

**DEVELOPING WALLIS:**  
**A Web-based System to Enhance Mathematics Teaching**

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**ABSTRACT**

Mathematics course-work is required for most science and engineering degrees. However, reports in the field of Mathematics Education address the growing deficiency in mathematical skills amongst students and the need for universities to take steps to moderate this problem. One of these is the development of material in an ICT format.

Based on our previous separate work we are developing a more generic tutoring environment. Our long-term goal is an authoring and tutoring system which will allow members of staff to design their own material and students to use it asynchronously as additional support to their conventional studies. It is hoped that interaction with the system will eliminate any misconception that they have from high-school and increase their motivation to study.

This paper presents our approach towards the implementation of the system and a preliminary pilot-testing which have so far raised significant issues.

# 1 Introduction

In the last few years researchers and university teachers are more concerned than ever with the evident problem of the growing deficiency in mathematical skills amongst science and engineering students, the so-called Mathematics Problem. Recent reports (for example, Hunt and Lawson, 1996; LTSN 2000) show a decline amongst students with apparently good A-level grades in Britain, and there are similar problems in other countries.

Apart from the grade inflation, which increases the complexity of teaching mathematics at university level, the other most common factor that universities have to face is the diverse background and level of the students (GCSE, A levels, Highers and different foundation courses for Britain and similar diversities in other countries). In addition, since these students do not come to university to study mathematics as a major subject, they are less motivated. Students, particularly in departments where they can postpone the module for a later year (as in Greek Universities), do not really understand the significance of studying mathematics at an early stage. This becomes evident to them later when they face problems with their other courses and although they may try to catch up, it is already too late. Finally, engineering (and other science) degrees cannot afford to spend a lot of lecture time in reinforcing basic mathematical skills. This should have been taken care of earlier, in school, and this is why reports (for example, LTSN, 2000; National Skills Task Force, 2001) urge a joint strategy involving schools, universities and government. Unfortunately, these efforts have brought no significant changes as yet. Consequently, universities need to take steps on their own to moderate the problem.

Based on the above, the design and delivery of an appropriate mathematical curriculum is of central importance to our department, which teaches some of these essential ‘non-specialist’ mathematics topics to many hundreds of students in science and engineering degrees. Currently the courses follow a more or less conventional structure with lectures, tutorials, weekly assignments as well as the final module assessment. As an additional support, much of the paper course material is also made available on the web. The university’s role, on the other hand, is to respond positively to the use of a variety of strategies in order to improve the situation described above and to provide a more efficient solution. After a major restructuring of these courses, the time is now ripe for course materials to be developed in an ICT format.

## 2 Background

Lately, many researchers (such as Major, 1993; Battista, 1998; Cumming, 2000) argue that despite the efforts, and the resources spent, very few educational systems are in ‘routine use’ due to the tendency to develop them in the isolation of researcher’s laboratories. On the other hand, there have been many reports (for example, Barron, 1998) portraying the web as a world-wide, efficient, easily integrated, interactive technology for learning, providing developers do not neglect its pedagogical features.

Clements and Battista, in (Kelly and Lesh, 2000) describe a model for integrated research and software development. Based on this as well as other researchers’ views in the Artificial Intelligence in the Education (*AI<sup>2</sup>ED*) field (Conlon and Pain 1996;

Koedinger, 1993; Cumming 2000), we decided to design the whole system based on observations and on a careful and lengthy user study of real tutorial situations instead of simply on our intuition and creativity.

Therefore one of the authors already delivers and attends tutorial and lecture sessions that are related to the material being developed, in order to explicitly explore some of the misconceptions that student have, what kind of help would be particularly interesting for them and what to base the design on. This way, while exploring possible solutions for delivering the material, we simultaneously consider what would be appropriate for the students and how to make them actively participate in the learning process rather than merely delivering knowledge through a different source.

Furthermore, in our design we are careful to take account of several issues that many researchers (for example Kyriazis and Mpakogiannis, 2000; Boshier et al., 1997; Strickland, 2001) consider particularly important. These include the visual interface (accessibility, interactivity, attractiveness), the input tools for answers and assessment, the dialogues and feedback techniques as well as the goals of the software, the material's accuracy, and its proper evaluation. To successfully address all these issues we are collaborating with researchers, technologists, lecturers and more importantly students in order to maximize the software's contributions.

Finally, from reports about educational software (Underwood et al., 1996; Pelgrum, 2001), we take into consideration the fact that teachers (or lecturers) would like the opportunity to be more involved in the whole design process of computer-based environments for their students and that they comment favourably (Wood, 1998) on systems which were designed to help them monitor their students' progress and identify individual strengths and weaknesses. At the same time, such a system should not require advanced programming skills so as to be useful to all members of staff.

### 3 Design and Implementation

Based on our previous separate work we are now developing *WàLLî* a Web Based Assistant for Learning in a Locally Integrated System. The project's main goal is to build a more generic tutoring environment together with an authoring tool which will allow members of staff to design their own material, and students to use it asynchronously as additional support in their conventional studies.

Many possible solutions were explored, but we decided to deliver the application through the Internet mainly because web availability will permit students to work on it independently and in their own time as extra support for their conventional studies. Consequently we employ the use of a Java Server to dynamically create some of the pages and Java applets for the interactive parts firstly because of their platform independence and, not least, because of the growing list of available mathematical applets which are freely distributed and which can be integrated easily into our system.

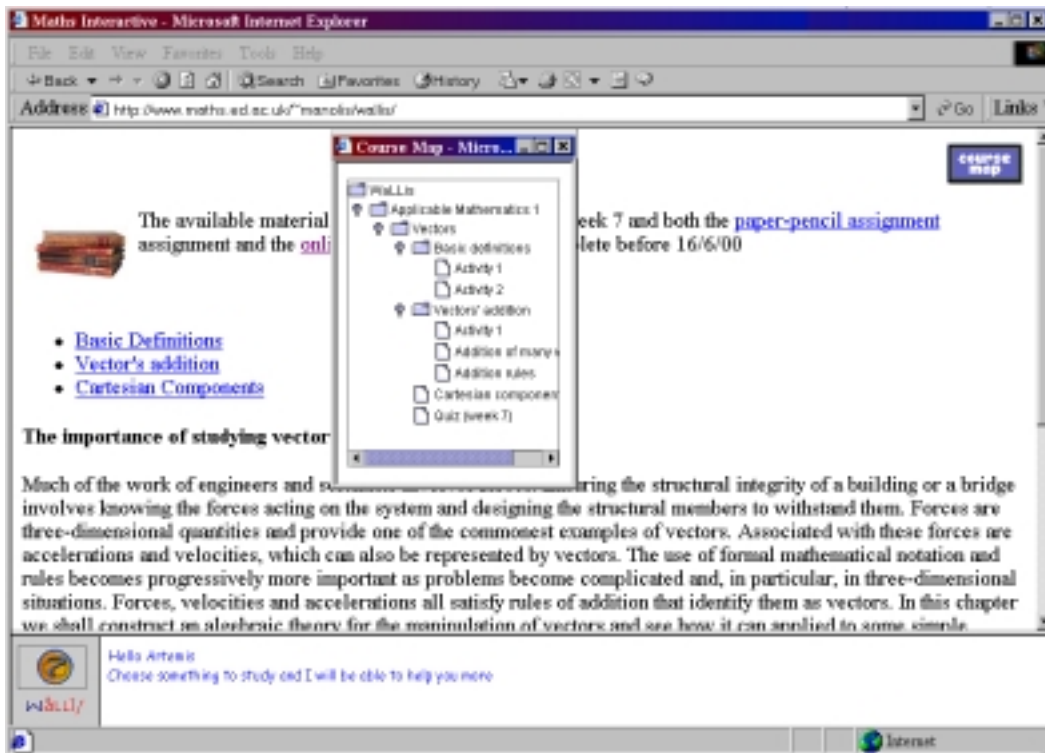


Figure 1: The Environment

### 3.1 The environment

The whole system is delivered through a web browser <sup>1</sup> and consists of two basic parts; the main frame and the feedback frame (see figure 1).

In addition to static text, the main frame contains, where applicable, interactive parts that are embedded into the whole HTML page. As students work through the material, they can interact with the insets to see various items such as, a different example, some special cases of a formula, animations on how to do things and material that cannot be seen in a static book or web page. In this way, aside from simply reading through some online text, which has proven to be very boring for some of them, they actively engage with it. The feedback frame consists of a text area where we provide help to the students when necessary and a button with which they can explicitly ask for help.

From early observations it was evident that we had to have an efficient way for the students to navigate through the material which was more sophisticated than hyperlinks between pages. Therefore we provide the students with a pop-up window (figure 1) which presents a tree-like map of the material and some other buttons which are activated according to the page the student is accessing. For instance the 'welcome page' as well as any separate interactive page contains a 'resume button' which takes the students to the last material they were studying. The use and necessity of this, as well as other buttons, is something that we need to test before continuing with the system's development.

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<sup>1</sup>the only requirement being the Java Plug-in which is freely distributed by Sun (<http://java.sun.com>) and easily installed on any platform

## 3.2 Interactivity and Feedback

The system knows which pages the student is currently accessing and if she/he asks for help the system suggests what they should study afterwards. As more material is developed we will be able to build a more detailed description of the user's knowledge and have the system suggest to the student to study other parts of the site.

In addition we provide a more specific kind of help to the students who are working on their own. We follow previous work (Mavrikis, 2001) which observed that a particular type of feedback called affective (in the sense of targeting the emotional and motivational state of the student) can be facilitated effectively to increase students' willingness to work with the system and study the material. In this we targeted Dynamic Geometry Environments (DGEs) (like Cabri, Geometers Sketchpad etc) which were enhanced with a feedback mechanism that not only avoids the need for a teacher always explaining the task and supporting those working in a lab, but also helps students interpret their actions in a meaningful way.

In a similar way, the interactive applets communicate with the feedback frame and provide task-specific hints, regardless of how the students use the help system. In addition, by monitoring mouse activity and the user's interaction with the rest of the system's components (for instance, toolbar, navigational menus etc,) we provide students with lively directed comments on their actions (figure 2).

## 3.3 A Prototype

As we have already pointed out, observation of lectures and real tutoring situations provide valuable information for the design of the system. Based on these, we developed a prototype system which addresses the subject of vectors and particularly the introductory aspects of their study. This prototype enabled us to run a pilot test to see how to proceed with the system's design.

### 3.3.1 The material and the activities

Usually students do not understand that vectors are completely different algebraic objects from numbers. They tend to neglect to use a different notation to denote a vector and they do not describe them in terms of components. To cope with that effectively when students study the relevant HTML page the interactive embedded applets demonstrate some of those aspects of the theory by allowing them to manipulate a vector and change its size, its direction, visualise the unit vector and generally 'play' with vectors while reading about their definition and properties.

In addition, some weaker students have difficulties with the graphical interpretation of a vector in a three dimensional (or even two dimensional) coordinate system. To deal with this, we designed separate activities that are linked to the main pages (figure 2). These direct students to work on cartesian axes where, by manipulating the vectors and using some tools, we expect them to answer relevant questions (such as giving the magnitude, direction or unit vector of a given vector). The rest of the activities deal with addition, subtraction or component notation.

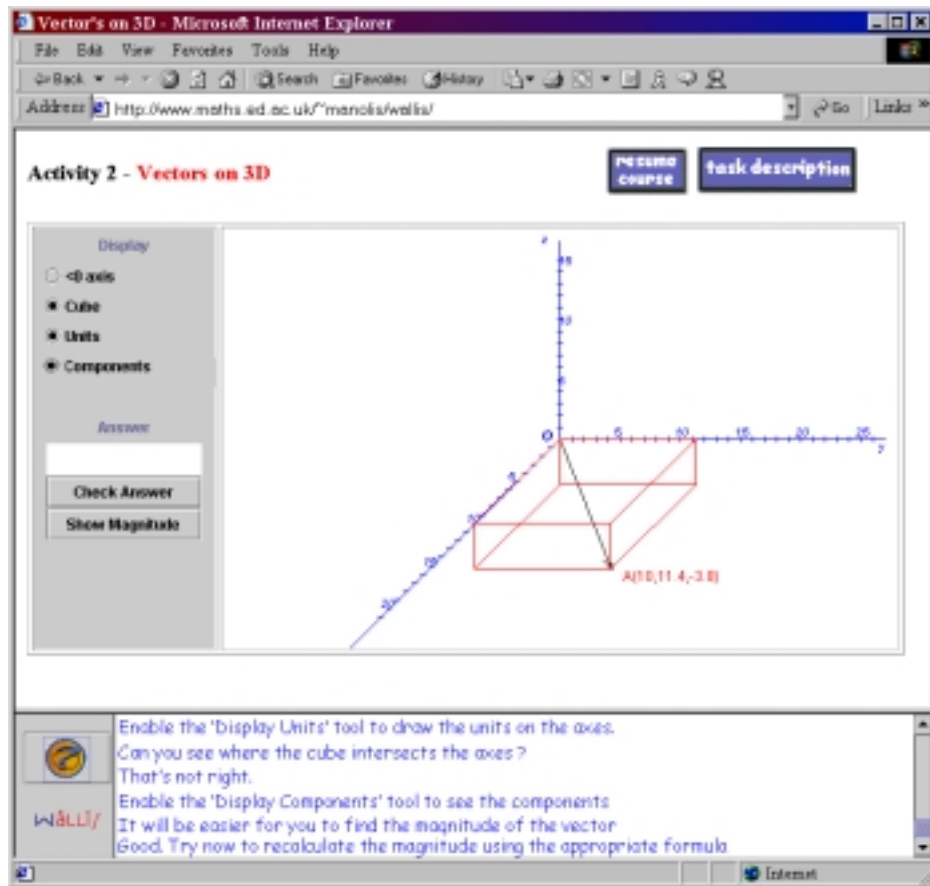


Figure 2: An example of a page with an interactive applet

## 4 Evaluation: a Pilot test

### 4.1 The Aims

It has long been argued that proper evaluation is an important aspect of the development of computer based teaching and assessment. As Conlon and Pain (1996) outline, only well designed steps based on research methodology can lead to effective software. One of the most important steps is that of the formative evaluation and in particular a phase which Clements and Battista (2000) call 'investigate the components' in the sense of testing the individual parts of the software.

In our situation, this means that we need to check if the students are indeed able to control the input devices, how they understand the screen design and actions they have to take, and where to put the various components on the screen. Apart from that, we need to know their general attitude to accessing material online as well as their view of online self-assessment or quizzes. This is the point of conducting a small pilot-test in such early stage of the project with so little material developed.

## 4.2 Participants and Methods

The participants were 9 female and 5 male first year students attending the module of ‘Applicable Mathematics’ consisting mainly of basic university level algebra. They come from diverse backgrounds and study for various degrees (Physics, Chemistry, Engineering). This small cohort of students had only taken GCSE or Standard grade mathematics which would not usually be sufficient to study numerate subjects in Edinburgh. But they may have had special circumstances which made it impossible to study more mathematics in school but there was still a reasonable expectation that they could pick up the necessary mathematics in a fast track course at the start of their studies. In fact, when asked how familiar they were with vectors, three of them ticked ‘just familiar’ on the questionnaire, all the rest said they were not familiar with them at all. The trial was run in a week when the students had no other contact hours.

The subjects were given an information and a questionnaire sheet which asked them to explore the site, study the online material and complete an online quiz in their own free time. They were asked to conduct the first session in a specific lab of the department so that an expert could be present to provide assistance, if necessary, either about the use of the site or about the material and the concept of a vector.

In addition to helping the students, the lab session would give us the opportunity to actually observe them in a real situation and see their reaction towards the system. Apart from one dedicated observer that the students were aware of (since they could ask questions of him) there were two more experts of whom the students were unaware. Although they were able to observe only five students in action, due to time constraints, their help together with the detailed log files, that were recording every action of the students, were particularly instrumental in reaching some important conclusions.

## 4.3 A Review of the Results

All of the subjects reacted favourably to having material online and although some had minor problems none were frustrated or confused to the point of discomfort.

Some problems that occurred with two of the first students that used the system had to do with a Netscape Navigator bug and how it handles applets. This frustrated the specific students and although the problems were resolved immediately, they were still unsatisfied, as was obvious from their comments. This event shows the significance of such a phase and the problems that can emerge; problems which otherwise might not have been found. The rest of the students, having not faced any problems, remarked favourably about the system both during their session and in the questionnaires. Moreover, eight of them used the site again after their introductory session, not only to complete the quiz but also to interact with the material again.

It was very interesting to see two of them to actually take notes using a notebook from the online material as they might do in a conventional lecture. Most of the students used a calculator for the answers, while some of the more experienced among them actually expected the existence of an online calculator.

In addition, from careful observation of their interaction (and from the detailed log files) it seems that all of them were capable of navigating through the site without many difficulties. The pop-up map proved useful to all of them, even the less literate ones. This is because from early observations we knew that students usually lose this kind

of window. This happens when the main browser window regains focus, i.e., becomes the selected window. To avoid this we decided to force the pop-up window to remain always on top unless the student explicitly closes it. This caused some problems to those more familiar with computers who wanted just to minimize the window but found that the window kept bouncing back; something that they found particularly annoying. Nevertheless, it is better to avoid the confusion for the less experienced ones since the others are always capable of finding their way through.

Other difficulties that students faced with the interactive applets interface were soon overcome either by discussing it with other students or after reading the task's description. The tools, although unfamiliar to them, were used appropriately. It seems though, that it was not always the system's hints that helped them to use the tools but rather the students' curiosities. The help button was used effectively by some of them but this is something that needs further analysis based on the log files. We need to see what their action was before and after the hint, as well as its effect. A preliminary analysis shows that most of the times that they explicitly asked for help they followed the suggestion accordingly.

More interesting results though, come from the experts who were observing the students without their knowledge. Apart from discussing how to do things (such as navigate or find particular material) they were all surprised by the feedback frame. 'Look it knows my name', said one and 'it talks back to you' were the first comments that students usually made.

Moreover, by watching their behaviour, the experts could see that they were not always reading the feedback but were just trying actions or asking questions of the person who was in the lab. The fact that they were able to ask questions of a person probably diverted them from seeking help from the system. When we suggested the use of the help button they usually followed the system's advice correctly. They were often surprised to find that their question had been anticipated in the system's help. This in conjunction with comments that they sometimes found the interaction boring probably means that we have to divert some important feedback to other sources such as a pop-up window, audio or even an animated agent, in addition to, or instead of, the feedback frame.

On the other hand, we implemented two applets that were not designed to give feedback at all. These were used deliberately, to observe the students' reactions. As expected, they asked more questions about their use as well as their meaning and a preliminary analysis of the log files shows that they sought help from the system more often, something that had, of course, no effect. This shows again how task-specific feedback can help the students interpret their actions and avoid the need for long descriptions or the advice of an expert.

Finally, the questionnaires that the students completed, provide us with information and ideas for further development of the system. For instance, students said that they would like to have increasingly more complex material, immediate feedback from the quiz, and the ability to print some material as well as a report of their achievements.

## **5 The Educational Impact**

From a learning perspective the development of the system provides the students with an alternative supportive medium which they can use in their own time. With it, they



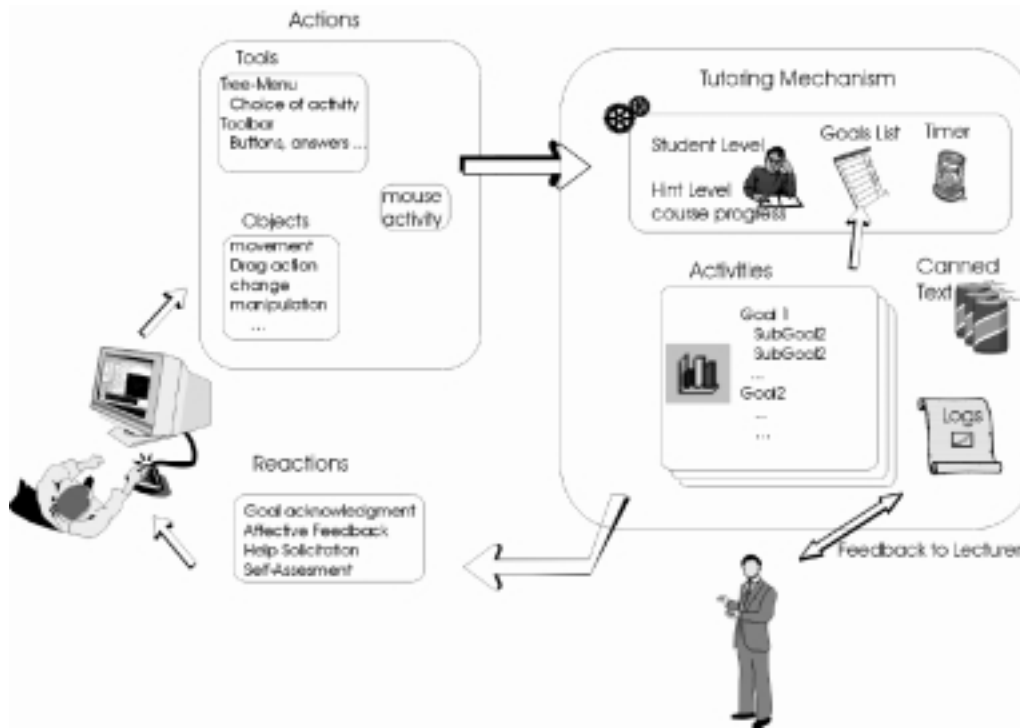


Figure 3: The system's impact

will be able to study on their own and assess themselves in a way which would otherwise consume too much of the department's resources and would be less motivating for the students.

The fact that our long term goal is to build an authoring tool for the lecturers will provide the latter with the ability, not only to create specific activities and online material, but also to monitor their students' progress and offer personalized help.

Students, on the other hand, engage in learning, explore and discover the subject (in a constructivist sense) instead of simply receiving information from a 'modern' lecture that uses computers for demonstrations. Moreover, by receiving tailored feedback specifically for each activity, as well as their actions they can rely on more information in addition to their own intuition and reflect on the knowledge they receive.

## 6 Further Work

Further development of the system will be based on direct feedback from the students and the lecturers and continuous loops of observations, changes, and development. For instance, from comments that other researchers we are collaborating with have already made, it is evident that we need to pay more attention to personalized fonts and the colours of the feedback and take into careful consideration disability issues. All these will lead to a more solid and effective system and to a product driven by the educational needs instead of a 'technological wizardry'.

By conducting further research on the development of the feedback mechanism, we will be able to build a more detailed user model that tackles students' actions as well as their 'help solicitation process' more effectively.

It remains to be seen if the interaction with the system will eliminate misconceptions that students have from high-school, how much they will use it, and if their initial motivation to work with it will remain active.

## REFERENCES

- Barron, A. (1998). *Designing web-based training*. British Journal of Educational Technology, 29(4):355-370.
- Battista, M. (1998). *Mathematics and Technology: A call for caution*. Educational Technology. pp. 31-33
- Boshier, R., Mohapi, M., Moulton, G., Qayyum, A., Sadownik, L., and Wilson, M. (1997). *Best and worst dressed web courses: Strutting into the 21st century in comfort and style*. Distance Education, 18(2).
- Clements, D. and Battista, M. (2000). *Designing Effective Software*. In *Handbook of research design in mathematics and science education*, LEA.
- Conlon, T. and Pain, H. (1996). *Persistent collaboration: a methodology for applied AIED*. International Journal of Artificial Intelligence in Education, 7:219-252.
- Cumming, G. (2000). *Mainstreaming AIED in education*. International Journal of Artificial Intelligence in Education, 11.
- Hunt, D. and Lawson, D. (1996). *Trends in the mathematical competency of a level students on entry to university*. Teaching Mathematics and Its Applications, 15(4).
- Kelly, A. and Lesh, R., editors (2000). *Handbook of research design in mathematics and science education*. LEA.
- Koedinger, K. (1993). Reifying implicit planning in geometry: Guidelines for model-based intelligent tutoring system design. In Lajoie, S. P., editor, *Computers as Cognitive Tools*, pages 15-45. LEA.
- Kyriazis, A. and Mpakogiannis, S. (2000). *Designing effective software for mathematics education*. In Kalabasis, F. and Meimaris, M., editors, *Assessment & Teaching of Mathematics*. Aegean University Greece, Gutenberg.
- LTSN (Learning and Teaching Support Network (Maths, Stats & OR), The Institute of Mathematics and its Applications, The London Mathematical Society and The Engineering Council (2000). *Measuring the maths problem*.
- Major (1993). *Teachers and intelligent tutoring systems*. In Proceedings of the Seventh International PEG Conference. Moray House Institute of Education, Edinburgh.
- Mavrikis, M. and Lee, J. (2002). *Towards more educational and affective Dynamic Geometry Environments*. Submitted to ITS 2002.
- National Skills Task Force (2001), *Towards a National Skills Agenda*
- Papadopoulos, G. (2002). *Educational Software Quality Control The plan and the work of the (Greek) Pedagogical Institute*, in Greek, <http://www.infosociety.gr/infosoc/policies/edu/index.html>
- Pelgrum, W. (2001). *Obstacles to the integration of ICT in education: results from a world-wide educational assessment*. Computers & Education, 37:163-178.
- Strickland, P. (2001). *How should a perfect computer aided assesment package in mathematics behave?*, LTSN (Maths, Stats & OR Network).
- Underwood, J., Cavendish, S., Dowling, S., Fogelman, K., and Lawson, T. (1996). *Are integrated learning systems effective learning support tools?*, Computers & Education, 26(1-3):33-40.
- Wood, D. (1998). *The UK ILS evaluations. Final report*, DfEE/BECT.