EDUCATION REQUIREMENTS FOR COMPUTER HARDWARE DEVELOPMENT

P. D. Atkinson

Rapporteurs: Mr. L. Waller
Mr. E. Satterthwaite

Abstract The educational requirements for a career in computer hardware development derive from the environment in which graduates will work. Major features of this environment are the wide range of technological skills involved, the continuing rapid changes in technology and the problems of interaction between hardware and software development staff.

There is a need to broaden the basic education of the graduate entry with emphasis on basic principles in preference to specific implementations and the state of the art.

Science and Technology courses will continue to provide a significant part of the graduate intake. However, there is potential for Computer Science to make an important contribution in two ways. Firstly, by broadening the background of science and technology graduates. Secondly, by turning out graduates with sufficient basic knowledge in technology and information science to enable them to contribute to bridging the gap between programming and engineering.

1. Introduction

The remarks which follow express the speaker's personal views, which are based upon 25 years experience in industrial research and development. In particular, they reflect twelve years spent at the IBM Laboratory in Hursley, which is currently engaged in systems development, programming and storage development projects. Thus they are based upon the needs and expectations of a relatively large organization. Since there are currently few computer science graduates at Hursley, no detailed comments about existing computer science courses are included.

2. Characteristics of Computer Hardware Development

2.1 Technology and Product Range

A wide range of technical skills is directly required for the development of computing hardware. These range from the core disciplines of circuit design, logical design, and programming to such areas as mechanical engineering, physics, materials science and applied mathematics. The importance of the mechanical engineer in product design is often underestimated. It seems likely that these skills will continue to be necessary in the future, but there will probably be a reduced dependency upon mechanical devices and thus a shift from mechanical engineering toward physics and materials science. Associated with the range of technologies is an increasing range of products of widely varying performance and capacity. This product diversity leads to further staff specialization.

2.2 Technology Change

Although the computing industry has existed for less than a man's normal working lifetime, its history has been marked by very rapid and substantial changes in all aspects of computer technology, design and application. This has created serious problems for technical staff, who must either keep pace with the changes or accept that their knowledge will become obsolete. The ability to hire personnel with the necessary new skills as well as to find meaningful positions for those whose technical knowledge has fallen behind can only be attributed to the rapid expansion of the computing industry. There is little doubt that computer products will continue to change relatively rapidly. Further progress in the associated technologies will be exploited. Forseeable trends and developments are particularly likely to provide opportunities for changing the trade-off between hardware and software; telecommunications systems and bulk data storage are also likely to become more important.

3. Some Problems which Education Can Help to Solve

There are two main areas of concern: technical communication and flexibility. These affect both the organization and the individual.

3.1 Communication

Many computer professionals have very little knowledge or appreciation of related disciplines and cannot communicate effectively with colleagues in such disciplines. This can create a barrier between groups, which is never desirable and sometimes intolerable. In extreme cases, specialist groups cannot be integrated into a technical team, and they develop their own, sometimes conflicting, goals.

The most severe communication barrier is observed between programmers and hardware designers; there is unlikely to be much improvement in the situation until significant numbers of senior people have had experience in both areas.

3.2 Flexibility

Because of the narrow training and experience of most technical staff, changes in the mix of skills required for new goals or a new technology are difficult to implement. The problem of inflexibility affects all skills; probably mechanical engineers and materials scientists are the most isolated. Flexibility can be increased by suitably broadened education and experience; of these, experience is the responsibility of enlightened management.

3.3 Impact on the Individual

The career of the typical individual might be expected to develop over a period of years, and the full impact of his educational background will not be immediately evident. He will obtain a knowledge of the details of his work from experience, contact with colleagues, and technical literature. After five to seven years, his direct working experience should be broadened by contact with new products and an actual change in professional duties. During this period, his education can contribute in two ways:- by providing the basic technical knowledge required to enter new fields, and by developing the ability to continue learning.

In the next stage, which is typically reached after ten years, he is likely to enter a senior technical position or intermediate management. Here he will become involved in strategy decisions based upon a knowledge of technical trade-offs and in the direction of technical work not entirely familiar to him. As he advances to more senior positions, his abilities to keep pace with technological change and thus to understand technical issues in many fields become increasingly important. His education will be a major factor in determining his success at this stage.

4. Education Requirements

Suitable education is initially the responsibility of the University, but should be supplemented later by internal training facilities and experience provided by the employer.

4.1 Company Internal Education

The employer can contribute to staff development both by providing internal training programmes and by adopting a deliberate policy of exposing employees to a variety of technical experience. IBM, for example, provide professional updating and broadening through an internal technical training programme. Originally undertaken as a programmer training activity, this has recently been expanded to include hardware topics. In general, those courses which present new technology and technical practices to staff familiar with the fundamental principles involved have been effective, but considerable difficulty has been encountered in attempts to teach basic principles and how to apply them.

4.2 Education Objectives

A university technical education should, from the employer's point of view, have two broad objectives:- providing the skills needed by the graduate for his first job, and giving him the academic knowledge and scientific approach needed to maintain throughout his career an understanding of the rapidly changing environment in which he will be working. Universities have largely achieved the first objective, although there has been a shortage of graduates with adequate programming knowledge. Fulfilment of the second objective requires that graduates be given a basic knowledge of the fundamental and theoretical aspects of all the important technical aspects of computer design, together with an understanding of how this knowledge can be applied. Such training has a double impact:- it provides basic tools for understanding and problem solving, and it promotes an attitude which seeks out underlying principles in new situations.

5. An Educational Strategy

The wide range of available backgrounds and required skills of computer staff demands a variety of courses by which graduates can be prepared for entry into the computer industry. Computer science and similar courses can contribute to the training of staff in three main areas; these are System Programmers, Technologists, and Computer System Designers.

5.1 System Programmers

The requirement here is to provide an effective conversion path for graduates of any faculty. Such conversion can and has been done by employers, but a university course is more likely to avoid overly narrow training as well as the biases of a particular organization. A one year post-graduate course is suggested, covering the following appropriate topics:

programming	numerical methods
structure of high level languages	information theory
compilers and assemblers	switching theory and logic design
data structures	elementary modern algebra
operating systems	computer systems
automata theory	

The programming and logic design courses should have a reasonable practical content; the others should emphasize a broad coverage of basic principles.

5.2 Technologists

Graduates of science and technology faculties are usually well prepared in their own fields for their first jobs. They would, however benefit from exposure to other aspects of computer design and programming. This could be provided by computer science departments, either as optional supplements to the first degree courses given by other faculties or as a one year post-graduate course. The latter would give technologists an understanding of basic principles of the following:

programming	switching theory and logic design
structure of high level languages	elementary modern algebra
compilers and assemblers	computer systems
operating systems	statistics and probability
automata theory	numerical methods

information theory and data transmission

In addition, some broadening of their technology background should be provided.

5.3 Computer System Designers

This course should be specifically designed to train future system architects, product planners, and technical managers. It should provide a thorough basic grounding in a wide range of scientific and technical knowledge as well as some practical skills in programming and logic design. The course would require 3 or 4 years and include the following topics:

Technology

electromagnetism and electrostatics	heat transfer
semi-conductor physics	statics and stress analysis
switching and storage devices	dynamics of machines
circuit theory and analysis	electrical materials
transmission lines	structural materials
electro-mechanical systems	

Computing

programming	switching theory and logic design
structure of high level languages	control theory
compilers and assemblers	simulation
operating systems	computer systems
data structures	
automata theory	
information theory and data transmission	

Mathematics

differential equations	vector methods
fourier analysis	set and group theory
complex variables	Boolean algebra
matrices	statistics and probability

Undue concentration upon any one group of these subjects must be avoided.

5.4 A responsibility of Computer Science Departments

Computer science departments must avoid creating the belief that their full degree courses provide the only proper entry qualification to the computer industry. They should also be willing to provide shorter, broadening courses for students and graduates of other faculties.

5.5 Subsidiary Subjects

Because interaction with people is a major factor in any working environment and because people are the primary resource of any research and development organization, the most rewarding field for subsidiary studies is people at work. This field, exemplified by the work of Douglas MacGregor and Rensis Lickert, includes such topics as communication, organization, and motivation of people in industry. These are likely to be of central importance to future managers.

6. Technical Obsolescence

There is a real need for refresher and updating courses for people, especially managers, who have worked in the computer industry for ten years or more. Universities can contribute by cooperating with people from the industry in designing and teaching appropriate courses. There is scope for experiment in the organization os such courses; probably a period of full time re-education for carefully selected and prepared individuals would be most appropriate.