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Physics: Implications for Computer Technology

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Abstract

Investigations of job advertisements in regional newspapers revealed a high level of demand for Computer and Network Support (CNS) positions. An in-depth analysis of employer expectations within the CNS field provided a checklist of knowledge requirements and skills. A subsequent analysis of 3rd year computer science students, both at Edith Cowan University (ECU) and internationally, revealed that they did not possess these necessary background skills – there was a mismatch between demand and supply. As a result two new first year single semester units, Computer Installation & Maintenance (CIM) and Network Installation & Management (NIM), were designed and implemented at ECU. Both CIM and NIM are regularly oversubscribed, attract students from a wide range of disciplines and also cross-institutional enrolments from other universities within Western Australia. Significantly these new units have a substantial 'hands on' component consisting of a weekly workshop and associated lecture, both of 2 hours duration.

Both units assume some knowledge of physics including basic electric circuits. A questionnaire based upon basic electric circuits was administered to CIM students in 1998 and the results clearly demonstrated that most students lacked sufficient physics in this area to fully support their learning. Given that students must work in a potentially hazardous environment, a knowledge of physics is also essential in understanding the principles behind Health & Safety. Furthermore, some students experienced difficulties with respect to formula derivation, manipulation and substitution. The importance of a basic knowledge of physics, particularly as a foundation for understanding technology and its curriculum implications are discussed. Possible solutions to students' problems with basic physics are presented.

1. Introduction

According to the 1991 ACM/IEEE-CS report: "The outcome expected for students should drive the curriculum planning" [1]. The computing science department at ECU conducted an exploratory market audit covering a wide range of companies offering employment in the area of computer and network support (CNS) within Western Australia. This took the form of a survey intended to ascertain the level and extent of the CNS related skills that prospective CNS employees needed to possess. Subsequently a checklist of basic required CNS skills was compiled. A random selection of ten, final year ECU computer science undergraduates were interviewed from a graduating population of approximately one hundred. According to Maj,

> "It was found that none of these students could perform first line maintenance on a Personal Computer (PC) to a professional standard with due regard to safety, both to themselves and the equipment. Neither could they install communication cards, cables and network operating system or manage a population of networked PCs to an acceptable commercial standard without further extensive training. It is noteworthy that none of the students interviewed had ever opened a PC. It is significant that all those interviewed for this study had successfully completed all the units on computer architecture and communication engineering" [2].

Interviews conducted with five ECU graduates employed in CNS clearly indicated that they were, to a large degree, self-taught in many of the skills they needed to perform their job. Preliminary investigations indicated a similar situation with computer science graduates from other universities within Western Australia. According to Campus Leaders

> "the predominant reason why they (students) have gone to university was to get skills, knowledge and a qualification that would assist them in either gaining employment or enhancing their prospects for promotion or a more rewarding job" [3].

The initial ECU student questionnaire, first used in 1993, was repeated in 1999 at two universities within the UK. Both universities have well established degree programs that are British Computer Society (BCS) accredited. Their degree programs offer students the opportunity to examine a PC in the first year, however they never take a PC apart. On such courses students are taught network modeling, design and management but they do not physically construct networks. The results clearly demonstrate that students lacked knowledge about PC technology and the basic skills need to operate on computer and network equipment in a commercial environment. This is despite the fact that most students thought such knowledge would be beneficial. Our surveys indicated that any practical knowledge students have of hardware is largely a result of experience outside the course.

2. Curriculum Design

At ECU a new curriculum was designed consisting of four units – Computer Installation & Maintenance (CIM) and Network Installation & Maintenance (NIM) are both prerequisites to Computer Systems Management (CSM) and Network Design & Management (NDM). All of these units have a significant practical component. Both CIM and NIM have been consistently oversubscribed and are single semester first level units whose success [4] led to the subsequent development CSM and NDM.

The unit CIM attempts to provide a practical, inter-disciplinary, problem oriented approach. For example the basic operation and limitations and problems inherent in the use of an ISA bus are discussed and compared to the more modern PCI bus. Rather then lowering academic standards the complexity of dealing with real PCs can lead to more, not less, complexity when compared to ‘theory only’ computer hardware units. For example Professor Lowe, cited by Armitge, has argued that:

> “the complexity of the real world is more intellectually taxing than living in imaginary worlds of friction-less planes, perfectly free markets or rational policy analysis” [5].

Such complexity can be very demanding and, as there are no unit pre-requisites for the CIM unit, one of the main problems is to control a student’s introduction to this complexity. Accordingly a systems engineering approach is employed ie. a top down, hierarchical, modular analysis. According to Scragg:

> “most (perhaps all) first courses in computer hardware are created ‘upside down’ - both pedagogically and pragmatically” [6].
>
> This has the consequence that:
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> “Pedagogically, this approach provides no ‘cognitive hooks’, which might enable students to relate new material to that of previous courses - until the semester is almost complete.” [6].

Accordingly Scragg recommends a top down approach starting with material already familiar to students and then working towards less familiar models. In contrast to traditional units in computer architecture/technology the unit CIM does not include digital techniques (combinatorial and sequential logic), details of processor architecture at register level or assembly language programming.

The PC is considered as a set of inter-related modules each of which is then addressed in detail appropriate to a first level unit. In particular the PC is treated as a ‘whole’ with detail carefully controlled on a ‘need to know’ basis. For example, the lectures on memory devices address the principles of operation of primary and secondary memory. Disc drive operation is considered along with typical performance figures and the advantages/disadvantages of the different types of controller (IDE, EIDE, SCSI). This is complemented by the associated workshops with a working demonstration of a disassembled but operational hard disc drive. Furthermore, in the workshops students are required to perform experiments that include: installation of a second floppy disc drive; addition of a second (slave) Integrated Drive Electronics (IDE) hard disc drive; upgrading from an Industry Standard Architecture (ISA) input/output card to a PCI Local Bus etc. This is complemented by experiments in fault diagnosis, correction and management. All operations are at the module rather than the component level.

3. Physics

CIM and NIM attract students from a wide range of disciplines. The students differ greatly in respect to both their physics and technology backgrounds [4]. Yet these units make use of many basic physics concepts particularly those concerned with basic electrical theory in its lectures, workshops and assignments. Due to the general nature of these units it was not considered possible or desirable to require that a basic level of physics be a unit prerequisite or to have had previous exposure the basic physics ideas incorporating the basics of electricity and magnetism. It was intended to keep the units as open as possible and it was initially assumed that nearly all university students would have had some exposure to basic physics concepts during their secondary education.

Both the CIM and the NIM curricula were analysed according to the expected knowledge of physics. Physics is not taught as a distinct topic within the CIM and NIM units but occurs in the context of understanding computer hardware operation and Health & Safety.

The following distinct conceptual groupings were identified:.

3.1 Voltage, Current, Resistance and Power

It is assumed that students understand the basic principles of a simple electrical circuit i.e. insulators, conductors and electrical continuity as well as voltage, current, resistance and power with the associated units. It is expected that students must, at some point, have used a multi-meter. From practical engineering perspective students must be able to measure voltage and be aware of the consequences of poor electrical connections, open and short circuits and the heating effect of an electrical current. A basic understanding of AC, DC, and transformer action is needed as a basis for understanding power supplies, non-interruptible power supplies, and power conditioning. Some understanding of the dangers of Extra High Tension (EHT) devices is essential.

3.2 Magnetism

It is the expectation that students have some understanding of magnetic fields and their ability to deflect electron beams. One complete lecture and associated workshop is concerned with the Visual Display Units (VDU). The principles of magnetization and de-magnetization and factors influencing such processes are fundamental to the understanding of the operation of hard disc drive read/write mechanisms. The deflection of an electron beam under the influence of a magnetic filed is important in understanding monitor operation

3.3 Electrostatics

An understanding of the principles of electrostatic charge is needed in order to explain the importance of the devices to protect integrated circuits from electrostatic discharge. Furthermore such principles required for an understanding of the operation of smoothing capacitors used in power supply units. Capacitor action is also important in dynamic memory data storage.

3.4 Light emission

Understanding of the VDU requires an appreciation by students that some materials emit light when hit by high-speed electrons and the fact that certain substances can be combined emit different colours. The concept of persistence of vision is important in relation to these emissions as well as to monitor scan rates The characteristics and use of solid state lasers are also important.

3.5 Throughput calculations

Conversions from periodic time to frequency and bits per second is important in calculating maximum throughput. Additionally the NIM unit also includes the transmission media characteristics relating to fibre optical cable, coaxial cabling and twisted pair cabling. An appreciation of electromagnetic radiation sources of electrical interference is also considered as well as throughput calculations applied to computer networks.

4. Safety & Health aspects

One of the most important reasons for encouraging an understanding of basic physics is to enable a better appreciation of potentially hazardous situations. Students must understand what they must and must not do. An appreciation of the effect of electrical current on the body is required as this could result in severe muscular contractions making it impossible for a person to release their grip of a 'live' or 'active' mains potential conductor. In Australia the electrical mains voltage is 240V.

The importance of the concept 'Electrical Earth' or 'Ground' underpins the appreciation of the need for Residual Current Detectors (Earth Leakage Detectors) is an essential feature of the workshops because not only are the PCs disassembled but some experiments require that the main computer system box be open for testing when the system is running. It should be noted that even though two earth, or ground, leakage detection circuits were installed (10 and 20 mA) in the workshop such circuits may afford no protection to the individual when a PC is mistreated or precariously malfunctions. Throughout the workshops the PC was treated as a potentially dangerous device. In the final analysis no one can ensure that an open PC is not in a dangerous condition and the potential for fatal accidents by electrocution cannot be discounted. High tension devices, the VDU and power supply, are never opened.

Other less obvious potential hazards exist such as a short circuit causing PVC covering on wires to become very hot. A student could grab this wire, in a belated attempt to avoid damage to the PC, and the hot PVC could stick their hand and resulting in burns and scaring. Safety considerations based upon basic physics principles are not only restricted to potential hazards of an electrical nature. The danger of implosion of monitor display vacuum tubes are also a safety concern.

5. Physics Education

A questionnaire develpoed at ECU and given to CIM students in 1998 to determine their physics background and test their understanding of simple electrical circuits. The physics of simple direct current circuits is normally covered in lower secondary school science and it has therefore been assumed by the staff involved that students enrolled in the CIM unit possessed this knowledge. Unfortunately, research suggests that students often have difficulties with these basic concepts, and some misconceptions are widespread [7, 8, 9, 10, 11].

The questionnaire was based around a simple electric circuit consisting of a light bulb (or light globe) connected through two wires to a battery, with the addition of a second light bulb for questions dealing with series and parallel circuits. In particular, a question that was used for surveying conceptions of current flow held by New Zealand students (aged 10 to 18) was included for comparision purposes[12]. No question required knowledge above that which is normally covered in lower secondary school science.

For a simple circuit with one light bulb students were asked about current flow in the connecting wires. A significant minority of students (32%) did not think that the current was the same in each wire. Most of these students believed that the current leaving the globe (through one wire) must be less than the current entering the globe (through the other wire), a common belief held by secondary school children [11]. Most students could not apply Ohm’s law to the above circuit. Given the battery voltage and the resistance of the light bulb, or globe, only 43% could calculate the current flowing through the bulb, and just 28% could calculate the power of the bulb.

Although a small majority answered the questions on parallel circuits correctly, students demonstrated little understanding of current, voltage and energy in questions referring to series circuits. When a second light bulb is placed in series with the first, about half of all students believed that the brightness of the first bulb would not change and (separately) that the current flowing through this light bulb would also remain unchanged. Less than a third of CIM students could draw a diagram showing how to measure the voltage and current for this first light bulb.

An analysis of the results showed a bi-modal distribution with an overall average mark of 43%. Students undertaking the CIM unit had a wide range of backgrounds in physics, ranging from an honours degree in theoretical physics, a degree in electronics or university entrance level physics, to absolutely no background in physics. A small majority of students had no physics above lower secondary school science. The practical backgrounds of these students ranged from no practical experience with computer hardware or electrical repair and general installation, to many years as a practicing electrician or as an electronics engineer. With very few exceptions, students with upper secondary school or tertiary qualifications with physics attained a mark in excess of 60%, and those with just lower secondary school science attained a mark of less than 40%.

Only 15% of students were able to answer all questions on simple electric circuits correctly. Most students had basic misconceptions of electricity theory that would at best inhibit, and at worst preclude them from learning the CIM content that relies upon such knowledge. Almost half of the students indicated that they would be interested in doing a short course in physics to

5. Physics Education

help with this computing unit. However, the results of this questionnaire indicated that most students on the CIM unit would benefit from a better understanding of physics.

A second questionnaire was designed with the specific intention of being able to distinguish basic problems with mathematics from basic problems with physics. The questionnaire also revealed that some students had difficulty in the basic mathematical operation needed to convert frequencies or bandwidths to periodic times and in the application of other formulae. Furthermore students in the lower result hump of the bi-modal distribution found difficulty with transformation of formulae and also difficulties with scientific notation and conversion between SI magnitudes.

6. Addressing the need for Physics Education

One approach could be to provide a separate, optional, short course on physics for students who require it. The advantages would be that all the students would have a comparable knowledge of the necessary principles of physics allowing the unit to build upon this material. However this would incur an extra unit load for students. Given the developments in multi-media technology it students may be possible to produce audio-visual materials as part of a distance learning package for to use in the university library or at home. Certainly this would allow students to study in their own time and at their own convenience. However one of the problems often associated with distance learning material is lack of immediate feedback. However many efforts have been made in physics teaching in this respect. One such system has been described by Whitlock et al[13]. In this study learners solved physics problems by working at a distance via a computer network and an audio link via pre and posttest analysis. The necessary physics material could be part of the standard lectures though this could detract from the main aim of the course and may also be inappropriate for students with a knowledge of physics.

Alternatively it may be possible to introduce and reinforce basic physics concepts as part of the allocated workshop time. The CIM workshops could provide a laboratory space where students can gain hands-on practical physics experience of relevant physics concepts and a real life context in which to learn. Approaches, which make use of a real life context, are increasingly being included in secondary school physics curricula as these are seen to make physics more interesting, relevant, accessible and useful to a wider range of students [14].

Depending upon the topic, physics concepts might be taught and applied to the CIM context, or the CIM context could be used to draw out the physics concepts to be studied. In both scenarios, the laboratory environment of the workshop would allow for a wide variety of practical activities to facilitate or support learning. In keeping with the basic philosophy of the CIM unit this would provide physics education on an ‘as needed’ and ‘demand driven’ basis. Furthermore, a workshop environment would allow for students to undertake practical physics experiments. Unfortunately, it is not possible to find sufficient time in the workshop program to undertake substantial physics experiments. There is also the additional problem that much of the equipment required is not readily available in a computing department. However, we have incorporated some small physics related demonstrations in order to make some inroads into the problem. For example, students are shown how to measure voltages with a multi-meter, and given a concrete experience of how magnetic forces affect moving charges by placing a magnet near a VDU.

7. Discussion and Conclusions

Both the CIM unit, and to a lesser extent the NIM unit, have been run on the implicate assumption that nearly all of the students involved would have had a good knowledge of basic physics principles. Unfortunately, especially with regard to electricity and magnetism, this assumption has been found to be incorrect. A small minority of our students have no physics experience past general science in lower secondary school. Even some students with upper school physics or equivalent demonstrated an insufficient understanding of basic electric circuits. Based on our experiences in the workshops, it is clear that most students have an insufficient understanding of basic physics, particularly in the areas of electricity and magnetism, to gain the high level of understanding of the CIM unit's content that we desire.

At present we are addressing some of the physics needs of CIM students through short demonstrations in their workshops. Due to time constraints, it is not possible to include teaching the underlying physics principles unless the extra time requirement is very small. We are presently looking at novel ways to incorporate the teaching of basic physics principles within the context of computer installation and maintenance units.

With the growth of demand from employers for computer graduates with first line computer and network maintenance and installation skills, reinforced in this demand by those students themselves, we expect that units like CIM and NIM which require some physics knowledge will become more common within university computing degrees. Therefore it will become increasingly necessary to gain more information about what basic understanding of physics such computing students lack, and how it might best be taught. It is worthy of note that the units CIM and NIM were based upon job advertisements and employer expectations. They were intended to provide students with the skills and knowledge meet these requirements. Nevertheless basic physics understanding, particularly in the area of electricity and magnetism, was still found to be an important requirement.

Two surveys based upon a single unit certainly do not in themselves constitute conclusive evidence. However, a lack of fundamental basic physics understanding can leave students at a disadvantage and deserves further investigation to determine the extent of this problem. We certainly would welcome any suggestions on how we might better incorporate basic physics into our CIM and NIM units within the indicated time constraints.

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