robustness of the software impacting on the amount of time spent using the TEL during class may be addressed by the data management layer described in section III.D.1 – Layered Architecture. Should it be deemed that the layer of the Mobile Application that accesses the Server Application lacks reliability, it may be re-implemented using a solution with greater robustness, without affecting other layers of the application.

4) Comparison to Related Technology

As part of the Related Technology research conducted (Section II.B – Related Technologies), a system called WIL/MA was identified as the closest example of the related work in the niche targeted by this project.

In addition to the Motivations for Project highlighted in section I.A – Introduction, it was the objective of this project to further the research performed as part of WIL/MA, to produce a better software product (both in terms of function and non-functional requirements).

Upon the completion of the TEL Teacher software produced by this project, an in-depth critical analysis was conducted, evaluating TEL Teacher against WIL/MA, facilitated by Low’s Taxonomy of Interactive Lecture Technologies.

Comparing the results of the taxonomy of TEL Teacher against the taxonomy (conducted by Low) of WIL/MA revealed several improvements made by TEL Teacher:

User Interface: The human computer interface (HCI) of TEL Teacher was highlighted as a large success in comparison to WIL/MA, with the easy to use Desktop Application GUI of TEL Teacher significantly reducing the teacher’s overhead of using TEL.

Additionally the HCI of the Mobile Application as part of TEL Teacher was acclaimed due to its feedback-based nature. The Mobile Application GUI clearly communicates current actions to the users and carefully explains errors to the user when they occur. Whereas WIL/MA often leaves the screen blank whilst loading, and does not handle errors in a user-friendly way.

Interaction Time: During an observed experiment using WIL/MA it required two members of staff to conduct a lesson: one to teach the lesson and one to receive feedback from the students (using WIL/MA). TEL Teacher, on the other hand, only requires one teacher due to its implementation preattentive processing (Section III.D.6 – Preattentive Processing).

Storage: The WIL/MA software does not store data collected during lessons, removing any possibility of the asynchronous case implemented by TEL Teacher. This prevents teachers from manually tracking students’ progress, whereas TEL Teacher automatically flags weak students and downloads student-specific homework based on the questions answered incorrectly during class.

Question Type: The expandable, generic nature of the TEL Teacher software gives the potential for a large array of different questions to be developed as they become technologically feasible. However, WIL/MA, on the other hand, only allows basic multiple-choice questions.

There were, however, some areas in which Low’s Taxonomy showed that WIL/MA provided functionality not offered by TEL Teacher. This focused on the Direction of Interaction; Although TEL Teacher allows students to interact with the teacher through questions specified by the teacher, WIL/MA allows students to input free-hand sketches and
handwriting, allowing the software to be used for brainstorming sessions. This allows less-confident students to contribute ideas with peer-anonymity.

It was noted that overall, TEL Teacher had several radical improvements over WIL/MA. However the reliability of both systems has been brought into question, with no clear advantage from using either system.

V. Evaluation

The final build of the TEL Teacher product implemented the vast majority of the functional requirements identified in the early stages of the project. As highlighted in Section I.B. Keys to Success, this did not guarantee the success of the project. Instead the software produced must be held against the Keys to Success described. These include: not requiring teachers to make changes to their pedagogical techniques; limiting the time-impact of TEL; not distracting students from lessons; producing a robust and reliable system.

Any attempt to create TEL software that does not require teachers to make any changes to the pedagogical techniques at all would be naive. However, by offering a wide range of (theoretically possible) ways to interact via the TEL Teacher with the plug-in architecture (Section III.D.7 – Component Reuse) the teacher’s pedagogical creativeness need not be stifled by the introduction of TEL Teacher.

To further ensure that pedagogical techniques are not impeded, one must also consider the second key to success: limiting the time-impact of TEL. A lot of focus was placed on HCI methods to overcome time-consuming processes, such as pre-attentive processing reducing the cognitive load on teachers who are trying to gain feedback from their class (Section III.D.6 – Preattentive Processing).

The third key, not distracting students from the traditional pedagogical techniques, can also be considered as part of the time-implication. This was addressed ensuring that the software was available and working when the students were required to interact with it, and unobtrusive when it was not required. Furthermore, by communicating the status of the application with the user using HCI techniques (Section III.D.5 – Human Computer Interface) ensured that the user was in control and aware of the Mobile Application’s status at all times.

The final key, producing a robust and reliable system, can be considered as the most important of the Keys to Success. As, if the application was unreliable and / or lacked robustness all of the other Keys to Success would have been greatly impacted. This is why the majority of the project focused on the concept of producing a dependable system. Despite this focus, the final build of TEL Teacher, still contained intermittent network functionality on the Mobile Devices. Although this did not prevent experiments taking place, before TEL Teacher could be seriously considered for day-to-day application these bugs would have to be removed.

Due to the large emphasis put on reliability and dependability, there was little time to consider the implementation of advanced question types. The implementation of a graph-sketching question, which would require an algorithm to compare free-hand input to a pre-defined graph, could constitute a third-year project of its own considering the lack of computational resources available on the PDAs. However, the generic platform created, which allows third-party plug-ins to be developed, can be considered as a proof-of-concept for such question types as / when technological advancements make such algorithms technically feasible.

Unfortunately, due to a lack of access to suitable candidates and time to conduct a
meaningful experiment it was not possible to evaluate the asynchronous use-case. Further studies on TEL Teacher could conduct this research with the software product “as-is”. By introducing the TEL Teacher as a homework device, it would allow a great deal of quantitative data to be produced, allowing students’ academic performance to be analysed.

The processes used to develop the TEL Teacher software were mostly successful. The Layered Architecture of the software made rapid prototyping quick and efficient, allowing entire layers to be re-implemented with no effect on other layers.

This was particularly useful after the first experiment (Section IV.A.1 – First Experiment) failed to produce data suitable for analysis. The data management layer of the Mobile Application was completely re-written after the difficulties with reliability were experienced in this experiment. This approach allowed emphasis on building-in successful attributes of previous prototypes, whilst removing or replacing parts of the implementation that failed.

Although the rapid prototyping was utilised, shorter bursts of implementation, focusing on proof-of-concept, rather than in-depth implementation, would have allowed approaches restricted by the PDA devices (due to unavailable libraries) to be identified, thus reducing the time wasted.

This rapid-prototyping process, supported by the applications’ Layered Architectures, would allow further research to be conducted on this project with ease.

VI. CONCLUSION

There are many faults with the traditional pedagogical paradigm in Higher Education (HE). These problems could be further exacerbated by recent government targets to include ‘50% of all 18 to 30-year-olds to participate in higher education’. To ensure that the increasing scale of the HE teaching paradigm does not have a negative effect on the learning outcomes of individuals it is only natural to look to the latest technologies to mitigate against these problems.

This project highlighted that by introducing ‘wireless-enabled mobile devices’ into the classroom it may be possible to enhance teaching. However, the outcomes of this project and other related technologies (including Scheele, 2005) have put an emphasis on Non-Functional Requirements (NFR) over Functional Requirements (FR). This project’s NFR were described as Keys to Success, which, if not implemented, would jeopardise the outcomes of the project, no matter how well implemented the project’s FR were.

In conclusion, rather than focusing on diversifying FR to research their implication on teaching and learning (and side-effects on traditional pedagogical techniques), future research should attempt to establish and secure a stable infrastructure to allow these FR to be investigated at a later date.

To create such a reliable and robust infrastructure several significant advances in technology are required. The critical nature of communication with the Server Application must be immunised against wireless network failures. This may become possible through advancements in wireless networking, mobile technology and dependable programming.

If wireless networking advances were able to guarantee a permanent network connection to the server, if mobile technology improved significantly enough to allow the PDAs to perform the majority of the processing or if dependable programming provided techniques to mitigate against the failure of the other two it may be possible to introduce this dependable platform, allowing us to focus on the development of new FR to address the shortcomings of the traditional pedagogical paradigm.

The Software Engineering design principles used as part of this project (Section III.D)
enable further research of this kind to be carried out on the TEL Teacher software. The re-implementation of process-critical layers of the application would provide the NFR support to enable the already well-implemented FR to function upon.

Furthermore, the extensible nature of the component-based design of this project will allow new, experimental FR to be developed as / when mobile computing technologies advance far enough to make them technically feasible.

Additionally, once reliability and other NFR problems have been eradicated, it would be possible to extend the application of the TEL Teacher software. This could include the introduction of the system into Further Education and / or Secondary Education environments or perhaps even work-based training and adult learning.

**REFERENCES**


