How Computers Really Work: A Children's Guide

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ABSTRACT

Current Information Technology teaching at elementary school level concentrates on teaching pupils "application skills". Very little time is spent in teaching pupils the fundamentals of "how a computer works" — computer architectures.

One source of this lacuna is the lack of suitable support material for teaching the basic concepts of computer architecture to this age group. This paper reports on the investigation, development and evaluation of a pilot computer architecture CD-ROM, aimed at 7–11 year olds.

1. INTRODUCTION

Children of today are different from those of 10–20 years ago. The majority of children going through the education system at the moment are the first generation having grown up with computers. Children need to be prepared for future employment, and to become full members of the "Information Society". They need not only to be able to use a computer, but also to understand the basics of how it works — e.g. to be able to name the major components of the machine and to understand how they affect its efficiency. However, current teaching at this level concentrates on application skills. Little, if any, time is dedicated to computer basics.

This is a missed opportunity. In a survey of teachers of this age group we found that 80% felt that children should be taught basic computer architectures. Just as children may learn a foreign language most fluently at an early age [14], so they may also be most receptive to the "foreign language" of computers at elementary school level. The difficulties that undergraduates often experience in understanding computer architectures are not due to any inherent difficulty of the subject matter, but are caused by having to "unlearn" incomplete, unrealistic and sometimes just plain weird misconceptions of how a computer works. Currently there is a shortage of useful, up-to-date information for children in the 7–11 age group on "how computers work". The majority of books and on-line resources are either outdated or too in-depth and complicated for this age group, or both.

Traditional text-based computer architecture teaching can be hard for children to digest. The use of multimedia can aid learning, as children can not only read and listen but also watch animations of computer components, thus enhancing the learning process. They can learn at their own pace and in a non-linear fashion.

In this paper we report on a pilot interactive CD-ROM aimed at teaching the basics of computer architecture to children aged 7–11.

2. BACKGROUND

2.1 How Children Learn

John Holt in "How Children Learn" [8] writes that children do not need to be made, told or shown what to learn as they are already active learners. Children learn from hands-on experiences that involve all their senses. Early attitudes and perceptions influence a child's learning. When children are learning new information and skills, they are also developing attitudes towards learning. Children learn well through play [8, 11]. Play is the primary way that children gather and process new information, learn new skills and practice old ones. It is also important for children to be able to reflect on what they know and how they solved a problem. "All of us, not just children, learn more effectively when we are at our most "playful" ... when we are actively participating in an enjoyable experience." [6] Games and game like learning environments can provide children with a challenge. Children delight in "new styles of learning" that can be delivered with new technologies.

2.2 How Computers Aid Learning

It has long been suggested that the computer will change how children learn. In 1966 Suppes [15] predicted that developments in educational technology, and especially computer usage, would change the face of education. He saw the computer as a tool that can be used interactively and present materials in different and novel ways. In 1981 Papert [12] also discussed the promise of classroom computers, suggesting that we can confidently allow children's minds to "develop through the exploration of computer simulated 'microworlds'".

Today these visions are closer to reality. The development of multimedia technologies offers new ways in which learning can take place. It has the potential to reduce the need for subject specific teacher expertise [13]. Schools across the world are embracing this new technology and looking for ways to use it to enhance learning. At the same time many of these institutions are attempting to manage on small budgets, inferior technology, limited access and a teaching staff that does not have up-to-date training in computer use. A recent *British Educational Communications and Technology Agency* (BECTA) report [5] reported that only 29% of children had used the Internet at school, and only 4% had used email. This suggests that a "low tech" CD-ROM that can be used as a stand alone program on a low specification machine is more likely to be successful than a "high tech" product requiring Internet access. In order to address the problem of teachers' lack of familiarity with the subject matter, any such teaching material must also be self explanatory, allowing children to use it without requiring too much teacher expertise.

2.3 Other Products

Although the market is flooded with educational software there is very little available in this area for this age group. In our survey a typical comment was "[...] terminology [is] aimed at older students".

2.3.1 Textbook Related Products.

[17] is a book and CD package that can be used in (pre-)university education. The book is expertly illustrated for visualization of computer processes at different layers of abstraction. The interactive CD provides a tour through the interior and exterior of a computer with animated explanations, video interviews, and computing tips. However, the CD does not include all of the information contained in the book and is in fact no longer being sold bundled with the book. [17] also does not synthesize the many separate components it describes, instead leaving as a mystery how all the parts of a computer work together in unison.

2.3.2 Stand Alone Products.

Two products are in the "Techno Quest" range produced by Eaglemoss Publications Ltd.: *scuz quest* is a game that covers binary code, computer memory, programs and operating systems; *bug quest* addresses integrated circuits, calculators, computer logic, the CPU and AI. Both are aimed at beginners, but have various shortcomings: "The game has to be played successfully right through in order to progress."; "After three incorrect attempts you are thrown out."; "The level is too low." [3, 4]. A similar program is "KeyBytes Plus for Windows". This is a heavily text reliant program [2]. It is therefore probably unsuitable for the target age range.

2.3.3 Internet Based Products.

The British Broadcasting Corporation gives a brief overview and explanation of each part of a computer [1], but this is totally text based and again unsuited to the age range. Another text-based source of (teacher support) material is the Computer Museum [16].

PV Insight [10] has a downloadable program explaining computer architecture. The program consists of very dense images of various parts of the computer with hotspots. When the user clicks on a hotspot a text box with very dense text appears giving an explanation of the corresponding component. This text window also covers the image so that the user cannot view both at once. This is a very complex program that children would struggle to use and understand.

EasyCPU is an Internet-accessible, simplified CPU simulator of the Intel X86 processor family designed for pre-university education [18]. EasyCPU uses colour changes and animations to illustrate data path operations during the execution of each instruction. Results from over 2000 students measuring the effectiveness of EasyCPU indicated that an interactive and animated software tool enhances both motivation and debugging skills [18].

3. THE DESIGN

The software is designed for children aged 7–11, who have been classified as novice users. With this in mind interaction between the child and the computer is limited to mouse clicks and rollovers. Interaction between the computer and the child is through animation, sound and text. Visual aids, such as animation, are used to highlight and to distinguish between different actions and areas of information. A schematic layout of the pages is shown in Figure 1.

Navigation has been kept simple, consistent and intuitive. At all times the user can easily decide where they are, where they can go and how they can get there. Navigation incorporates the well documented "three-step rule", where the user only needs to jump three levels to get to any point in the CD-ROM. To help with this every page contains a shortcut back to the "welcome page".

Because of the age of the intended audience, buttons and icons include sound as well as text. As the product was aimed specifically at children all voiceovers and sound effects were provided by children from the target age group. A nine year old girl recorded the sounds naming the buttons. An eleven-year-old boy read the voiceovers for the introductory text in each section. There is a facility for toggling the voiceovers.

4. THE MAIN AREAS

4.1 The Welcome Page.

A classroom metaphor has been chosen for the main "welcome page" (see Figure 2). Rather than having a standard text menu, images of a computer and its main components are placed in the classroom. By clicking on any of these images the user will be taken to the pages explaining that component. A bookshelf containing books links to the quiz pages, a world map to the Internet section, and the blackboard to the history pages.

Children are guided throughout by "Chip", the animated floppy disk that can be seen near the bottom right hand corner of Figure 2. An element of fun is added by making Chip ticklish — if the mouse pointer touches Chip he will laugh or tell the user to stop tickling him!

4.2 Peripherals

Each of the main peripherals — keyboard, mouse, printer and monitor has its own area in the CD-ROM. In each of these areas the operation of the peripheral device, and its role in the operation of the computer system is explained using a combination of text, images sound and animation.

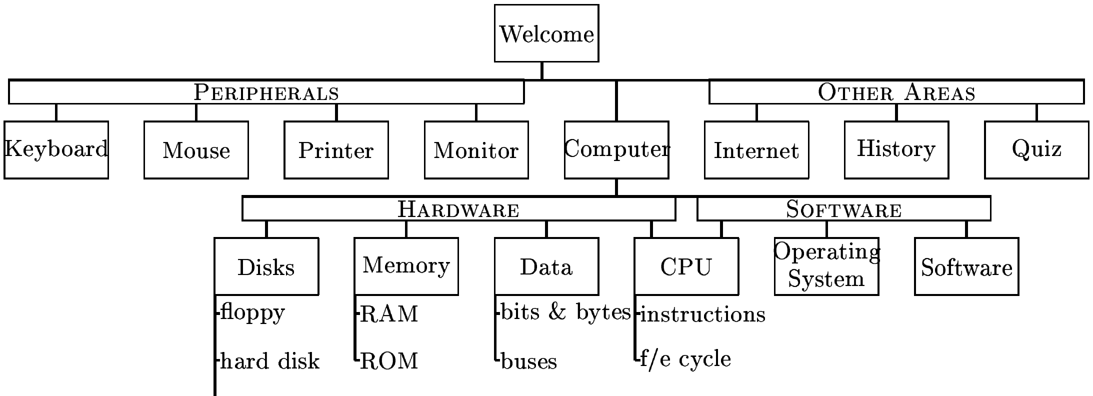

Figure 1: Layout of the CD-ROM

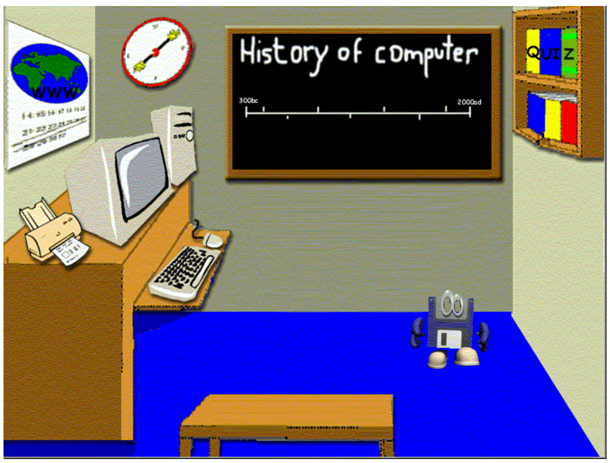

Figure 2: The Main Welcome Page

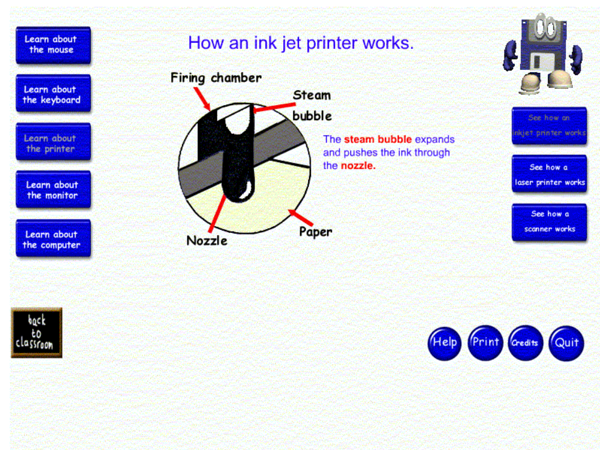

Figure 3: An Inkjet Printer

The printer area, for example, contains links to two animations illustrating the operation of laser and inkjet printers (see Figure 3, which shows a bubble of ink forming in an inkjet printer).

4.3 The Computer.

This is the largest section of the CD-ROM. The main areas here are the CPU, the Data area and Memory.

The CPU. This section is based on the Little Man Computer developed be Stuart Madnick at MIT in 1966 and described in e.g. [7], and its extension, the Postroom Computer [19, 9]. In this paradigm a "computer" consists of a walled mailroom, 100 mailboxes numbered from 00 to 99 (the memory), a calculator (the Arithmetic Logic Unit), a counter (the location counter) and input and output baskets. The animation first shows the "Little Man" explaining what each of the components does. He then explains that he has a short list of basic instructions that he can execute. Children can then choose from this list and the animation will explain the relevant behaviour. Currently there is no facility for composing your own programs within this animation, but we hope to integrate this with a simplified version of the Postroom Computer undergraduate teaching aid.

Data. The data area illustrates the (ASCII) encoding of a keypress in a byte, and shows how the byte is composed of bits. The roles of the data, control and address buses are explained.

Memory. The difference between RAM and ROM is shown metaphorically — the word ROM is shown engraved in stone, while RAM is being wiped off a blackboard. Each subsection also contains a more extensive description of the uses of each type of memory.

4.4 Other Areas

The Internet. A metaphor of posting a letter containing a request for a specific web page was used here to explain what "happens" when a web page is requested, and the problems that may arise such as time out (due to congestion or computer failure) and restricted access.

History. The history is presented as a simple time line. Children can either progress through the timeline sequentially or pick and choose time slices. Key events in the development of the computer are presented for the time slice(s) selected.

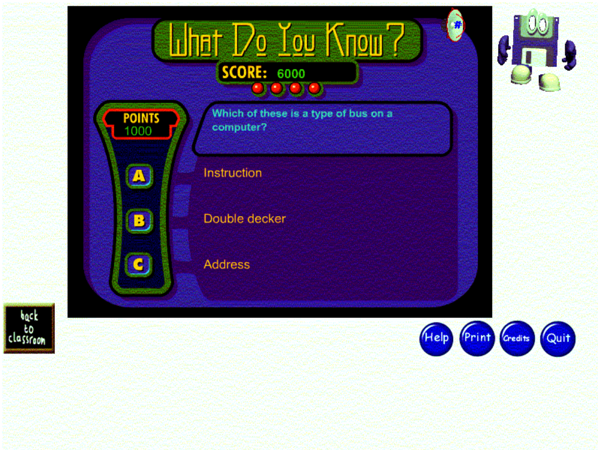

Figure 4: The Quiz

The Quiz. The quiz consists of a selection of multiple choice questions covering material from all sections of the CD-ROM. "Silly" answers are included as a fun element — see Figure 4. User involvement is also increased by adding "congratulation" and "commiseration" sounds.

5. EVALUATION

During production alpha multimedia testing — testing the functionality, interaction and navigation — was performed by a small group of children who reviewed and evaluated the product. Once the pilot CD-ROM was ready for release a group of potential users — children in the target age group and their teachers — were used for an opportunistic test. Data collection methods were by observation and semi-structured interviewing of the participants while being recorded on video.

The children were asked to work through the package and give feedback. Before starting the package there was some discussion with the children about their current knowledge of "how computers work". The majority of the children said that they knew how a computer worked, but further questioning revealed that this meant that they knew how to use them — e.g. how to log on to the Internet — not that they understood computer architecture concepts. After using the package the children were asked for their overall impressions and whether they enjoyed this method of learning.

The quiz and animated aspects of the product were the most popular with the children. Half of the children went straight to the quiz and then realised that they had to actually go through the package before being able to answer the questions. The colours, fonts etc. were chosen with ease and speed of reading in mind. The children all enjoyed the interface and liked the classroom metaphor. The bold colours and larger fonts were popular and not considered patronising. The teachers found it bright and cheerful, and felt that the animations — especially Chip — would catch the children's attention. All of the children said that they were happy working with a computer program of this nature. Most of them felt that it was better than traditional learning methods, though some felt that it should only be used to complement traditional classroom learning.

Generally the product was well received by both the children and the teachers. The most successful parts of the product were clearly the animated components. There is some evidence that they aided understanding and offered a clearer explanation than is available on paper-based materials, or even achievable by a teacher in a traditional classroom situation. The children had the most difficulty in understanding the "Little Man Computer" section of the package, though some of them did successfully remember (part of) the instruction set. Some of them stated that they would prefer it if they could interact with the "Little Man Computer" — i.e. create Little Man Computer programs. This would almost certainly help to increase their understanding. As mentioned above, we hope to integrate the Postroom Computer with the CD-ROM to offer just this capability.

6. CONCLUSIONS

We have piloted a prototype of a teaching aid aimed at 7–11 year olds which allows them to explore the various components of a computer. The CD-ROM is user oriented and based on what children like and want. Interactivity is provided through animation, text and speech. It is designed to provide a game like environment and to create opportunities for children to be involved in the learning process, and to allow them to work things out for themselves. It is, of course, intended to be enjoyable and to relate to the target age group.

Our survey of teachers suggests strongly that there is a market for this type of product, and the results of tests of the pilot version are very encouraging. Children and teachers were enthusiastic about the design and content of the software.

Though our reasearch has been heavily aimed at the British market we believe that the lessons we have learned are applicable to a much wider market. We now hope to develop the CD-ROM further, extending both the breadth (the target age group) and the depth.

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