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An investigation into computer and network curricula

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An Investigation into Computer and Network Curricula

**A thesis submitted in fulfilment of the requirements for the
award of**

DOCTOR OF PHILOSOPHY

by

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2003

USE OF THESIS

The Use of Thesis statement is not included in this version of the thesis.

Acknowledgments

I should like to thank my principal supervisor Associate Professor Dr S.P. Maj for his dedication, assistance, insight, encouragement and patience in helping bring this undertaken to its conclusion. I should also like to thank my associate supervisor the Dean of Teaching and Learning Dr J Millar for his help and assistance. For the educational component I wish to thank the help of Associate Professor Dr T Fetherston of the School of Education at ECU for his help in this field and Mr P Halfpenny the Post Graduate Information Officer for his invaluable help and assistance in navigating a path through the degree requirements. I should also like to thank all collaborators of the published papers and especially my colleague Mr G Kohli for his collaboration with internetworking bandwidth experiments. I should like to thank Mr G Murphy for his help, especially with the Cisco based experiments. My thanks also to the research support officers Mr S Cikara and Mr G Robbins for their help with the experiments.

Declaration

I certify that this thesis does not to my knowledge and belief:

- i. Incorporate without acknowledgement any material previously submitted for a degree or diploma in any institution of higher education;
- ii. Contain any material previously published or written by another person except where due reference is made in the text; or
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ABSTRACT

This thesis consists of a series of internationally published, peer reviewed, journal and conference research papers that analyse the educational and training needs of undergraduate Information Technology (IT) students within the area of Computer and Network Technology (CNT) Education.

Research by Maj et al has found that accredited computing science curricula can fail to meet the expectations of employers in the field of CNT:

"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" (Maj, Robbins, Shaw, & Duley, 1998).

The students' curricula at that time lacked units in which they gained hands-on experience in modern PC hardware or networking skills. This was despite the fact that their computing science course was level one accredited, the highest accreditation level offered by the Australian Computer Society (ACS). The results of the initial survey in Western Australia led to the introduction of two new units within the Computing Science Degree at Edith Cowan University (ECU), Computer Installation & Maintenance (CIM) and Network Installation & Maintenance (NIM) (Maj, Fetherston, Charlesworth, & Robbins, 1998). Uniquely within an Australian university context these new syllabi require students to work on real equipment. Such experience excludes digital circuit investigation, which is still a recommended approach by the Association for Computing Machinery (ACM) for computer architecture units (ACM, 2001, p.97). Instead, the CIM unit employs a top-down

approach based initially upon students' everyday experiences, which is more in accordance with constructivist educational theory and practice.

These papers propose an alternate model of IT education that helps to accommodate the educational and vocational needs of IT students in the context of continual rapid changes and developments in technology. The ACM have recognised the need for variation noting that: "There are many effective ways to organize a curriculum even for a particular set of goals and objectives" (Tucker et al., 1991, p.70).

A possible major contribution to new knowledge of these papers relates to how high level abstract bandwidth (B-Node) models may contribute to the understanding of why and how computer and networking technology systems have developed over time. Because these models are de-coupled from the underlying technology, which is subject to rapid change, these models may help to future-proof student knowledge and understanding of the ongoing and future development of computer and networking systems. The de-coupling is achieved through abstraction based upon bandwidth or throughput rather than the specific implementation of the underlying technologies. One of the underlying problems is that computing systems tend to change faster than the ability of most educational institutions to respond. Abstraction and the use of B-Node models could help educational models to more quickly respond to changes in the field, and can also help to introduce an element of future-proofing in the education of IT students. The importance of abstraction has been noted by the ACM who state that:

"Levels of Abstraction: the nature and use of abstraction in computing; the use of abstraction in managing complexity, structuring systems, hiding details, and capturing recurring patterns; the ability to represent an entity or system by abstractions having different levels of detail and specificity"(ACM, 1991b).

Bloom et al note the importance of abstraction, listing under a heading of: "Knowledge of the universals and abstractions in a field" the objective:

"Knowledge of the major schemes and patterns by which phenomena and ideas are organized. These are large structures, theories, and generalizations which dominate a subject or field or

which are quite generally used in studying phenomena and problems. These are the highest levels of abstraction and complexity" (Bloom, Engelhart, Furst, Hill, & Krathwohl, 1956, p.203).

Abstractions can be applied to computer and networking technology to help provide students with common fundamental concepts regardless of the particular underlying technological implementation to help avoid the rapid redundancy of a detailed knowledge of modern computer and networking technology implementation and hands-on skills acquisition. Again the ACM note that:

"Enduring computing concepts include ideas that transcend any specific vendor, package or skill set... While skills are fleeting, fundamental concepts are enduring and provide long lasting benefits to students, critically important in a rapidly changing discipline" (ACM, 2001, p.70)

These abstractions can also be reinforced by experiential learning relevant to commercial practices. In this context, the other possibly major contribution of new knowledge provided by this thesis is an efficient, scalable and flexible model for assessing hands-on skills and understanding of IT students. This is a form of Competency-Based Assessment (CBA), which has been successfully tested as part of this research and subsequently implemented at ECU. This is the first time within this field that this specific type of research has been undertaken within the university sector within Australia. Hands-on experience and understanding can become outdated hence the need for future proofing provided via B-Nodes models.

The three major research questions of this study are:

- Is it possible to develop a new, high level abstraction model for use in CNT education?
- Is it possible to have CNT curricula that are more directly relevant to both student and employer expectations without suffering from rapid obsolescence?
- Can an effective, efficient and meaningful assessment be undertaken to test students' hands-on skills and understandings?

The ACM Special Interest Group on Data Communication (SIGCOMM) workshop report on Computer Networking, Curriculum Designs and Educational Challenges, note a list of teaching approaches: "... the more 'hands-on' laboratory approach versus the more traditional in-class lecture-based approach; the bottom-up approach towards subject matter versus the top-down approach" (Kurose, Leibeheer, Ostermann, & Ott-Boisseau, 2002, para.1).

Bandwidth considerations are approached from the PC hardware level and at each of the seven layers of the International Standards Organisation (ISO) Open Systems Interconnection (OSI) reference model.

It is believed that this research is of significance to computing education. However, further research is needed.

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CHAPTER 1

INTRODUCTION

1.1 Description

This thesis consists of a series of internationally published, blind peer reviewed, refereed, journal and conference research papers that analyse the educational and training needs of undergraduate Information Technology (IT) students within the area of Computer and Network Technology (CNT) Education.

These papers attempt to develop a model for university based IT education that helps to accommodate the educational and vocational needs of students and the needs of employers, within the specific context of continual and rapid changes in CNT.

If these papers can be judged as contributing new knowledge in the field of CNT education, one part of such a contribution would relate to the work on abstraction, and specifically how abstract 'Bandwidth-Node' (B-Node) models may help in the evolution of a method of understanding of how and why CNT systems have developed over time, and the way they are likely to continue to develop in the future. A key idea, here, is that by devising appropriate abstract models that can be de-coupled from their underlying technology, which is subject to constant and rapid change, the abstract model can help to future-proof the student knowledge and understanding of the ongoing and future development of CNT systems.

The de-coupling is achieved through abstraction based upon throughput rather than the specific implementation of the underlying technology. In 1991 the

Association for Computing Machinery (ACM) noted the use of abstraction (ACM, 1991b, p.75).

Despite relatively early published observations about the potential of abstraction, there has been very little published work linking abstraction to the main problem in CNT education. A core problem in CNT education is that CNT systems tend to change faster than the ability of most educational institutions to respond (Abelman, 2000; Naraymann & Neethi, 2001). Another major problem within the field of CNT education is the need for students to have hands-on experience that may support learning and meet employer expectations. Thus, the papers in this thesis have also aimed to develop an efficient, scalable and flexible model for assessing hands-on skills and understanding of IT students. This is a form of Competency-Based Assessment (CBA), which has been successfully tested as part of this research and subsequently implemented at Edith Cowan University (ECU). This is the first time within this field that this specific type of research has been undertaken in the Australian university sector, and might also be judged as potential new knowledge to the field of CNT education. However, hands-on experience and understanding can quickly become outdated and hence the need for future proofing provided via B-Node models. While further research needs to be undertaken it is believed that this research is a potentially significant advance.

1.2 Underpinning Framework

Professional accreditation is critically important in computing science education at university level. This is to fulfil the requirements of degree recognition by professional bodies, for migration and skills recognition purposes, as well as for mutual international recognition of qualifications by international professional bodies.

Computing science accreditation at university level is provided for within Australia by the Australian Computer Society ACS (ACS, 2002). However, the world's leading organisation with respect to computer science education is the Association for Computing Machinery (ACM), which is based in the United States but has global membership. The ACM establish Joint Curricula Task Forces with

the Institute of Electrical and Electronic Engineers (IEEE) Computer Society. These produce extensive reports and recommendations each decade for computing curricula. They note that:

"Enduring computer concepts include algorithms, complexity, machine organisation, information representations, modelling and abstraction. Understanding these fundamental concepts is essential to the effective use of computer specific skills. While skills are fleeting, fundamental concepts are enduring and provide long lasting benefits to students, critically important in a rapidly changing discipline" (ACM, 2001, p.70).

The ACM also noted that "All computer science students must learn to integrate theory and practice, to recognize the importance of abstraction, and to appreciate the values of good engineering design" (ACM, 2001, p.12). Thus, the use of abstraction should be an integral part of computer science education at university level.

Within computer technology education the ACM suggests a bottom-up approach. Each level in the hierarchy uses a different abstraction. By example, at the lowest current level digital techniques are taught via the abstraction of Boolean algebra. At the next higher level combinational and sequential circuits can be modelled as registers and functional blocks. However, due to rapid changes in CNT it is recognised that a new high-level abstraction is now needed. Clements notes:

"While the knowledge base academics must teach is continually expanding, only a fraction of that knowledge can be taught during a student's time at university. Consequently raising the level of abstraction" (Clements, 2000a, p.11).

The development of such a new high level abstraction would have major implications for teaching CNT. It should be noted that the transistor and associated logic gate circuitry was originally taught as part of computing science hardware units, but now the level of abstraction has been raised and the lowest level building blocks considered are often logic gates or higher level abstract functional blocks such as registers, adders, or memory (Cragon, 2000; Messmer, 1997; Stallings, 2003).

The first major research question addressed by this thesis is: Is it possible to develop a new high level abstraction model for use in CNT education? The model arising from possible answers to this question is the B-Node model which allows hierarchical, recursive decomposition through the progressive hiding of lower level details. The model can also be self documenting. This model was used in this thesis as a pedagogical foundation for teaching CNT and the results were evaluated and published. One paper was presented at the ACM Special Interest Group in Computing Science Education (SIGCSE) annual conference (Maj, Veal, & Duley, 2001), a conference regarded as the premier conference on computer science education. This research also resulted in a publication in the Journal of Research into Information Technology (JRPIT), the flagship research journal of the ACS (Maj & Veal, 2000b; Maj, Veal, & R. Duley, 2001) and others (Maj & Veal, 2000a; Maj & Veal, 2001; Maj, Veal, & Boyanich, 2001; Maj, Veal, & Charlesworth, 2000).

The second main research question addressed in these papers: Is it possible to have CNT curricula that are relevant to both student and employer expectations? Barnett notes that universities have had to face a "growing clamour from industry for the graduates it employs to have more work-related skills" (Barnett, 1990, p.158).

Despite the above, within the ACM Computer Curricula 1991 and 2001 guidelines, little mention is made of practical, employment relevant hands-on skills. However, employers within the field of CNT have expectations that potential employees should possess both the technical knowledge and the appropriate skills to work effectively with such new technology. Research by Maj et al has found that accredited computing science curricula can fail to meet the expectations of employers in the field of CNT:

"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" (Maj, Robbins et al., 1998).

It should be noted that the students' curricula at that time lacked units in which students gained hands-on experience in modern PC hardware or networking skills. This was despite the fact that their computing science course was level one accredited, the highest accreditation level offered by the ACS. The results of the initial survey in Western Australia led to the introduction of two new units within the Computing Science Degree at ECU, Computer Installation & Maintenance (CIM) and Network Installation & Maintenance (NIM) (Maj, Fetherston et al., 1998). Uniquely, these new syllabi require students to work on real equipment. Such experience excludes digital circuit investigation, which is still a recommended approach by the ACM for computer architecture units (ACM, 2001, p.97). Instead, the CIM unit employs a top-down approach based initially upon students' everyday experiences, in line with constructivist educational theory and practice. In order to minimise hazards to both students and equipment, strict working practices had to be enforced in line with both employer expectations, and legal, and ethical and safety requirements. In addition to an understanding of computer hardware, actual hands-on experience is also required in many occupations such as Multimedia (Maj, Kohli, & Veal, 1999), Information Technology (IT), and Information Systems (IS) management (Gramignoli, Ravarini, & Tagliavini, 1999). Demands for such experience have come from students on computer science units as discovered from feedback to student questionnaires (Maj, Fetherston et al., 1998; Veal & Maj, 2000a; Veal, Maj, Fetherston, & Kohli, 1999). This has been confirmed by the work in this thesis.

Introducing such hands-on skills led to the problem of how such skills and understanding could be meaningfully assessed. Such assessment needed to be used in units with around 100 students per semester. The assessments also need to be verifiable and reproducible by different tutors to ensure consistent assessment practices. This led to the formation of the third main research question, namely, can

an effective, efficient and meaningful assessment be undertaken to test students hands-on skills and understandings?

Different forms of assessment have different strengths and weaknesses (Ewin, 1991; Fletcher, 1992). A range of assessment methods were investigated including the use of multiple choice questions, sometimes using images of PC hardware (Brooks, 1999). Although multiple-choice questions can be useful in assessing a range of understandings about hardware, they are no substitute for assessing the capacity of students to adequately cope with the real problems that can occur with actual equipment.

While simulations can be useful, (Coe, Williams, & Ibbett, 1996; Reid, 1992; Searles, 1993) they can't accurately reproduce all of the problems that occur with computer technology (Parker & Drexel, 1996), neither do they provide the practice necessary to develop relevant psycho-motor skills (Krathwohl, Bloom, & Masia, 1964). Another form of assessment that has been considered was to require students to assemble and test a PC (Heuring & Jordan, 1997; Hyde, 2000; Pilgrim, 1993; Utd, Lo, Sun, Daly, & Kowalski, 2000). However, this would involve devoting more time to workshop training than is currently available within the university CNT curriculum. It would also result in considerable extra costs for education providers.

In response to these investigations a new competency-based approach to student evaluation has been developed in this thesis that that could generate meaningful results to students, lecturers and potential employers. Today, many students desire education that will provide not only a theoretical understanding of subjects that can help them in their present or future employment, but also a practical understanding to help them gain a first position in their chosen career:

“...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” (1996a, p.4).

However, up-to-date skills alone are not enough, and the ACM note that:

“A course that focuses only on skills acquisition may be useful in the short-run but will quickly become dated and of little benefit to those who take it. Similarly, a class that addresses only abstract ideas and general concepts may not provide the skills that students need to make effective use of computing technology” (ACM, 2001, p.70).

Hence, the two major themes of this study are (1) the need for understanding and (2) hands-on skills and their integration. However, this needs to be coupled with overarching concepts and abstractions to avoid early knowledge redundancy which requires a top-down approach.

In the ACM SIGCOMM workshop report on Computer Networking: Curriculum designs and educational challenges, Kurose et-al include in a list of approaches: : “... the more ‘hands-on’ laboratory approach versus the more traditional in-class lecture-based approach; the bottom-up approach towards subject matter versus the top-down approach” (Kurose et al., 2002, para.1).

Research into overarching abstractions led to various publications (Maj, Veal, & Boyanich, 2001; Veal & Maj, 2001). Within a university level educational context, research into a competency based approach for CNT is the first of its kind within the Australian university sector and has led to various publications such as papers being presented at the annual ACM SIGCSE conference (Maj, Veal, & Duley, 2001; Veal, Maj, & Duley, 2001), and a paper in the Australian Computer Society’s (ACS’s) flagship publication the Journal of Research and Practice in Information Technology (JRPIT) (Maj & Veal, 2000c).

CHAPTER 2

LITERATURE SEARCH

2.1 Student and Employer Demands for Practical Skills

This important topic has been a subject of much debate with a long history, (Abelman, 2000; Bacon, 1668; Barnett, 2000; Carnoy, 1995; Dewey, 1916/1966; Grubb, 1984; Jaspers, 1960; Maj, 2000; Mill, 1867; Newman, 1854; Russell, 1930/1960; Russell 1935/1966; Whitehead, 1932/1962; Wolf, 1995). The authors noted are but a small selection of those that have written about this topic.

2.1.1 Computing Science Accreditation

The Association for Computing Machinery (ACM) is arguably the world's leading body in computing science course accreditation. Many other comparable bodies such as the Australian Computer Society (ACS) and British Computer Society (BCS) having accreditation schemes that are similar to the ACM within this field.

The ACM recommend curricula to help ensure consistent national and international standards. However, they recognise the need for variation noting that: "There are many effective ways to organize a curriculum even for a particular set of goals and objectives" (Tucker et al., 1991, p.70), and that "Different undergraduate programmes place different levels of emphasis upon the objectives of preparing students for entry into the computing profession" (Tucker et al., 1991, p.72). The ACM also note the need for abstraction:

"Levels of Abstraction: the nature and use of abstraction in computing; the use of abstraction in managing complexity,

structuring systems, hiding details, and capturing recurring patterns; the ability to represent an entity or system by abstractions having different levels of detail and specificity" (ACM, 1991a, p.75).

An Australian Government commissioned report by the National Board of Employment Education and Training (NBEET) commenting on the recruitment of new graduates also noted that employers:

"... recruit on the assumption that graduates have satisfied the academic requirements of each institution, thus allowing them to focus on the particular skills and attributes they believe are most essential for the particular work environment. Generally, employers emphasise skills and attributes which are more difficult to evaluate than academic skills" (NBEEB, 1995b, p.21).

An earlier Australian government report had found that 90% of employers surveyed indicated that they used academic results as part of their criteria to select new graduates, and only 36% used previous job experience (NBEEB, 1992, p.14). Academic skills were apparently considered more important by many employers. Significantly, however, an A. C. Neilson report commissioned by the Australian government noted with respect to the skills of new graduates that: "In regard to course content we found very few complaints by employers except in regard to more advanced areas of information technology and electronic communications" (Neilson, 2000, p.9). These are the areas vital to the new economy and are areas of high importance to future employment growth.

Yet another Australian government commissioned report noted that: "Employers expect graduates to be able to apply the theoretical applications they have been taught to practical tasks over time" (Deloitte Touch Tohmatsu, 1995, p.28). Such expectations lead to the questions such as: what appropriate skills should be taught in Computer and Network Support (CNS) units?

2.1.2 CNS skills

Computer and Network Support (CNS) skills could be defined as the skills required for effectively designing, commissioning and managing computer and

computer networking systems. This could involve troubleshooting, upgrading, and evaluating systems as well dealing with users. Goldsworthy notes that skill:

“... refers to a person’s ability to do something well. It relates to expertness, a practiced ability, a dexterity in performing a task. It is an outcome that flows from knowledge, practice, inherent abilities and an understanding of the task to be performed”. (Goldsworthy, 1993, p.133).

There has been a significant demand from employers for students with skills and knowledge in CNS (Beeson & Gay, 2000; Maj, Fetherston et al., 1998; Naraymann & Neethi, 2001). This has manifested itself as a need not solely for theoretical skills but also for accompanying hands-on skills and experience in these fields. This has been reciprocated by a student demand for employment relevant education (Abelman, 2000; Grubb, 1984; Maj, Robbins, Shaw, & Duley, 1997). Ramsden notes that lecturers’ expectations of students include the application of: “ideas learnt in formal classes to the world outside the classroom” (Ramsden, 1992, p.38) and that:

“Many students can juggle formulae and reproduce memorised textbook knowledge while not understanding their subjects in a way that is helpful for solving real problems” (Ramsden, 1992, p.38).

Today’s graduates are expected to be effective when they first enter their profession (Dunn & Carson, 1998). A situation that prompts Carson to ask:

“Does the current system produce people who are ‘essay-processing machines’? Is the student who writes the best examination paper or the best essay the one who is best prepared for their chosen profession?” (Carson, 1997, p.152).

High emphasis placed upon academic rather than practical qualifications can be result in qualification spirals.

2.1.3 Qualification Spirals

Qualification spirals can result from ‘academic drift’ in which courses attract higher ‘prestige’ by moving towards greater academic skills at the cost of practical skills (Wolf, 1995). Despite the need for more employment based skills,

qualification spirals have been an issue with hands-on practical skill provision within many occupations. Wolf argues that:

"Once qualification spirals have started they tend to be self fuelling for a long time. The more occupations become graduate entry, the more others feel under pressure to do so – to attract good entrants and for reasons of status and self-respect. And the more this happens the more individuals feel that they must obtain degrees" (Wolf, 1995, p.39).

Whilst Pryor and Schaffer state that:

"It is often argued that as a result of skill based technical change; many particular occupations require increasingly more knowledge and thus more education. ...Nevertheless, the average education of those in particular occupations may increase because of credential creep, a phenomenon independent of job performance or requirements" (Pryor & Schaffer, 1999, p.43).

They distinguish between these two situations referring to them respectively as 'upskilling' and 'upgrading' (Pryor & Schaffer, 1999).

2.1.4 Results of Qualification Spirals

Spiralling qualification requirements have led to some unexpected results. Pryor and Schaffer, from a U.S. labour market perspective, note that:

"... contrary to conventional wisdom, fewer jobs for prime-age workers with high levels of education have opened up than those possessing the requisite educational requirements. At the same time more jobs have opened up for those with fewer occupational qualifications. As a result, an important downward occupational mobility has taken place, so that workers with more education are displacing those with less education. That is, the more educated workers are holding jobs for which they are educationally overqualified and, as a result, much of the educational upgrading is apparent rather than real" (Pryor & Schaffer, 1999, p.45).

Rumberger has noted that: "There is a large discrepancy between the level of education achieved by an increasing number of American workers and the educational requirements for their jobs" (Rumberger, 1983, p.2).

2.1.5 Summary

A case may be made that there is employer demand for practical hands-on skills and experiences from graduates. Despite this, there is a tendency for courses to become more academic and less practically relevant. There has also been a tendency towards qualification spirals resulting in higher academic requirements than those strictly necessary to perform actual job functions. However, should universities provide employment relevant skills and education or should this be left to the institutions set up for such purposes within Australia, namely the vocationally orientated Tertiary and Further Education (TAFE) system?

2.2 Higher Education, Vocational Education and TAFE

Within Australia TAFE is the main provider of vocational education. These institutions, and those in the Further Education (FE) sector in the UK, are the descendents of the nineteenth century mechanics institutes designed to provide work related technical education and training.

2.2.1 Vocationalism

Vocationalism asserts that the primary focus of education is vocation. Winch and Gingell state that: "Vocationalists maintain that the main aim of education, at least for some students, is to prepare them for employment" (Winch & Gingell, 1999, p.246). They also note that vocationalism should not be confused with instrumentalism because:

"Instrumentally-orientated education sees it as a means to an extrinsic aim. Many liberal educators see the aim of education as intrinsic, that is, its pursuit is a self fulfilling aim, valuable in its own right." (Winch & Gingell, 1999, pp.116-117).

The ACM also note that: "One important aspect of the complete curriculum involves the study of professional practice" (ACM, 2001, p.5). Non-vocationally specific university education has its critics as noted by Kolb:

“Finally there is a marked trend toward vocationalism in higher education, spurred on by a group of often angry critics – students who feel cheated because the career expectations created in college have not been met, and employers who feel that the graduates they recruit into their organizations are woefully unprepared” (Kolb, 1984, pp.6-7).

Vocationalism is at odds with ideas of liberal education. Bagnel notes that with respect to the ideas of liberal education and knowledge required for employment in the nineteenth century:

“... advocates of this liberal education saw a clear difference between these two types of knowledge. The later was justified by its leading to practical results such as the building of a piece of furniture or a steam engine. The other was a self justifying end in itself ...” (Bagnall, 2000, p.462).

A disassociation between education and employment criteria has long been a cause for concern as shown by the following extract from a letter to King James Ist of England from Francis Bacon written in 1611:

“... they find want in the towns both of servants for husbandry and apprentices of trade; and on the other side there being more scholars bred than the state can prefer and employ, and the active part of that life not bearing a proportion to the preparative, it must needs fall out that many persons will be bred unfit for other vocations and unprofitable for that in which they are brought up” (Bacon, 1658) cited in (Cressy, 1975, p.24).

Such an argument could be perceived to be based upon efficiency. Shepard notes that:

“For John Franklin Bobbit, a leader in the social efficiency movement, a primary goal of curriculum design was the elimination of waste (1912), and it was wasteful to teach people things that they would never use.” (Shepard, 2000, p.4).

However, such criticism could also be levelled at much employment relevant education and training if it is not subsequently utilised.

Barnett states that vocationalism has its own ideology, noting that:

"Vocationalism is not as value-free as it would pretend. It is an ideology representing the interests of corporatism, of economy and of profit. Vocationalism asserts the desirability of a fit between higher education and the world of work and of graduates being enterprising in it. Consequently vocationalism drives up the value of the world of work as such" (Barnett, 1994, p.68).

Carnoy notes, with respect to the rapid changes in information based economies, that:

"...with the increase in the velocity of these changes, the vocationally educated will probably become increasingly penalised – governments that invest heavily in vocational education could be burdening their labour forces with relatively greater inflexibility" (Carnoy, 1995, p.214).

Echoes of vocational debate in higher education occasionally reach the popular press with comments such as those by the social commentator and critic Hugh Mackay who notes that in the view of many parents:

"... in an increasingly competitive world, education and qualifications (meaning in this context, technical qualifications) are the most effective passport to the emotional and financial rewards of secure employment" (Mackay, 2001, p.18).

Grubb adds a note of caution stating that:

"Vocational education has been prone to rhetorical inflation, especially in the claims that it can reduce unemployment and poverty, increase productivity and reduce inflation, and improve our international competitiveness" (Grubb, 1984, p.443).

Grubb notes that there are reasons for unemployment other than merely a lack of appropriate education and training, adding that: "The problems with such claims is that they miss the real sources of economic problems and then promise more than vocational programs can possibly deliver" (Grubb, 1984, p.443). However, universities have had to face a "growing clamour from industry for the graduates it employs to have more work-related skills" (Barnett, 1990, p.158). Grubb also notes that:

"In the case of High-Tech vocational education, much larger forces drive educators, students, businesses and social commentators to call

for a renewal of our 'human resources'... And finally it claims to simultaneously serve the 'hand' and the 'mind', the practical and the abstract, the vocational and the academic" (Grubb, 1984, p.451).

Yet a perceived lack of vocational relevance in some university programs, even in areas such as computing science, has prompted Nwana to note that: "some employers seem to distrust computer science qualifications" (Nwana, 1997). Cervero has noted that practicing professionals find knowledge acquired from practice more useful than that gained through formal education (Cervero, 1992).

The OECD has noted that:

"The need to increase employment and social relevance of university first-degree programmes is mentioned by most member countries as a major consideration in many proposals and actual reforms of the structure and content of university studies. Despite this common concern there is no consensus on how this objective should be translated into practice" (OECD, 1983, p.95).

The predominant reason students undergo university education is to improve employment prospects (Campus Review, 1996) and students have noted the importance of the ability to apply knowledge in the workplace (Kelly & Else, 1996). However, a university is today seen by many as a required form of education or training for a vocation as indicated by the findings of *Brown v. Secretary of State for Scotland* 1988 legal case (De Lacey & Moens, 1990, pp. 34-36).

The legal position of the university in England was historically undefined. Hailsbury's Laws of England stated: "A university is nowhere legally defined. The term is usually understood to be a body incorporated for the purposes of learning" (Hailsbury, 1935). Whilst Whitehead has noted the initial work related reasons given for university establishment, stating that:

"In England at Cambridge, in the year 1316, a college was founded for the special purpose of providing 'clerks for the King's service'. Universities have trained clergy, medical men, lawyers, engineers ..." (Whitehead, 1932/1962, p.138).

Reeves also notes that:

The universities were a product of the particular conditions of medieval society in Western Europe. They took their institutional forms from it; they provided the elite which developed the church and state" (Reeves, 1969, p.82).

A warning on where the high value of work relevant skills in a modern university context might lead is sounded by Barnett who notes that it could result in learning: "being dominated by technique; and that the techniques are imported from the outside world and are imposed arbitrarily upon, and unconnected with the curriculum" (Barnett, 1990, p.159). This point is enlarged upon by Pham who states that:

"... it would be foolish not to recognise the benefits and innovations resulted from new knowledge and research, and to expect that new generations of students should only be imparted with sufficient skills to enable them to find some employment" (Pham, 1996, p.152).

Jaspers takes the view that what should distinguish university from non-university education is the primacy of research stating that: "Above all, teaching vitally needs the sustenance which only research can give it" (Jaspers, 1960, p.58). Noting this is not for reasons of economic expediency or to enable researchers to do their research but that only the research worker can communicate the knowledge of discovery. He adds that: "Others only pass on a set of pedagogically arranged facts. The university is not a high school but a higher institution of learning" (Jaspers, 1960, p.58).

Furthermore, the financial cost entailed in providing students with employment relevant, practical, up-to-date vocational training and experiences can be high (Lei & Rawles, 2003). Grubb notes that:

"Vocational education has always been plagued by the problem of keeping up with changing production methods and techniques... Moreover, in the case of hi-tech vocational programs because hardware and software change so rapidly and because hardware costs are often high" (Grubb, 1984, p.445).

To which could be added the high cost of failing to take part in these changes. The non university tertiary sector now also attracts many graduates. Notably, there are

more university students going on to TAFE than TAFE students going on to university (Dorrance & Hughes, 1996).

Commenting on tertiary education within Australia Pham notes that:

“Employability was seen as a by-product of a university degree. Research played a major part, if not the most important part in the role of universities. Vocational training was left to colleges of advanced education or TAFEs. This elite view of universities has gradually been eroded as external forces demand their activities to be more accountable to the outside world” (Pham, 1996, p.152).

It is perhaps highly significant that Dorrance and Hughes state that:

“Australia wide, 468,000 young men and women attend TAFEs while nearly 600,000 attend universities... In rough terms, Australia has more students at university than in TAFEs though managers, professionals and para-professionals only represent 30 per cent of the labour force” (Dorrance & Hughes, 1996, p.52).

Some universities have themselves introduced employment based education into some of their units (Cisco, 2001; Naraymann & Neethi, 2001). The Dawkins higher education policy statement noted that:

“In the past institutions have not paid much attention to employers’ views about course design and content. On the other hand employers have complained of a lack of relevance of courses to their needs, while taking little action to address the problem. That model is unsatisfactory for both higher educational institutions and employers...” (Dawkins, 1988, p.66).

From the USA, Gay and Beeson note that a certificate curriculum was in place within a year of the results of an employee needs survey and that they: “... surveyed its local business and service sectors to discover that computer systems support was the most frequently stated employee need” (Gay & Beeson, 2001, p.3) This finding is in line with those from Maj in Western Australia (Maj, Fetherston et al., 1998).

The ACS mission statement includes the need: “To promote, develop and monitor competence in the practice of information technology by persons and organizations” (ACS, 2001). When applied to education and training the common

feature is that: "competencies are about being able to do things" (Hillier, 1997, p.33), which means that having a population possessing necessary competencies, is of international significance (OECD, 2001).

2.2.2 Education and Training

The introduction of relevant employment-based experiences into a university setting constitutes the entry of work-based requirements into higher education. Finn has noted the convergence of education and work:

"Traditional notions of separation between education and work, especially the notion of a one-off period of education followed by employment, will be replaced by an integrated concept of work intertwined with lifelong learning, commencing with post-compulsory, education and training" (Finn, 1991, p.5).

The notion of training can be seen by some in contradistinction to education. Hillier notes that: "Traditional forms of education have been concerned with the process of acquiring knowledge, training has concentrated on assessing if people can do something" (Hillier, 1997, p.33). Furthermore, meaning attached to training can also vary as training can also be regarded as acquisition of attitude (Goldstein & Gessner, 1988). Campanelli et al further note the unclear boundary between education and training (Campanelli, Channell, McAulay, Renouf, & Thomas, 1994).

Fisher and Rubenson note that:

"The education versus training labels will no longer characterize the binary structure of the postsecondary sector as in the past ... as universities take on more responsibility for training the highly skilled technical employees in, for example, computer science, and for retraining professionals" (Fisher & Rubenson, 1998, pp.93-94).

Under a heading of "*Education v Training*" applied to the area of Computing Science, Denning notes that:

“Learning the professional practices of a specialty of information technology is every bit as important as learning the intellectual core of computing. The mark of a well-educated professional will be a balance of the two, earned perhaps through partnerships and training companies. The current academic inclination to disdain skill-specific training does not fit a profession” (Denning, 1998, p.17).

Jesson distinguishes between Professional and Industrial Training in table 1.

Table 1 Professional Training and Industrial Training (Jesson, 1997, p.352)

A Comparison of Professional Training and Industrial Training		
	Profession	Industry Training
Nature of education	Broad knowledge usually supplemented by applied field-based practice	Narrowly focused training emphasis on learning the skills of the craft in the field
Choice	Qualification chosen by individual	Training chosen by employer
Regulation/Registration	Recognition of effective practice through standards endorsed by external professional council	Recognition of effective standards set by ITO and signified by employer
Ongoing developments	Further education a professional expectation. May be linked to salary structures	Up-skilling linked to pay increments or job improvements
Supply factors	Career choices	Apprentice/Traineeship offers
Lead time for change	Long lead time	Shorter lead time
Locus of control	Profession – Educational	Employer – Enterprise

When discussing professional training courses Esnault noted that: "... they have often changed their nature and have tended to lengthen and become more academic" (Esnault & Le Pas, 1974). Hall also notes this phenomenon of upward academic drift caused by professional and trade bodies seeking increased 'respectability' (Hall, 1993, p.7). Wolf observes that once courses are established there is a tendency for academic drift within them and that qualifications within academic institutions tend to be academic qualifications because it is what staff know about (Wolf, 1995).

Modern requirements may not conveniently fit within the older subject demarcations, and Small comments upon the importance of cooperation between disciplines in making curricula relevant to modern society and business (Small, 1999).

2.2.3 Summary

There is an overlap between education and training. It may be concluded that there is a strong demand from students for employment relevant education and also that professional practice is important in IT, as well as intellectual development. New knowledge requirements are likely to cross traditional subject boundaries. The primacy of the research role of the university is seen by some as a distinguishing feature. Furthermore there appears to be a tendency amongst some academics to disdain skill specific training. Up to date hands-on relevant retraining can be expensive as well as liable to rapid change. Increasingly, university graduates find it necessary to undergo training at TAFEs to gain job relevant skills and qualifications. The fact that there are more university students going on to TAFE than TAFE students going on to university raises the issue of what forms of knowledge should be taught at university level? This also poses questions about different forms or types of knowledge. The role of the university has been and still continues to be an issue of contention.

2.3 Forms of Knowledge

The inclusion of employment relevant knowledge and skills into university curricula raises the issue of their effective appraisal. This can involve assessing both hands-on skills and theoretical understanding, which in turn leads to questions of the different types or forms of knowledge:

“Epistemologists disagree about how many different types of knowledge there might be, but two have attracted most analysis, the first being propositional or informational knowledge - ‘knowing that’, and the second ‘knowing how’ or competent performance. (Bennet, Dunne, & Carre, 1999, p.72).

2.3.1 Integration of Practical and Theoretical Knowledge

McInnis et al note the importance of integrating practical and theoretical knowledge to reduce non completions by undergraduate studies (McInnis, Hartley, Polesel, & Tesses, 2000). Whilst Eraut notes that: “there is continuing pressure within higher education for theory to be situated within the context of discipline-based professional knowledge” (Eraut, 1995, p.171). This poses the question of how to integrate practical and theoretical knowledge and what constitutes their essential difference?

2.3.2 Knowing-How and Knowing-That

The philosopher Gilbert Ryle devoted an entire chapter both titled and devoted to “knowing-how and knowing-that”. He noted:

“Theorists have been preoccupied with the task of investigating the nature, the source, and the credentials of theories that we adopt that we have for the most part ignored the question what it is for someone to know how to perform tasks. In ordinary life, on the contrary, as well as in the special business of teaching, we are much more concerned with people’s competencies than with their cognitive repertoires, with the operations than with the truths that they learn” (Ryle, 1949/1963, p.28).

However, Barnett is critical of the use of this example. He notes:

"Ryle's text has re-emerged to serve a purpose, to bolster a particular cause. Whether read or not the suppositions that (for example, in distinguishing knowing-that from knowing-how) Ryle has somehow written a text that legitimises high marks for performance" (Barnett, 1994, p.176).

Ryle uses the case of a boy learning chess noting:

"It should be noticed that the boy is not said to know how to play, if all he can do is recite the rules accurately. He must be able to make the required moves. But he is said to know how to play if, although he cannot cite the rules, he normally does make permitted moves and protest if his opponent makes forbidden moves. His knowing-how is exercised primarily in the moves that he makes, or concedes, and in the moves that he avoids and vetoes. So long as he can observe the rules, we do not care if he cannot also formulate them" (Barnett, 1994, p.41).

Brown takes issue with this idea and notes a case where such assumptions of 'knowing-how' are not so readily assumed. He notes:

"As to behavioural or performance criteria, on the other hand, no type of performance not involving formulations of the fact is uniquely relevant. There is only an indefinitely wide variety of actions, corresponding to a wide variety of intentions, motives, desired and the like of which the fact in question would make the action appropriate" (Brown, 1971, p.246).

The thrust of this thesis is emphasised by Ryle's ideas of combining knowing-how and knowing-what, namely, the combination of practical experiences with theoretical understandings. Knowing-what is used interchangeably with knowing-why, or knowing-that. Both traditional assessment methods and competency-based approaches may be required in today's education. Young notes: "What our education should be is a balance between the vocational and the academic, between the theoretical and the pragmatic, between knowing how and knowing that" (Young, 1984, p.14) cited in (Wellington, 1984, p.39).

Knowing-how and knowing-that and when to apply knowledge have also been described in terms of Declarative, Procedural and Conditional knowledge.

2.3.3 Declarative Procedural and Conditional knowledge

These terms arise from a cognitive perspective to learning (Woodfolk, 1998) who also notes that Declarative knowledge is "... 'knowing that' something is the case" (Woodfolk, 1998, p.284). Whilst Farnham-Diggory describes declarative knowledge as:

"... knowledge that can be declared, usually through words , through lectures, books, writing, verbal exchange, Braille, sign language, mathematical notation, and so on" (Farnham-Diggory, 1994, p.468).

Woodfolk describes: "Procedural knowledge is 'knowing how' to do something such as divide fractions or clean a carburettor - procedural knowledge must be demonstrated" (Woodfolk, 1998, p.284).

Declarative and procedural knowledge are included by Anderson in a list of educational learning objectives (Anderson et al., 2001, p.28). The need for the integration of declarative and procedural knowledge is also noted by Paris, Lipson, and Wixson (1983) who describe knowing when and why to apply the appropriate procedural and declarative knowledge as conditional knowledge. This is also noted by Schunk:

"Possessing the requisite declarative and procedural knowledge to perform a task does not guarantee students perform well ... This situation is not uncommon. Achievement depends on knowing facts and procedures and knowing when and why to apply that knowledge" (Schunk, 1996, p.203).

Dufresne et al note that experts require both procedural and declarative knowledge and that experts have many strong links between these types of knowledge, whereas for a novice such links are weaker (Dufresne, Leonard, & Gerace, 1995). However, other potentially relevant classification schemes (Barnett, 2000) and (Gibbons et al., 1994) have also been investigated.

2.3.4 Knowledge 1 and Knowledge 2

Yet another knowledge classification scheme is described by Barnett who notes that: "Knowledge 1 is essentially theoretical knowledge inside of the

university sector, and Knowledge 2 is essentially knowledge-in-use outside of the university" (Barnett, 2000, p.17). Gibbons uses the terms mode 1 and mode 2 knowledge and notes that:

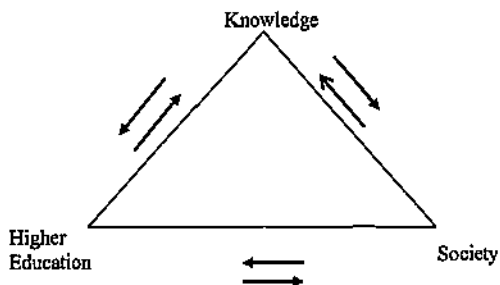
"For many, Mode 1 is identical to what is meant by science. Its cognitive and social norms determine what shall count as significant problems, who shall be allowed to practice science and what constitutes good science" (Gibbons et al., 1994, pp.2-3)

Barnett also notes that these modes of knowledge are both intermingling and broadening (R Barnett, 2000). Scott has considered historical development of mode 1 and 2 knowledge noting:

"It has been suggested that Mode 2 is not a new phenomenon. Rather it describes how many disciplines originally developed (Applications first, theory afterwards) and how much industrial research and development has traditionally been organised" (Scott, 1997, p.23).

Referring to the learning triangle (Figure 1) Barnett notes that the relationship is triangular and goes both ways.

Figure 1. Knowledge Created and Used Inside and Outside of Universities (Barnett, 1994, p.12).



The importance of both types of knowledge is noted with respect to the workplace skill requirements of Information Systems (IS) graduates (Davis, Gorgone, Couger, Feinstein, & Longnecker, 1997).

They further note that: "Many of these competencies are shared within the computing professions..." (Davis et al., 1997, p.37).

2.3.5 Small and Medium Enterprises (SMEs): The Need to Know 'How' and Know 'That'

Both 'knowing how' and 'knowing that' may be especially important within SMEs where Information Systems (IS) management students may find themselves in the position of dealing with IT outsourcing and may be responsible for a much greater range of IS activities than may be the case within a large company. The Dearing report has also noted that:

"The SME sector, which we believe to be of increasing importance, needs a distinctive response from higher education institutions in terms of initial skills of graduates and consultancy support. For initial skills, SMEs told us they need graduates who can make an immediate contribution to work as soon as they arrive in the company" (Dearing, 1997, Chap. 4.23).

This may be due to the shortage of appropriately trained technical personnel in SMEs. A report to the UK Department for Employment and Education (DfEE) notes that "Despite the lower costs of new technology, it seems unlikely that many SMEs will have the technical personnel to develop, implement and maintain complex IT operations" (Beard & Breen, 1998, p.27). Benamati notes that: "... the emergence of new skill requirements have made finding and retaining a skilled workforce especially difficult" (Benamati & Lederer, 2001). Both hands-on skills and deep technical knowledge can also be important to SME IS management with respect to evaluating employee end-user training. In a paper entitled "A profile for the IT manager within SMEs" Gramignoli stated that: "the deeper the IT manager's technical knowledge, the more effective will be the end users training programme and day-by-day support". They further note that:

"Within SMEs the traditional IS management activity is often replaced by the management of the relationship with the technical partners: because of the shortage of IS dedicated staff, the IS design, implementation, and development are often outsourced. In such a context, in-depth technical knowledge is essential to correctly weigh

up the technical validity of the partners' proposals" (Gramignoli et al., 1999, p.201).

In their book 'Client/Server Information Systems a business orientated approach' Goldman et al note that:

"In order to understand the full impact of client-server architectures it is necessary to comprehend the physical relationship or technology implementation configuration of the elements of a typical client/server architecture as well" (Goldman, Rawles, & Mariga, 1999, p.32).

Whilst Englander notes that:

"There is a tendency for people in information systems and technology to neglect the study of computer architecture After all, the technology changes so rapidly – is it really worth trying to understand something that may be out of date before I finish this book ... ?" (Englander, 2000, p.vii).

Outsourcing may not solve skill shortages in SMEs as companies can lose their brightest and most skilled employees (Ruber, 2000). Todd, Mckeen and Gallupe whilst investigating job skill requirements from newspaper advertisements "concluded that organizations are looking more to technical requirements in the hiring process" (Todd, Mckeen, & Gallupe, 1995) cited in (Crook and Crepeau, 1997, p.138). O'Brien notes SMEs problems with misleading advice and poor support from IT suppliers (O'Brien, 2000). SME IS mangers with more hands on experience could avoid such situations.

The results of a study specifically concentrating upon the perceptions of IS students of the needs of the IS Industry found that they were: "in remarkable agreement with employers" (Mawhinney, Morrell, Morris, & Helms, 1999, p.234). The Master of Science in Information Systems (MSIS) 2000 Model curriculum notes that to increase their employment potential: "... students take a related set of courses reinforced by practical experience within information systems" (Gorgone et al., 1999). The Model Curriculum and Guidelines for Undergraduate Degree Programs in Information Systems, under a heading of "Networks and Telecommunications" states that: "Installation, configuration, systems installation

and management of infrastructure technologies will be practiced in the laboratory" (Gorgone et al, 2002, p.28). IS managers are increasingly dealing with contract partners who perform their IT and IS department functions and so they now need in-depth technical knowledge.

Willcocks (1996) and Trauth et al have highlighted serious mismatches between the requirements of what industry needs from new IS graduates, and what IS faculties are producing (Trauth, Farwell, & Lee, 1993). A UK Department for Employment and Education IT labour assessment report found that:

"Increasingly, university IT graduates can no longer expect to be employed in large companies with graduate training programmes. Many SMEs want graduates who are job ready, have good practical and business skills and are up to date with the latest systems. However, SMEs are frequently unable to articulate their specific skills requirements and unable to invest significantly in training" (Beard & Breen, 1998, p.36).

2.3.6 Summary

It may be concluded that there are calls for the integration of 'knowing-how' and 'knowing-that' and that both are required to achieve mastery, as is the experience of when and why to use them. There are calls for education to achieve a balance of knowing how and knowing that. Procedural and Declarative knowledge are other terms used for the description of knowing how and knowing that. Both are important, as is the conditional knowledge of when and why they should be applied. Other classification schemes can also be of use such as Mode 1 and Mode 2 knowledge.

There appears to be a mismatch between what industry requires from IS management students and that provided by universities. This is similar to findings in CNS provision. SMEs have problems with IS provision because an IS manager may be expected to have wide IS knowledge and experiences and may take on a variety of roles within an organisation. Outsourcing does not necessarily solve SMEs problems with respect to skill shortages of IS managers.

2.4 Assessment

Regardless of type, all knowledge needs to be assessed at university, not only as a form of quality assurance of the level of attained, but also as a form of feedback both to students and lecturers. Moreover, assessment can be crucial for many students in deciding whether a topic is worth learning (Lazarus, 1981). The form of the assessment has also been shown to promote different forms of learning (Scouler, 1998). McInnis and Devlin note an indicator of effective assessment in higher education is that: "a variety of assessment methods is employed so that the limitations of a particular method are minimised" (McInnes and Devlin, 2002, p.9). In a recent thesis entitled: "The competing discourses in the WA upper school curriculum in WA" Murphy notes:

"That practical 'hands on' skills and knowledge is fundamental to conceptual understanding. That knowledge is more transferable to different situations when acquired by a gradual process of conceptual understanding" (Murphy, 1998, p.246).

There are many other studies that have shown that 'hands-on' experience reinforces the learning process (Cheng, Holyoak, Nisbett, & Oliver, 1986; Reed & Actor, 1991). Their separation is advised against by Tarrant who warns:

"In fact both practical skill and knowledge of certain principles are jointly sufficient for success. This should warn against any scheme in which practical knowledge is rigidly separated from theoretical knowledge" (Tarrant, 2000, p.77).

Competency testing has often been used in the workplace to assess practical employment relevant skills and understandings.

2.4.1 Competency

Competency has been defined as: "The ability to perform in the workplace" (Goldsworthy, 1993, p.113). A competency can also be defined as "A knowledge, skill, or characteristic associated with high performance on a job" (Mirabile, 1997, p.75). Whilst Dalton notes that: "Competencies are behaviours that distinguish

effective from ineffective performers" (Dalton, 1997, p.48). Chappell and Hager observe that: "Ultimately it is the application of specialised knowledge and cognitive skills 'within practice based contexts' which leads to competent performance" (Chappell & Hager, 1994, p.13), whilst Sandberg notes that the identification of competence as a classic managerial problem that encourages a consideration of different forms of knowledge (Sandberg, 2000). Schoonover Associates, Inc. note:

"A competency model is a set of success factors, often called competencies, that include the key behaviours required for excellent performance in a particular role. These behaviours are demonstrated by excellent performers on-the-job much more consistently than average or poor performers" (Schoonover Associates, 2001).

Sandberg notes that: "the concept of competence encourages scholars to think not only about knowledge itself, but also about the knowledge that is required in competent work performance" (Sandberg, 2000, p.9). Nguyen found that with respect to the engineering industry, management places more importance on competency than either students or academics (Nguyen, 1998). An Australian Government report "Learning for the knowledge society: An education and training action plan for the information economy" noted the importance of universities ensuring that graduates enter the workforce with the required competencies (DETYA, 2000). Yet Moore and Striebe note that:

"Ideally, industry would like to have new employees be productive from the very first day of employment. But, are graduates ready to become productive employees? Often the answer is surprisingly 'no'. Whilst this may be unexpected by some, it is a consequence of hiring employees from across the country from a variety of educational backgrounds and abilities. In general employees are hired because of their perceived potential to adapt to new environments and ideas. Companies need innovative ideas of new employees to remain competitive" (Moore & Streib, 1989, p.53).

A 1995 Australian Government National Board of Employment Education and Training (NBEEB) report on the "Demand for and Dimensions of Education and Training" noted:

“Employers are increasingly emphasising a broad range of non-academic factors as more accurate indicators of a new employee’s potential to succeed in the workplace. ... They recruit on the assumption that graduates have satisfied the academic requirements of each institution, thus allowing them to focus on the particular skills and attributes they believe are most essential for the particular work environment. Generally, employers emphasise skills and attributes which are more difficult to evaluate than academic skills” (NBEEB, 1995b, p.21).

Another NBEEB report noted that: “The major problems that employers identify with higher education graduates are their attitude, and their knowledge of, and experience with, the world of work” (NBEEB, 1995a, p.x). Although employers recognise the academic importance of university education, they can also recognise the importance of fulfilling industry expectations (Imel, 1989). Naraymann and Neethi of Tata Consultancy Services, the largest recruiter of manpower from engineering institutions within India, state that:

“We are careful not to dilute the academic ambience in schools of learning. We do not want to convert them into training shops. We expect them to cover the wider body of knowledge over which we can build skills. In most of the institutions the time constants for curriculum revision are of a very large order since they have to go through a whole maze of committees. However, of late, the urgency to meet the expectations of the industry is visible” (Naraymann & Neethi, 2001, p.170).

The needs of industry can include a hands-on skills component and Competency Based Assessments (CBAs) are often used to help ensure that employees have the necessary skills and understanding required to perform a job function. CBAs are sometimes employed in what are known as vendor endorsed training programmes (Fage, Agosta, Merchant, Foltz, & Barnes, 2000; Hornbaker, 1999).

2.4.2 CBAs

CBAs are not new (Grant, 1979; McLagan, 1980/1996) and Riesman notes their use for accountability within education where they arise from a: “... concern for what students can do rather than for what the faculty believe they have taught”

(Riesman, 1979, p.57). Karmel discusses competency testing within an Australian context (Karmel, 1995). Masters et al assert the importance of assessed competency in occupational skills (Masters, 1990). Wolf notes the origins of CBAs from a UK perspective, where:

“Competency-based assessment appealed to reformers of both the right and left at a time when the UK Conservative government had become convinced of the need for major reforms in the vocational training sector. Huge increases in youth unemployment in the 1970s and early 80s had created an emergency response in the form of work experience programmes, for which long term and more structured objectives were needed” (Wolf, 1995, p.6).

The possible uses to which CBAs can be put according to Fletcher include Certification, Identification of Training needs, Enhancing Standards, Performance Appraisal, Skills audits, Selection and Recruitment, and Evaluating Training (Fletcher, 1992). To which could be added the experience of utilizing the employment skills required before taking up employment in a field, enabling a student to decide not to attempt to enter particular forms of employment, although this could perhaps be described as a form of self selection.

Denning writes: “The call for competence is a cry from the hungry for nourishment” (Denning, 1998, p.12). However, it is necessary to be able to measure competency, thereby providing essential feedback to students and information to prospective employers. A possible requirement of CBA is the de-coupling of the assessment from particular institutions or learning programmes (Wolf, 1995). This can help to ensure consistent tests and procedures. However, utilisation of CBAs in an educational context has not been without detractors.

2.4.3 Criticisms of CBAs

In much of the above consideration of hands-on skills there is the implicit assumption that such skills should be taught in higher education and that it is appropriate to assess such skills within the context of a university education. This view has by no means attained a position of general acceptance with the university sector where competency testing and vocationally based units are seen by many to

conflict with a major area of traditional purpose of university education. However, Jaspers notes that: "The idea of the university requires that the university be open to new ideas" (Jaspers, 1960, p.110).

A contemporary view is given by Barnett who notes four dominant concepts in judging higher Education quality as "the production of qualified manpower, ... training for a research career, ... the efficient management of teaching provision ... as a matter of extending life chances". He also notes that: "This final contemporary conception is none other than the potential consumers of higher education" (Barnett, 1992, p.18). Thus, one of the arguments for the adoption of more employment related higher education is from the perspective of student demand. Furthermore, there is the concomitant question of the most appropriate assessment methods to employ to assess hands-on skills. Whilst CBAs are well established within the vocationally orientated TAFE system within Australia, there exists some debate as to their relevance in higher education. Goldsworthy mentions a critique of what might be inferred from CBAs:

Competency based standards in effect are an ad hoc measure of skills; they measure performance after the event. The activity is performed and measured after the skills, experience and knowledge have been acquired...The flaw in the logic of this process can then be applied to predicting how well the task might be performed either in the future or in different circumstances" (Goldsworthy, 1993, p.117).

However, in a written examination, the assessment activity is also performed and measured after the acquisition of the skills, experience and knowledge. Standard written examinations don't necessarily provide a prediction as to how well students might perform in the workplace.

Algie interprets the present day use of CBAs in terms of classical production management systems noting:

"Competency based assessment is an application of quality management principles to a process that has a variable input (students) and a variable process (training and education). This calls for a test of the output against standards. This says at least the product (the graduate) satisfied those tests to which it was subjected, but maybe no more than that" (Algie, 1999, p.3).

However, a similar argument could be made against standard written examinations.

In the paper "Competency-based Education and Training: Between a Rock and a Whirlpool" Harris et al note the difficulties and the controversial nature of using CBAs in an Australian educational context (Harris, Guthrie, Horbart, & Lundberg, 1995). CBAs have been accused of promoting minimum levels of attainment (Stanley, 1993).

2.4.4 CBAs and Minimal Attainment

To assess large numbers of students via CBAs can be costly both in time and equipment. This can encourage over simplification, which has led to the charge that they may promote minimum levels of attainment (Stanley, 1993). Lazarus makes a similar case (1981). Furthermore, Wolf notes that:

"minimum competency tests in the United States have been criticised consistently for the low standards that they embody..."Their critics have also (like many contemporary critics of competency testing in the vocational field) argued that the tests carry another attendant danger, viz. that the minimum level will become the maximum, and that teaching and learning be narrowly defined by test content" (Wolf, 1995, p.85).

Nevertheless, more complex tests can be implemented to yield a wider range of results. For example these could be fault-finding exercises on PCs with a range and combination of simulated faults. There are CBAs such the hands-on laboratory examination that is both highly complex and very difficult to pass (Abelman, 2000). Furthermore, Osterich notes that:

"The lab exam takes place over two days. The first day the candidate has the task of setting up a complex internetwork using disparate technologies. During the evening of the first day, test administrators essentially sabotage the work you did in the morning, so the second day you spend troubleshooting and diagnosing those issues. The CCIE exam has a high failure rate: generally, more than 80% of first time candidates fail" (Osterich, 2000, p.7).

2.4.5 CBAs and Behaviourism

CBAs have also been criticised as merely testing learned habits. From such a perspective CBAs could be seen to accord with behaviourist principles. Morgan, Ponticell and Gordon note: "behaviourists have viewed individual differences in terms of biological differences and learned habits" (Morgan, Ponticell, & Gordon, 1998, p.210). Whilst Winch and Gingell note that:

"Behaviourism is a psychological doctrine about the nature of mind. It includes a theory of learning which suggests that the only proper concern of the teacher is behaviour modification" (Winch & Gingell, 1999, p.25).

Ramsey notes that: "The essence of Behaviourism is the training of individuals to respond in a uniform predictable manner to pre-determined situations" (Ramsey, 1993, p.76). Whilst Norris expands upon this theme noting:

"There is a fundamental contradiction between the autonomy needed to act in the face of change and situational uncertainty and the predictability in the specification of outcomes" (Norris, 1991, p.335).

Behaviourist association with hands-on skills attainment has a long tradition, for example, the behaviourist Skinner notes in his novel "Walden II" that: "A good share of our education goes on in workshops, laboratories and fields" (Skinner, 1948, p.119). Skinner again notes that: "The whole process of becoming competent in any field must be divided into a very large number of very small steps" (Skinner, 1954, p.94).

Barnett expresses the notion that: "competence is concerned with predicable situations" (Barnett, 1994, p.72) and Neill notes that: "There are three common characteristics of competency based tests: 1. They are based on clearly defined objectives representing defined competencies; 2. Test items are specifically designed to measure the objectives. 3. Scores are interpreted in terms of attainment of a pre-set criterion or standard of performance" (Neill, 1978, p.72). Yet Jessop notes that: "... when unexpected circumstances occur the procedures are often not appropriate or sufficient and the performer must improvise to achieve success.

Coping with the unexpected is a crucial part of the concept of competence" (Jessop, 1989, p.33).

Thus the phrase that 'We must expect the unexpected' finds its application with respect to competency assessment as noted by Brown (1971). This need for more realistic tests of competence is also noted by Chomsky who states that:

"Obviously one can find out about competence only by studying performances, but this study must be carried out in devious and clever ways, if any serious result is to be obtained" (Chomsky, 1971, p.66).

However, Usher et al note the importance of competence, adding:

"Even if we are sceptical about, for example, the value of a learning defined in terms of questions of pre-defined competences or adaptation to a pre-defined environment, it is difficult on the face of it to deny that to become more competent is to become more empowered" (Usher, Bryant, & Johnston, 1997, p.82).

Not all competency outcomes need to be expressed in precise specifications, even though this may have been case for the UK's National Vocational Qualifications (NVQs) (NCVQ, 1991). Hillage et al note that: "NVQs are made up of a number of units that set out industry-defined standards of occupational competence" (Hillage, Uden, Aldridge, & Eccles, 2000, p.4). Whilst Heywood notes that:

"NVQs came in for much criticism. Apart from complaints about the amount of paper work involved they were also criticized because they paid insufficient attention to the role of knowledge in determining outcomes" (Heywood, 2000, p.307).

Smithers notes, when discussing the implications of Britain's NVQs, that: "It has been assumed that if students can show themselves capable of carrying out specified tasks, the necessary knowledge and understanding must have been acquired also and need not be separately assessed" (Smithers, 1993, p.9). Such methods accord with Behaviourist interpretations (Mestre, 2000). Whilst Soucek

argues that performance in a CBA does not guarantee knowledge (Soucek, 1993) and Gonczi and Hager note that:

“... competence in an occupation involves more than the mastery of a large number of discrete tasks. It includes the capacity to integrate skills and knowledge and often, attitudes to the actual practice of work” (Gonczi & Hagger, 1992, p.33).

The use of competency in the workplace invites the question: Are there alternatives to CBAs?

2.4.6 Alternatives to CBAs

Ashworth and Saxton argue that there are other more effective ways to enhance practice such as sandwich placements. Sandwich courses in the UK consist of prolonged periods in industry such as a semester alternating with periods of full time study:

“The student on placement ought to come to see that theory plays the role of an interpretive resource; it is a system of tools with which to make sense of his or her work experience, so that experience is raised to the level of reflection partly through the employment of theoretical concept, and theory is related to things which have real significance for the student” (Ashworth & Saxton, 1990, p.20).

Kelly and Else have noted that these can help to increase opportunities of future employment for students undertaking such courses (Kelly & Else, 1996). Yet Smithers questions the benefits of sandwich courses stating that: “The chief reason for disappointment is the generally acknowledged failure to bring the academic and industry parts into a satisfactory relationship” (Smithers, 1976, p.149).

Close industrial and academic cooperation can occur in regard to course content (McDonald, Rickman, McDonald, Heeler, & Hawley, 2001) and Beeson and Gay have noted that graduates of their PC and computer networking skills based programme that have completed a work experience programme in this field are, according to local employers, better prepared for the job market (Beeson & Gay, 2000). Being able to do a job is a relevant form of assessment but can also be undertaken in addition to CBAs. Student project work in cooperation with industry

(Daniels & Asplund, 1999) is yet another method whereby students can gain relevant practical experience.

Potential workplace assessment can include oral assessments. McCurry notes that: "This can assess candidates' skills of thinking on their feet" and "... that oral assessments are uniquely capable of providing insight into a candidate's occupational competence" (McCurry, 1992, p.235). However, this can lead to the question of scaling and brings forth the attendant question of levels of competence and the question of how competence is exhibited at different levels of attainment (Bowden & Marton, 1998; McCurry, 1992).

2.4.7 Levels of Competence

Bowden and Marton, describe increasing levels of competence as one goes from level 1 to level 4 there are:

"Increasing complexity of outcome; Broader curriculum requirements; Increasing ambiguity in the relation between objectives and assessment outcome; Increasing need for interpretation and professional judgement in assessment" (Bowden & Marton, 1998, p.105).

They further characterise level 1 as the impractically long lists of specific tasks derived from the analysis of professional work. Whilst level 2 avoids this it: "runs the risk of attempting to spell out knowledge skills and attitudes that underlie professional competence without considering what it is that professionals actually do in the workplace". By contrast the level 3: "attempts to consider knowledge in context in relation to performance rather than separate from it". With respect to level 4, they note that it:

"... represents the attempt to integrate as well the person's way of seeing themselves as professional. It is more holistic than and subsumes the previous levels. In our view, competency-based approaches have not gone much beyond level 2 and we believe that the educational approach should be directed at least to level 3 and preferably to level 4"

Adding that this level:

"... represents a three-way integration among a person's way of seeing their professional role, their capacity to undertake that role and the knowledge base with which professional identity and performance are intermeshed. Assessment of such an outcome is not simple and it is difficult to assess it directly. Competency-based approaches do not in practice address these matters. ... It is not surprising that, initially, the competency movement focused on minimal ambiguity and greater certainty, viz level 1. They were concerned with generating greater recognition of the role of education in preparing students for the workplace, within an educational world that they saw as focused on book-learning and theory. As a consequence their terminology and their practices focused almost entirely on the workplace connection" (Bowden & Marton, 1998, pp105-107).

2.4.8 Confusion over a Definition of Competency

A further problem with the notion of competency is that of a common definition. Within an Australian context Laver (Laver, 1994), states that:

"Semantic confusion has arisen because the term 'competency' is used in at least three different senses: in the training sector, it means the capability to perform certain designated tasks satisfactory so that defined outcomes can be met; in the Mayer Committee's Report it covers more generic skills, such as problem solving and planning; and in the university sector, though generally rejected, it is sometimes recognised as comparable to such concepts as graduate attributes" Cited in (Reid, 1996, pp.133-134).

Barnett in referring to competence in a UK context notes:

"that there are two versions of the idea jockeying for position in academe: one is an internal or 'academic' form of competence, built around a sense of a student's mastery within a discipline; the other - now being pressed robustly - is the 'operational' conception of competence, essentially reproducing the wider societal interest in performance, especially performance likely to increase the economic performance of UK inc" (Barnett, 1994, p.159).

Barnett compares the operational and academic versions of competence in Table 2.

Table 2. Barnett's Two Rival Versions of Competence (Barnett, 1994, p.160).

	Operational Competence	Academic Competence
1. Epistemology	Know how	Know that
2. Situations	Defined pragmatically	Defined by intellectual field
3. Focus	Outcomes	Propositions
4. Transferability	Metaoperations	Metacognition
5. Learning	Experiential	Propositional
6. Communication	Strategic	Disciplinary
7. Evaluation	Economic	Truthfulness
8. Value Orientation	Economic survival	Disciplinary strength
9. Boundary Conditions	Organizational norms	Norms of intellectual field
10. Critique	For better practical effectiveness	For better cognitive understanding

Barnett also adds that: "From cognitive culture to economic performance: the changing definitions of competence are a microcosm of the changing definitions of the university" (Barnett, 1994, p.159).

2.4.9 Classification of CBA Methods

McCurry compares and contrasts the different forms of assessing competences as in Table 3.

Table 3. Different Forms of Assessing Competences (Simplified) (McCurry, 1992, p.237)

Methods of Assessment	Distinctive Purposes and Uses	Advantages and Strengths	Disadvantages and Weaknesses	Practical Considerations
Multiple Choice Tests	Factual and procedural knowledge and understanding of principles	Consistency and reliability Uniform and standardised	Access ability to recognise rather than recall Difficult to use for problem solving and higher order thinking	Difficult to write Cheap and efficient to use
Written responses Short Answer Extended Answer	Use of Information Application of knowledge Generating ideas and solutions	Tests more complex set of skills Higher order thinking and problem solving	May assess language skill in addition to knowledge or competence	Difficulties ensuring reliable judgements Expensive to process
Oral Assessments	Interpersonal skills Interactive thinking	Assessment of thinking skills Multi-dimensional	Difficult to standardise Variable conditions	Problems with the reliability of judgements
Performance Product	Psycho-motor skills Functioning Ability to produce	Holistic and direct assessment of skills	Expensive of time and resources	Difficulties ensuring reliable judgements Logistical difficulties
Work based assessment	Overall performance and functioning	Directness, breadth, range of assessment	Duration and availability	Dependant on supervisor and supervisor's judgment

However, no matter under what classification scheme a CBA may fall there is still a need for it to be tested for consistency (DEET, 1994).

2.4.10 CBA Consistency Checks

As with other forms of assessment CBAs need consistency and Rutherford notes the practical considerations of which those involved in CBA implementation need to be aware (Rutherford, 1995). Field and Drysdale define reliability as related to the absence of error, noting that: "A reliable test is one that consistently estimates the 'real' level of skill regardless of who administers it, which learners are tested and who marks the results" (Field & Drysdale, 1991, pp.220-221). However, it should be remembered that the absence of proof of error is not proof of the absence of error. Hyland notes that there are different types of types of validity:

"Content Validity: The degree to which a test measures an intended content area (e.g. Science, History or Biology). Face Validity: The degree to which a test appears to measure what it purports to measure. ... Concurrent Validity: The degree to which a test measures an intended hypothetical construct such as intelligence or creativity. Predictive validity: Which indicates the degree to which a test can predict how well an individual will do in a future situation" (Hyland, 1994, p.39).

2.4.11 Generic Skills and CBAs

Generic skills are characteristic of a whole class of skills. They are increasingly recognized as an important component of undergraduate courses (Bartley, 1999). Such competencies in a national context have been considered in the Mayer committee report (Mayer et al, 1992). The committee stated that: "The concern is to identify competencies required for effective participation in employment rather than those required to undertake specific tasks" (Mayer et al, 1992, p.3). However, Bennet asks: "Are, for example, the generic skills promoted in academic settings the same kind of generic skills sought in the world of work?" (Bennet et al., 1999, p.91). Furthermore, Stevenson argues that while tasks may appear to an observer to possess commonality, such commonality does not automatically extend to the knowledge involved in these tasks (Stevenson, 1999).

2.4.12 Summary

The notion of competency has been, and will no doubt continue to be, hotly debated. Some definitions allow for the notion of competency to include deep levels of understanding and reasoning. Hands-on skills can be tested by CBAs. In many fields of knowledge, within a university context, CBAs constitute a non-traditional form of assessment. CBAs have also been criticised as promoting minimum attainment testing. However, other forms of assessment may fail to assess hands-on skills. There are many different forms of assessment and CBAs can form a useful addition to the range of tests where each form of assessment has its strengths and weaknesses. A skilful assessment blend could allow the strengths of one form to cancel another form's weaknesses. CBAs need consistency checks, especially in cases involving multiple assessors. CBAs are sometimes employed in what are known as vendor endorsed training programmes.

2.5 Vendor Endorsed Training Programmes

Industry supported qualifications such as the CompTIA A+ Certification are known as 'vendor neutral' (Andrews, 2003b; Meyers, 2001). Andrews notes that: "CompTIA has over 13,000 members which includes every major company that distributes or publishes computer-related products... Other certifications are more vendor specific" (Andrews, 2003a, p.1015). Major IT companies are now endorsing training specifically tailored to the use of their product lines. These include companies such as Cisco (Odorn, 2003, 2004) Microsoft (Rada, 1999) and Novell (Clarke IV, 1999). These companies have either implemented (Abelman, 2000; Cisco, 2002; Clarke IV, 2001; Lammie, 2002) or have endorsed their own certification programmes (Microsoft, 2000). Such qualifications are known as 'Vendor Certifications' (Fage et al., 2000; Hornbaker, 1999; Meyers, 2001). These are very different in nature to the traditional offerings of the university sector (Montante & Zahira, 2001). Hornbaker notes that:

"Over the years, vendors have created their own certification programs because of industry demand. The demand arises when the marketplace needs skilled professionals and an easy way to identify them. Vendors benefit because it promotes people skilled in their product. Professionals benefit because it boosts their careers. Employers benefit because it helps them identify qualified people" (Hornbaker, 1999, p.xxxii),

Within Australia many universities, TAFEs and secondary schools, are now offering vendor endorsed programmes such as the Cisco Network Academy Program (CNAP) (Cisco, 2003a, 2003b).

2.5.1 Vendor Endorsed Training, Universities and CBAs

Abelman compares CBAs talked about in higher education with the very demanding Cisco CCIE laboratory assessment (Abelman, 2000). Rada looks at Microsoft skills certification noting that:

"The skill standards are defined by Microsoft, and the delivery of training and certification is brokered by Microsoft. In developing IT skills standards, Microsoft follows a systematic approach to the study of what people want and need to know" (Rada, 1999, p.25).

Rada also notes that such standards are based upon a definition of job analysis and objectives noting that:

"The job analysis is a breakdown of all tasks that make up a specific job function, based on tasks performed by people who are currently performing that job function... Microsoft focuses on quality control over the certification exam. Microsoft is not in the business of training but relies almost exclusively on other organizations to do the training process" (Rada, 1999, p.25).

This is contrasted with Novell who market networking products. It is perceived as an important part of Novell's strategy to educate its customers and their employees about its products (Rada, 1999, p.25). Novell have internationally recognized professional development program - the Novell Certified Network Engineer (CNE) which consists of a number of courses (Clarke IV, 2000; Clarke IV, 2001).

The education of employees and customers is also seen as a reason behind vendor certification programmes by Odom who notes that:

"Cisco requires a partner to accumulate points based on the number of employees with certain certifications, to become a Premier, Silver, or Gold Channel Partner. The status in turn, dictates the discount received by the reseller when buying from Cisco. This practice continues to be a good way for Cisco to judge the commitment of resellers to hire people with proven Cisco skills, which then improves customer satisfaction – and customer satisfaction is tied to every senior executive's bonus plan" (Odom, 2002, p.4).

Whilst the fast moving nature of technology is given as another reason for vendor certification programmes, Fage et al note that:

"In the networking industry, technology changes too often and too quickly to rely on traditional means of certification, such as universities and trade associations. Because of the investment and effort required to keep network certification programs current, vendors are the only organizations suited to keep pace with the changes" (Fage et al., 2000, p.xxx).

The ACM guidelines for associate degree programs to support computing in a networked environment notes that:

"More and more post-baccalaureate coursework is being completed at two-year colleges as IT related workers address their needs for continuing education. This phenomenon, together with the enormous demand for workers with technical skills has shifted the focus of many students away from program completion to pursuing selected course topics and preparation for vendor-specific industry certification" (ACM, 2000, chap.1, p.6).

Yuan et al consider the possible effects of alternative certification paths on higher education (Yuan, Moffitt, Bailey, Nix, & Terrell, 2002) and Watt asks: "What are the implications for the universities and their autonomy if professional bodies establish competency standards incompatible with the educational processes?" (Watts, 1992) cited in (Reid, 1996, p.134). There is concern about this situation expressed in the view that: "... a crises exists, rooted in the loss of monopoly" (McNair, 1997, p.38). This view is echoed by Barnett who states that:

"No longer are academics in the position of near monopoly that they have long held (for the past 100 years) in defining what is worthwhile knowledge. Now, industrial corporations, finance houses, consultancies and professional bodies are all involved in quite formal ways in producing knowledge and in defining key problems" (Barnett, 1997, p.170).

Barnett also notes that: "The crisis goes further, in a fast-moving world, where one just has to keep up with the game, performance is becoming severed from understanding" (Barnett, 1997, p.175).

Industry certification paths can present integration issues for post secondary education (Koziniec & Dixon, 2001; Nelson & Rice, 2001), whilst Capell questions the value of such certifications from the perspective of cost (Capell, 2003), yet, higher education also has an attendant high cost.

The UK Dearing report interviewed a large number of employers, including Small to Medium Business Enterprises (SMEs) and larger companies and noted their use of Higher Education (HE) providers for Continuing Professional Development for this task. They found that HE is not the first choice of these employers. (Dearing, 1997). This point is echoed by Page:

"Employers recognize that certifications, like university degrees, do not guarantee a level of knowledge, experience, or performance; rather they establish a baseline for comparison" (Fage et al., 2000, p.xxxi)).

The importance of having people skilled in the use of their products is of importance to vendors as reiterated by Fage:

"By seeking to hire vendor certified employees, a company can assure itself that not only has it found a person skilled in networking, but also it has hired a person skilled in the specific products the company uses" (Fage et al., 2000, p.xxxi)).

It should be noted that merely because a curriculum is employment relevant does not mean it is sub-standard. For example medical school education is, hopefully, both relevant to a student's future employment needs as well as being of a high standard. However, much vendor based certification is not based upon CBAs but upon tests often using computer administered Multiple Choice Questions (MCQs) (Bixler, Chambers, & Phillips, 2000; Clarke IV, 2000; Odom, 2002).

2.5.2 Multiple Choice Questions

MCQs have been studied by Christianson and Fajen who note that: "Some critics assert that a single multiple-choice test can't tell you whether a person can handle real world problems using a particular product". They answer this by stating that:

"... the multiple-choice tests that vendors use are typically designed – by teams of practicing and skilled 'prometricians' (professionals in testing and measurement) – to assess knowledge and abilities as will be needed in real world applications" (Christianson & Fajen, 2001, p.790).

However, actual hands-on skills are not tested by MCQs as could be shown by discovering applicants who, though able to pass the requisite MCQ tests, lacked the necessary hands-on skills. Commenting of MCQs, McCurry notes that:

"... they can also assess higher order skills when they are well written... MCQ tests are described as 'objective' because their scoring can be mechanical and unambiguous. However, there is

always an element of subjective judgement about what to include in a multi-choice examination and about what constitutes adequate performance on such a test" (McCurry, 1992, p.232).

A common objection to MCQs is that they may be answered just through guessing.

Swanson et al note that:

"Critics of MCQs often focus on 'cuing' inherent in MCQ format: they argue that examinees need only recognize the correct answer, rather than work through the problem and construct it. This is a legitimate concern, but it is generally straightforward to reduce cuing by increasing the number of response options" (Swanson, Case, & van der Vleuten, 1997, p.270).

Farthing et al have developed permutational MCQs making such an event very unlikely. Farthing et al also note a common objection to MCQs is that: "they assess only trivial recognition of facts rather than high level thinking" (Farthing, Jones, & McPhee, 1998, p.81). McPeck calls this "The Trivial Pursuit Theory of Knowledge" and goes on to state that: "Like the game Trivial Pursuit, knowledge is assumed to be the kind of thing which can be fitted into one-sentence questions, with one-sentence answers" (McPeck, 1990, p.27). However, Pithers notes the difference between select-type questions where the student needs to select answers from a range of alternatives and supply type questions where they need to provide the answers and that:

"Supply-type items have typically been shown to have the capacity to tap deeper levels of cognitive understanding and application. It should be noted however, that if well thought out, sometimes select-type multi-choice items can achieve this as well" (Pithers, 1998, p.214).

McCurry notes that MCQs can quickly assess across a wide range of procedures and facts (McCurry, 1992). The use of distracters provides false options to candidates that they may not have previously considered (Farthing et al., 1998). Farthing also notes that a common criticism of MCQs is that they do not ask a candidate to construct an answer, but rather offer a choice of answers. However, the use of permutational MCQs can avoid this problem as the answer is achieved via a sequence of correct choices to questions (Farthing et al., 1998).

Mestre argues: "... selecting the correct answer from an array of choices is not an accurate depiction of what people do when they solve problems in the real world" (Mestre, 2000, para.68). Now some industry certification tests mix MCQs with exercises that simulate responses from a real world networking devices. For example, Odom notes that: "... Cisco is including router and switch simulations in the exam. So your ability to not just remember command syntax but also to know what commands to use will be very important" (Odom, 2002, p.3).

Where a large bank of questions is available adaptive testing can be part of the MCQ process (Bixler et al., 2000). IT trainers and assessors have used adaptive testing as part of their certification processes. An example of this type of combined MCQ/adaptive testing is the A+ Technicians exam, and CompTIA, will eventually convert all of its exams into adaptive mode (Brooks, 2002). Odom commenting on Cisco Certifications notes that: "The test adapts to you – if you answer a question wrong, you will get more questions on that topic" (Odom, 2002, p.3).

2.5.3 Summary

Vendors have developed their own programmes that involve alternative methods and certifications than those provided by universities. Higher education institutions are now offering some of these commercial certification programmes as a component of their degree offerings. Arguably, in these cases, universities have lost control over part of their own course content and standards. Higher education may well not be the first choice of business to update employees' skills and knowledge. Hence some universities now find themselves constrained in needing to conform to external, but also, employment relevant curricula. Vendor endorsed training may include MCQs. MCQs can test a wide range of knowledge quickly but they have been criticised for a failing to assess in-depth understanding.

2.6 Testing of CNT s Skills and Knowledge

Could CBAs be used within a specific area such as CNT curricula? After investigating third-year university computing science students, Maj found that none of the students questioned satisfied the employer expectations in the field of computer and networking installation and maintenance with regard to safety, or proper work procedures to avoid machine damage (Maj, Fetherston et al., 1998). Molina III notes the student demand for a networking course that would help them gain employment opportunities immediately after graduation (Molina III, 1997). Pithers notes that:

“To become truly competent, learners need supervised, deliberate practice that is trainer assisted, especially in the initial stages. ...Expert performance takes time (i.e. much practice feedback); trainers all too often tend to underestimate the practice/feedback required for excellent performance” (Pithers, 1998, p.175).

Moreover: “Skilled performers need to perceive encoded information and develop sequences or schemas in the situation as well as execute rapid movements” (Chamberlin & Magill, 1992, p.314). Maj (1998) has also noted the need for repeated practice for skill attainment as has Molina: “... because of rigorous hands-on experience, students become extremely proficient in applied networking and obtain a deep understanding of the related theoretical aspects” (Molina III, 1997, p.1).

If students are to be involved in practical hands-on tasks then there is the problem of safety. Staff who have not been involved in practical issues that have a safety component, or who are not conversant with modern safety law, might overlook modern mandated requirements. Such an understanding is not necessarily based upon intelligence but on experience.

2.6.1 Safety

Leonard notes: "... many activities involve hazards of which the participants are aware. It is the function of warnings to provide information about hazards in order that they may be avoided" (Leonard, 1999, p.290). Maj notes the importance of safety with respect to hands-on workshops in computer installation and maintenance (Maj et al., 1997).

The importance of correct lifting technique is reinforced by Marcel who notes that: "One out of every 25 men changes his work because of low back pain resulting in early retirement and disability pension payments" (Marcal, Costigan, & Stevenson, 1999, p.89). However, Albert et al note that: "Researchers to date are still trying to determine the optimum lifting technique for minimizing lumbar load". (Albert, Stevenson, & Costigan, 1999, p.73).

Bigelow warns that people who repair monitors: "Do not operate the monitor without its X-ray and RF shields in place (if applicable). It is also advisable to work with a second person nearby" (Bigelow, 1999, p.39). Brooks warns that: "Unlike other printer types, the laser printer tends to have several high-voltage and high-temperature hazards inside it" (Brooks, 1999, p.354). Taylor notes factors that affect the severity of electric shock on the human body (Taylor, Easter, & Hegney, 1998). Severe burns can also result from electrical current passing through the body. Goldwasser warns that when engaged in maintenance work on computing equipment people should not wear rings or jewellery that could either cause burns and or electric shock or get caught in moving parts (Goldwasser, 1999).

Butrej and Douglas use case studies to demonstrate accidents or potential causes of accidents to enhance safety appreciation and awareness. They note a hazardous situation where the Residual Current Devices (RCDs) were tested but would still not disconnect the active or live line. The test button only tests the internal circuit. If the circuit is incorrectly wired the RCD may fail to cut off the mains supply (Butrej & Douglas, 1995). Using the energy exchange model Haddon, Suchman and Klien apply fundamental principles of conservation of energy to explain and trace sequences of events resulting in accidents (Haddon, Suchman, &

Kleine, 1964). Taylor, Easter and Hegney note that: "In this model the hazard is described not in terms of the object itself but rather the type of energy exchange which caused the injury" (Taylor et al., 1998).

The ever present risk of fire is of critical importance to safety. Chellis, Perkins and Strebe note when referring to PVC coated cabling that. "If burned, one of the gases it creates is chlorine, which, when inhaled into the lungs, turns into hydrochloric acid. This can do great damage to lung tissue" (Chellis, Perkins, & Strebe, 1997, p.165). Mueller notes the possible fire hazard which can result from having more than one earthing or grounding point on shielded networking cable (Mueller, 1999).

Materials used that can cause harm are also becoming an increasingly important component of hazard awareness and legislation. Mueller also notes that the A+ Technicians certificate requirements includes the requirement that the candidates should be able to: "Identify items that require special disposal procedures that comply with environmental guidelines". He also notes that they should be aware of Material Safety Datasheets (MSDs) (Mueller, 1999, p.1440). Polychlorinated Biphenyls (PCBs) present in electrolytic capacitors can also present a hazard particularly in old machines. Lester notes the World Health Organisation (WHO) research findings (WHO, 1987) stating that: "The World Health Organization's International Agency for Research on Cancer (IARC) considers PCBs to be probably carcinogenic to people" (Lester, 1999)

2.6.2 Legal implications of Safety

One of the employer requirements, according to Maj, was that potential employees in computer and network support be aware of their legal responsibilities and obligations (Maj, et al. 1998). A failure to implement safety training could leave both staff and institutions exposed to possible legal challenges in the event of an accident. Maj has noted the lack of student knowledge of legal issues (Maj, Robbins et al., 1998).

2.6.3 Hazard Awareness

Ramsey notes that: "Investigating near misses as well as actual injuries can also pay dividends" (Ramsey, 1999, p.10). Bell and Fogler have noted the potential of virtual reality in simulating potential accidents in helping to promote discussion (Bell & Fogler, 2000). Morrow and Crum note that: "Prior injury or accident is a commonly used measure of objective risk" (Morrow & Crum, 1998). However, waiting until after an accident has occurred before preventative action is undertaken invites needless harm. A genuinely proactive approach fully supported in both word and action by the workforce and the management is required to build an effective safety culture. Hofman and Stetzer note the influence of a safety culture on accident rates and unsafe work practices (Hofman & Stetzer, 1996).

2.6.4 Summary

Hands-on skills in the area of CNS are increasingly important. The increasing popularity of vendor endorsed certification provision can pose both a threat and an opportunity to the university sector. The providers of vendor endorsed certification can define both syllabus and the relative importance of forms of knowledge via their ongoing certification programmes. This leads naturally to the question of how such changes are being responded to by computer and computer networking curricula provided by bodies such as the ACM, ACS and BCS. Concomitant with the need for hands-on skills and the problem of their effective assessment is safety implementation, legal implications and hazard awareness. These problems flow over into the need for university staff being aware of such issues.

2.7 CNT Curricula

As well as practical skills, an understanding of theory is essential to computer science education. Abstraction can be a significant aid to understanding.

2.7.1 Abstraction

Howe notes that:

“Abstraction can place conceptual knowledge in context and hide underlying details. Abstraction is defined as the generalisation; ignoring or hiding details to capture some kind of commonality between different instances” (Howe, 2003, para.8).

Atkins notes that:

“One of the developments of science these days is the increased level of abstraction, and so the more that you go into the great achievements of science the more you find them more and more abstract... You get the greatest power in the application of an idea if you can make it abstract ... ” (Atkins, 2003).

Abstraction along with the importance of integrating theory and practice is emphasised by the ACM who note under a heading of “principles” that: “All computer science students must learn to integrate theory and practice, to recognize the importance of abstraction, and to appreciate the value of good engineering design” (ACM, 2001, p.12). Hence, both practice and abstraction are seen as important components of undergraduate computing science study by the ACM, who are arguably the world’s foremost body in this field. The ACM also notes that:

“Enduring computer concepts include algorithms, complexity, machine organisation, information representations, modelling and abstraction.... While skills are fleeting, fundamental concepts are enduring and provide long lasting benefits to students, critically important in a rapidly changing discipline” (ACM, 2001, p.70).

And the ACM note that:

“Levels of Abstraction: the nature and use of abstraction in computing; the use of abstraction in managing complexity, structuring systems, hiding details, and capturing recurring patterns; the ability to represent an entity or system by abstractions having different levels of detail and specificity” (ACM, 1991a, p.75).

Significantly, the ACM does not recommend a specific sequence of units for courses preferring instead to give a range of approaches noting that:

“Although some institutions will presumably follow these models with little modification, the course designs presented here are intentionally designed to be flexible, allowing individual institutions to customize them to fit their own needs” (ACM, 2001, p.157).

2.7.2 The Bottom-up Approach to CNT Education

It should be noted that the ACM syllabi outlines are presented in a bottom-up sequence (ACM, 2001), where the Computer Architecture syllabus and the Architecture and Operating Systems syllabus both commence with digital logic (ACM, 2001, pp.206-208). In describing the ‘hardware first’ approach the ACM note that: “The first course in the sequence covers the computer from the bottom up” (ACM, 2001, p.34). Under a heading of “Topics” the ACM include: “... Fundamental building blocks (Logic gates, flip-flops; counters, registers, PLA); Register transfer notation; Physical considerations (gate delays, fan-in, fan-out)” (ACM, 2001, p.34). The sequence of topics results in a bottom-up approach going from lower to higher levels of abstraction as shown in Table 4.

**Table 4. Architecture and Organization (AR) (ACM, 2001, pp.97-101).
(Modified)**

Level of Abstraction	Code	Course	Core /elective	Teaching Order
	AR8	Architecture for networks and distributive systems	Elective	
	AR7	Multiprocessing	Elective	
	AR6	Functional Organisation	Core	6th
	AR5	Interfacing and communication	Core	5th
	AR4	Memory system organisation and architecture	Core	4th
	AR3	Assembly level representation of data	Core	3rd
	AR2	Machine level representation of data	Core	2nd
	AR1	Logic and digital systems	Core	1st

Some overarching understanding of architectural details may still be advantageous to many students. For example, Beeson and Gay note that the University of Cincinnati associate degree program is advantaged by: "Having a background in digital electronics and microprocessor architecture and programming allows the student a more fundamental understanding of new technologies as they appear on the scene" (Beeson & Gay, 2000, p.5). However, with a bottom-up approach students may find it difficult to see the overall picture by being initially introduced to large quantities of underlying detail (Staggers & Porcio, 1993), with

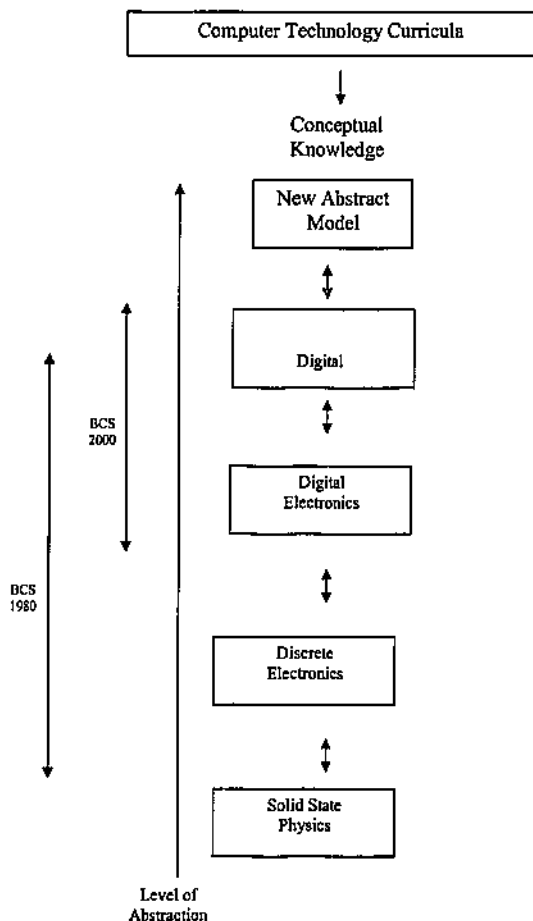
a resulting large conceptual gap that students would need to bridge in order to understand the operation of an actual computer. Constructivism suggests starting with student's models of the world (von Glasersfeld, 1992b) and bottom-up approaches make it difficult for the students to see the whole picture and to fit the pieces together (Scragg, 1991). Furthermore, the relevance of the lower levels of abstraction may be questioned and the movement in curricula to higher levels of abstraction has been noted by Clements who states that:

“... academics must continually examine and update the curriculum, raising the level of abstraction. For example the generation of students studying electronics in the 50's learned about the nature of electrons in magnetic fields. The next generation studied transistor circuits, and the one after that studied integrated circuits” (Clements, 2000a, p.11).

2.7.3 Migration of CNT Syllabi towards Higher Levels of Abstraction

Clements also notes that the many improvements in computer architecture education mean that: “students operate at a much higher level of abstraction than they once did” (Clements, 2000a, p.12). This can be seen by a consideration of figure 2 where the rising level of abstraction in the BCS curriculum can be seen to have increased over time. For example, a solid state physicist may regard digital logic as a high level abstraction, whereas, from a computer systems perspective, it may be regarded as form of low level abstraction as show in figure 2. The topic areas shown in figure 2 form a hierarchy of abstraction levels starting at solid state. The conceptual knowledge covered in BCS, alongside conceptual knowledge required at different levels of abstraction, is shown on the diagram.

Figure 2. An Overview of Abstraction Levels in Approaches to Computer Technology Education across Different Topic Areas.



Digital logic gate symbols allow abstractions that de-couple such models from a particular underlying technological implementation. Hence:

- This model is suitable for digital logic gates based upon relays, thermionic valves (US: tubes), discrete transistors or various integrated circuits based on a range of implementations.
- This model is also an example of a top-down modelling scheme that has not only stood the test of time but also has been used for teaching to different age groups and across a range of educational levels (Clements, 2000a; Duncan, 1985; Lancaster, 1974, 1977; Mano & Kime, 2000).
- Models of registers and other devices using such gates can be represented at a higher level of abstraction without the requirement to understand the digital gates that make up such a function, although the gates may be shown if required.

The success of the use of abstraction in digital logic gate modelling, and the need for a higher level of abstraction, provides motivation for the following question: can an abstract model be found upon which to base developments and provide a framework for student understanding within the field of CNT?

2.7.4 The Need for a High Level Abstract Model

Mudge notes that:

“Teaching students architectural details of particular computers or networks can lead to rapid obsolescence of much of the knowledge acquired as the rapid pace change affects factors such as cost compatibility, marketplace, and applications” (Mudge, 1996).

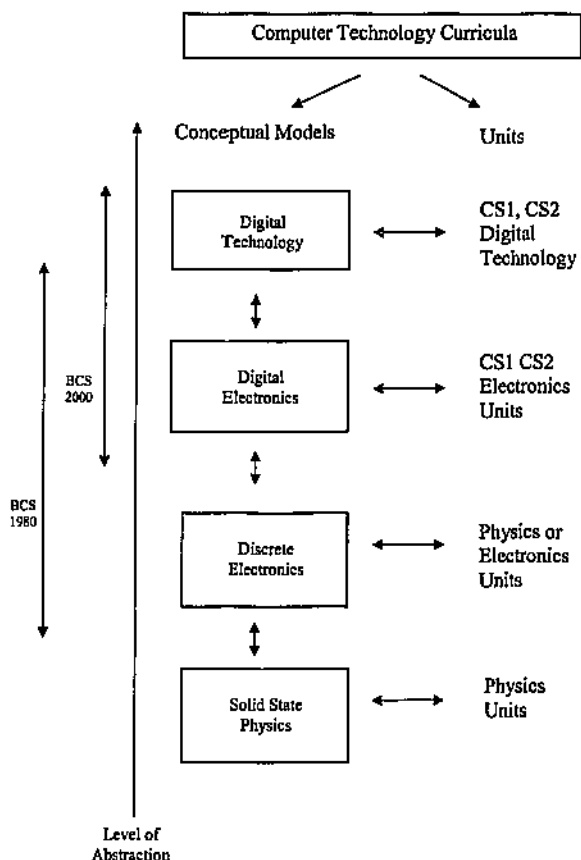
Furthermore, traditional approaches to teaching computer hardware may not be relevant to modern employment requirements (Mudge, 1996) and (Nwana, 1997).

A bottom-up approach may no longer be appropriate for many computer science students possibly due to the following reasons: there is a large conceptual gap in proceeding from the bottom upwards with traditional syllabi due to the

difficulty of reaching the point of understanding how a machine works, based upon a foundation of traditional digital logic, due to the complexity within modern computer systems and net-centric computing. For many students, a bottom-up approach is not best suited to introducing concepts from a constructivist perspective, as will be described in further detail later, especially given the expansion and development in computer science curricula (ACM, 1991a, 2001).

An overview of abstraction levels in approaches to teaching computer hardware technology units is shown in figure 3 where the columns show examples of the conceptual knowledge and associated procedural domain implemented via given units. It should be noted that higher levels of abstraction have been applied as time proceeds, as can be seen from the areas covered by the BCS curricula. The rows show examples of conceptual topic areas and associated examples of common devices to which procedural knowledge and skills may be applied.

Figure 3. An Overview of Abstraction Levels in Approaches to Computer Technology Education across Different Units.



2.7.5 Knowledge of Computer Systems and Networks

The new ACM/IEEE joint curriculum task force note new areas such as multimedia and net-centric computing (ACM, 2001), as does Clements who notes that: "Computer Science is expanding to include new areas such as net-centric computing, multimedia, and visualisation" (Clements, 2000c, p.19). There are now many undergraduate and postgraduate degrees offered in these subjects. However, Clements also notes that: "Students in such programs don't see the point of studying computer architecture, and pressure is growing to drop it from the curricula ..." (Clements, 2000c, p.19).

In order to help to address concerns about the relevance of traditional computer technology education Barnett suggested that standard computer architecture is too complex for introductory courses, and a simple instruction set computer should be used instead (Barnett III, 1995). This also has the advantage that students can learn relationships between machine code and assembly statements and the underlying computer hardware.

2.7.6 Building CNT Pedagogical Frameworks

Many different pedagogical frameworks have been used to aid student understanding of CNT, including simulation, modelling, and building a machine. Each of which will now be considered. It should be noted that simulation and modelling are often used in an interchangeable way within the field of CNT. Pooch and Wall note that:

"A model may be described as the body of information about a system gathered for the purpose of studying the system. It is not only an orderly collection of information, but is an orderly representation or structuring of the information. The characteristics should be representative of the characteristics of the real system" (Pooch & Wall, 1993, pp.14-16).

With respect to simulation Kheir notes that:

"Basically, simulation is the process by which an understanding of an already existing (or to be constructed) physical system is obtained by observing the behaviour of a model representing the system. Thus

simulation is justly considered the art and science of experimenting with models" (Kheir, 1996, p.3).

2.7.7 Simulation and Modelling

Simulation can be used as a teaching tool for computer architecture (Donaldson, 1995; Hyde, 2000; Ibbett, 2000; Reid, 1992; Searles, 1993). The use of simulation as a tool for performance evaluation has also been noted (Bose, 1999; Lilja, 2000). The difficulty of providing a suitable pedagogical framework due to the constantly changing nature of computer hardware and its high levels of complexity has also been noted (Coe et al., 1996). Skadron et al note that

"... the tremendous complexity of computer systems is making them both difficult to reason about and expensive to develop. Detailed software simulations have therefore become essential for evaluating ideas in the computer architecture field" (Skadron et al., 2003, p.30).

Djordjevic et al note that an educational system simulation should support a range of architectures and organizations, should graphically depict the system from the block to the register level and provide a means to follow the working of the system at the program and instruction clock cycle levels (Djordjevic, Milenkovic, & Grbanovic, 2000). As such, simulations can be used to support a top-down or bottom-up approach to support student understanding.

Dewdney distinguishes between the critical event technique and the time slice method. In the critical event technique the simulation clock is just incremented to the time of the next change in the system being simulated and the new system state computed; whilst the time slice method increments simulation clock by some small unit of time and the system being simulated has its new state computed with each increment (Dewdney, 1989).

Whatever method is used, all simulations require a model. Models can aid the effective conceptualisation of a problem domain (Saaty & Alexander, 1981). The results of simulation models also need to be tested both against real world situations and against each other. Shriver and Bennett mention co-simulation where two models, using different simulation techniques, receive identical inputs, and any

differences in output between these two models can be observed, which helps to ensure equivalence of representation (Shriver & Bennett, 1998).

As simulations require a model, then the question must be asked, is there a simulation model which can provide a suitable foundation for teaching CNT? Furthermore, are there suitable models on which to base top-down abstractions that are appropriate for student use in the field of CNT? Such abstraction is an important antidote to the inevitable redundancy of much hands-on skills attainment due to the rapid rate of change in the CNT field. Abstraction is an aid to the understanding of fundamental concepts. The ACM note that: "While skills are fleeting, fundamental concepts are enduring and provide long-lasting benefits to students, critically important in a rapidly changing discipline" (ACM, 2001, p.70). This is also important in enabling students to fulfil employer expectation in this field for graduates to possess both the relevant skills and understanding. The answers to these questions will be attempted in the papers presented in this thesis.

The modelling of computers has been described by many authors (Cragon, 2000; Mano & Kime, 2000; Shriver & Bennett, 1998). The importance of modelling in respect to networking is noted by Ranbar (2001) and Kurose and Mouftah (1988), and many others. Heidelberger and Lavenberg note that:

"Performance modeling is widely used not only during design and development but also for configuration and capacity planning purposes" (Heidelberger & Lavenberg, 1984, p.1196).

Skadron et al note that:

"Analytical models and simulation are not mutually exclusive. Analytical models can help to understand a system in ways that simulation does not. They can also be used to validate a simulation-based model" (K. Skadron et al., 2003, p.34).

Whilst Hassan and Jain note that: "Simulations can incorporate more details than analytical modeling; thus, more often results can be produced that are closer to reality" (Hassan & Jain, 2004, p.76). Analytical models are mathematically based (Boyce, 1981; Klamkin, 1995; Sanderfur, 1993) and queuing is a form of analytical modelling (Cady & Howarth, 1990; Klienrock, 1975, 1976; Murdoch, 1978).

Networks of queues can also be analysed (Falkner, Devetsikiotis, & Ioannis, 1999; Gatetto & Townsley, 2003; Menasce & Almeida, 2002; Robertazzi, 1990). However, queuing analysis often assumes a Poisson distribution, which isn't the case with most networks (Lilja, 2000; Paxton & Floyd, 1995). A point endorsed by Tanenbaum who states that: "As researchers begun looking at real data it now appears that network traffic is rarely Poisson but self-similar" (Tanenbaum, 2003, p.281). Furthermore, Stallings notes that:

"Video and Internet traffic exhibit self similar character. By self similar it is meant that it has structure at arbitrarily small scales. ...the structures repeat. A self similar structure contains smaller replicas of itself at all scales" (Stallings, 1999, p.184).

Ethernet networks may also exhibit self-similarity (Leland, Taquq, Willinger, & Wilson, 1994; Willinger, Taquq, Sherman, & Wilson, 1997). However, Jain and Dovrolis note that shorter TCP connections suffered greater variability than longer connections when examining TCP flows across the Internet between Greece and the USA (Jain & Dovrolis, 2002). Self similarity also has heavy-tailed distributions, meaning that it exhibits a small number of long length data transmissions. Salehi and Zhang note the self-similarity of the bit rate variation of video transmission over the Internet, and observe that smoothing significantly improves throughput rates (Salehi, Zhang, Kurose, & Towsley, 1998). With respect to the self similarity of network transmissions, Tanenbaum notes that:

"What this means is that averaging out over long periods will not smooth out the traffic. The average number of frames in each minute of each hour has as much variance as the average number of frames in each second of each minute. The consequence of this discovery is that most models of network traffic do not apply to the real world and should be taken with a grain (or better yet a metric ton) of salt" (Tanenbaum, 2003, p.281).

A fully developed bandwidth model to predict actual performance of internetworks may need to take findings such as self-similarity into account. This has become an increasingly difficult undertaking leading to situations where the application of Chaos Theory (Nagashima & Baba, 1999) may be required:

"As networks grow to connect millions of nodes, and as these nodes all communicate in unpredictable patterns, the resulting behavior becomes very difficult to model or predict. Large highly connected systems can show aggregate behavior with complex characteristics: they can become chaotic, show self organising features or oscillate. We see the possibility that large networks such as the Internet have these tendencies, but we lack the tools or methods to explore this eventuality, to model how it might happen, or control the resulting behavior if necessary" (Clarke & Pasquale, 1996, p.668).

Many queuing simulations use Monte Carlo methods and Gross and Harris note that:

"Often it turns out that it is not possible to develop analytical models for queuing systems. ...the vast majority of queuing problems encountered, either enough data do not exist, or the data are not in the proper form to be utilized directly in the simulation. Hence, most queuing simulations are of the Monte Carlo type" (Gross & Harris, 1974, pp.455-447).

They further note that the Monte Carlo technique:

"... mathematically generates a stream of pseudo random numbers from any given probability system. These are referred to as pseudo random because they are in reality a deterministic sequence (they are generated by a completely specified mathematical procedure and can be reproduced as required) which 'acts' as if it is random" (Gross & Harris, 1974, p.459).

Special purpose computer programming languages such as General Purpose System Simulation (GPSS) (Gordon, 1975) can be used to deal with systems with multiple queues (Dewdney, 1989), (Bull, 1992) as can the language SIMULA (Birtwistle, Dahl, Myhrhaug, & Nygaard, 1973). However, Ofelt and Patterson note that "Detailed simulation, one of the most common methods for estimating performance, suffers from potentially long run times" (Ofelt & Hennessy, 2000, p.229). With respect to models in the field of computer architecture Skadron et al note that:

"Some modelling assumptions are essential for achieving relative accuracy, while others add needless complexity. The current understanding of correct abstraction levels and other important aspects of accurate models is poor. This leads to a wasted effort on

models and simulations that contain unnecessary detail while simultaneously lacking certain essential information. For hypothetical systems, a high precision – no matter how detailed the model – can be wasted if the assumptions that underlie the detail are inappropriate or change overtime” (Skadron et al., 2003, p.34).

Modelling may be top-down or bottom-up depending upon the direction taken; for example, modelling that proceeds from logic gate to registers to PC is bottom-up, whereas an abstract performance based model could be regarded as top-down. However, a meaningful metric would need to be utilised that could be translated into perceived differences by students when observing a PC.

Yet, despite being able to provide some insight into their operation, modelling machines will not, in itself, give students hands-on experience of PCs, which is often required in the workplace, as PCs can fail in many ways not shown in models.

2.7.8 Building a Machine

An approach to teaching computer hardware that adopts a hands-on approach, and also addresses employer expectation for practical skills, is requiring students to build and/or design their own computer (Heuring & Jordan, 1997; Hyde, 2000; Mueller, 2003; Pilgrim, 1993; Reid, 1992; Utd et al., 2000). However, this could be expensive and may not give students experience of a range of machines. Adequate storage space for the PCs in various states of completion for hundreds of students could be problematic. Beil describes intensive workshops taking place over three days where students pay for, build and keep the computers (Beil, Lange, Olsen, & Spiecker, 1998). However, this in itself may not negate the need for an overall conceptual model. Building a relatively simple machine can be a bottom-up approach if it starts from logic gates and registers to Microprocessor Units (MPUs). Building a machine could also be top-down approach if it commences with the requirement for a PC and uses Hard Disk Drives (HDDs) and MPUs to construct such a PC.

Building a machine is also a bottom-up approach that can be used to allow students to gain an appreciation of how individual devices are put together to form

a working PC. However, taking apart a working PC, noting how the various devices fit into it, can be regarded as a top-down approach. However, it may be better to allow students to gain an understanding of how the devices fit together to form a working PC before attempting to construct their own PC from these components and again, for this reason, a top-down approach that starts with a working PC is to be preferred. Furthermore, there is a gap between appreciation of a HDD and logic gates and again the difficulty in understanding the HDD controller operation via an understanding of gates.

2.7.9 Summary

Abstraction is important because in respect of a given purpose it can de-emphasise the inessential details whilst emphasising the essential details. The ACM recognise the importance of abstraction in CS education. Abstraction can aid a top-down approach to CNT curricula, yet the ACM recommend a bottom-up approach starting from digital logic. There has been a movement over time in CNT curricula towards higher levels of abstraction. There is arguably a need for a high level abstract model to avoid teaching students details of PCs and networks that suffer rapid rates of obsolescence.

Various high level frameworks have been used to teach CNT including simulation and modelling. Modelling can include the use of queuing theory simulation languages or the use of chaos theory. Building a computer adopts a hands-on approach, and also addresses employer expectation for practical skills.

Some forms of abstraction can provide a de-coupling from the underlying technological implementation, hence allowing some future proofing of student learning. Digital logic gates have provided an abstract model which has stood the test of time. However, such a model is at too low a level with respect to modern CNT for a top-down approach but is used in the bottom-up approach, which may not accord with constructivist ideas fitting concepts starting with student's models of the world. It may therefore be appropriate to consider conceptual understanding.

2.8 Conceptual Understanding

The ACM in quoting from the National Research Council's fluency report states that:

"Concepts explain the how and the why of information technology and they give insight into its opportunities and limitations. Concepts are the raw material for understanding new information technology as it evolves" (ACM, 2001, p.70).

The dominant theory aimed at the development of conceptual understanding in education is constructivism. This has been extensively tested in the field of science and mathematics education (Coburn, 1991; Confrey, 1991; Driver & Bell, 1985; Wheatley, 1991). Constructivism is also a foundation of many modern teaching practices. Yet Ben-Ari notes the lack of influence of constructivism within computer education stating that:

"Constructivism is a theory of learning which claims that students construct knowledge rather than merely receive and store knowledge transmitted by the teacher. Constructivism has been extremely influential in science and mathematics education, but not in computer education" (Ben-Ari, 1998, p.257).

2.8.1 Constructivism

According to this theory students construct knowledge in order to be meaningful in the student's life situation (Coburn, 1991). They achieve this by testing their constructed mental models against reality making necessary changes (Brandt, 1998). Constructivist educational theory is based upon enabling students to build increasingly complex understandings based upon their current framework. In particular, Constructivism uses the concept of Vygotsky's Zone of Proximal Development (ZPD). Matching learning tasks within students' ZPDs is a vitally important component of the teaching process from Vygotsky's Constructivist perspective (Ridgeway & Passey, 1991). Vygotsky, when referring to childhood learning, described the ZPD as:

"The distance between the actual developmental level as determined by independent problem solving and the level of potential development as determined through problem solving under adult guidance or in collaboration with more capable peers" (Vygotsky, 1930/1978, p.86).

Yet there is no single ZPD for individuals because the zone varies with culture society and experience (Tharpe, 1988). Vygotsky was interested in social relationships, and MacNamee notes:

"The ZPD is a concept that explains how thinking that is initially carried out among people in groups becomes reorganized with individuals gradually taking over more control and direction of their own thinking and relationships in a world in which they always remain interdependent" (MacNamee, 1990, p.288).

Berger when discussing Piaget's ideas on intelligence noted:

"People organize their thoughts so that they make sense, separating the more important thoughts from the less important one as well as connecting one idea to another. At the same time, people adapt their thinking to include new ideas, as new experiences provide new information" (Berger, 1978, p.55).

Wadsworth notes that:

"Piaget believed that the mind had to have structures much in the same way as the body does... Schemata are intellectual structures that organise events that are perceived by organism into groups according to common characteristics... Assimilation is the cognitive process by which the person integrates new perceptual matter or stimulus events into existing schemata or patterns of behaviour..." (Wadsworth, 1971, pp.10-12).

Wadsworth goes on to note that:

"Sometimes a stimulus cannot be placed or assimilated into existing schemata because there are no schemata into which it fits... What does the child do? Essentially he can do one of two things He can create new schema or he can modify an existing schema so that the stimulus will fit into it; both are forms of accommodation" (Wadsworth, 1971, pp.15-16).

Piaget notes that: "mental life is also accommodation to the environment" (Piaget, 1953, p.6), and Dewey notes: "that there is an intimate and necessary relation between the processes of actual experience and education" (Dewey, 1938, p.20).

• Whilst von Glasersfeld and Steffe note that:

"Because there is no way of transferring meaning, i.e. concepts and conceptual structures, from one student's head to another, teachers, who have the goal of changing something in student's heads must have some notion of what goes on in these heads. Hence it would seem necessary for a teacher to build up a model of the student's conceptual world" (von Glasersfeld & Steffe, 1991, p.96).

However, new knowledge needs to be fitted into their existing structure of knowledge (von Glasersfeld, 1992a). Piaget notes that: "The essential functions of the mind consist in understanding and in inventing, in other words, in building up structures by structuring reality" (Piaget, 1971, p.27). Whilst von Glasersfeld also notes that:

"... knowledge cannot simply be transferred by means of words. Verbally explaining a problem does not lead to understanding, unless the concepts the listener has associated with the linguistic components of the explanation are compatible with those the explainer has in mind. Hence it is essential that the teacher have an adequate model of the conceptual network within which the student assimilates what he or she is being told. Without such a model as a basis, teaching is likely to remain a hit-or-miss affair" (von Glasersfeld, 1989, p.136).

This is reinforced by Mestre who notes that the knowledge the learner has already constructed will affect how they interpret new knowledge (Mestre, 2000), a point reiterated by Wheatly (1991) and reinforced by von Glasersfeld who notes:

"Put in the simplest way, to understand what someone has said or written means no less but also no more than to have built up a conceptual structure that, in a given context, appears to be 'compatible' with the structure the speaker had in mind, – and this compatibility, as a rule, manifests itself in no other way than that the receiver says and does nothing that contravenes the speaker's expectations" (von Glasersfeld, 1989, p.134).

The consequences of this situation are noted by Mestre who states that:

"What is deceptive is that students will often display 'understanding' in standardized science tests, in tests constructed by teachers, or in text-embedded tests provided by textbook publishers, thereby giving teachers a false impression of their student's true understanding. Tests that probe for factual knowledge or that do not force students to apply the concepts covered in class will continue to show that students 'understand' the material covered in class" (Mestre, 2000, para.35).

The need for a conceptually correct framework to be constructed by the student is of the upmost importance for effective learning to take place. With respect to CNT education a common starting point for building a correct framework could be computers and their performance as separate machines and as components of a computer network. Yet, it should also be noted that constructivism has not been without its detractors.

2.8.2 Criticisms of Constructivism

Criticisms of constructivism include attacks upon its foundation, for example McCarty asks: "... if all learning is constructing, there can be no explanation of how one first learns to construct" (McCarty & Schwandt, 2000, p.80). Piaget takes a biologically based approach in that this construction is part of an organism's adaptation to its environment (Piaget, 1952).

Olsen notes an embedded conformism within constructivist educational processes, stating that:

"Given that there are no independent epistemological criteria in terms of 'truth' by which to anchor their assessments.... Is the criterion simply 'what the teacher thinks?'; or is it the wisdom of the elders?; or perhaps the 'current orthodoxy' in the community. Whatever it is, such guidance is hardly indubitable, nor likely to encourage innovation or change" (Olsen, 1996, p.288).

Constructivism has also been criticised in respect to the ethical implications that could arise from its application. Devitt notes that he has: "a candidate for 'the' most dangerous contemporary intellectual tendency, it is ... constructivism" (Devitt, 1991, p.11). Whilst Popper who notes that:

"... belief in the possibility of a rule of law, of justice and of freedom, can hardly survive the acceptance of an epistemology which teaches that there are no objective facts; not merely in this particular case, but in any other case" (Popper, 1974, p.5).

However, should a theory be tested only by its internal logic or should it be tested on what it may, or may not achieve? Furthermore, should the requirements of intellectual integrity be such that a theory ought to be pursued to where it leads and not cease merely because it contradicts cherished beliefs? Scientific method could be said to lack a moral imperative, hence a need for a system of ethics approval.

Constructivism has also been attacked for the lack of an objective interpretation of reality in the teaching of science. Matthews notes that:

"The goal of science is to eliminate error variance or bias in the explanation of the effect of the independent variable on the dependant variable. While such error variance or alternative explanation can never be entirely eliminated, through careful experimentation and based on probabilistic statements generalizable causal inferences to inform the practice of teaching to inform student learning" (Matthews, 2003, p.59).

He then notes that: "notions of an objective and observable reality are in direct conflict with the basic assumptions of a developmental/constructivist worldview" (Matthews, 2003). Yet, if students were to undergo constructivist based experimentally orientated learning then this may enable them to arrive at a better scientifically based understanding of a topic. Einstein and Infeld have noted that: "Physical concepts are free creations of the human mind, and are not, however it may seem, uniquely determined by the external world" (Einstein and Infeld, 1967, p.31). They draw upon the analogy of a closed watch, whereby a person can see the effects, but can't determine its mechanism without opening the watch case.

Davson-Gale describes a hypothetical problem where a student who believes in Aristotelian ideas of force and motion and yet despite rational efforts of persuasion, refuses to change their view (Davson-Galle, 1999). However, an appreciation of why modern theories of physics are to be preferred over Aristotelian physical theories could enable a better appreciation of scientific

reasoning by both students and teachers. It is important to both encourage and challenge student understanding (Zahorik, 1997). Hewson notes that:

"The purpose of conceptual change is not to force students to surrender their alternative conceptions to the teacher's or scientist's conceptions, but rather to help students both form the habit of challenging one idea with another, and to develop alternative strategies for having alternative conceptions compete with one another for acceptance" (Hewson, 1992, pp.9-10).

A critical experiential based approach to science can be vital for in-depth understanding. Popper mentions that:

"Einstein consciously seeks for error elimination. He tries to kill his theories: he is consciously critical of his theories, which for this reason, he tries to formulate sharply rather than vaguely" (Popper, 1979, p.25).

Whilst Feynman, at the very beginning of his first lecture in a series that became a seminal three volume work, notes: "The principle of science, the definition almost, is the following: Experiment is the sole judge of scientific 'truth'" (Feynman, Leighton, & Sands, 1963, p.1). A theory needs to survive many tests. Bondi notes that: "A theory is tested by experiment and observation and if it has passed one test, then it is the task of the theory to make further forecasts - to go as it were, living dangerously - and to stick out its neck. So that it can be tested again and again" (Bondi, 1967, p.1).

An objection to the requirement to counter students' beliefs, such as postulated by Davson-Galle (1999), is that this was not the manner in which most teachers were taught; they may not know the arguments for and against the myriad of accepted physical theories, or the experimental evidence, some of which may require complex equipment. Furthermore, teachers themselves may misunderstand parts of an accepted theory (Reif & Allen, 1992). Airasain and Walsh note the extra time required for teachers to respond to student constructions and the extra time required for students and teachers to become familiar with constructivist methods (Airasain & Walsh, 1997).

2.8.3 Potential Benefits Constructivism in CNT Education

Applying constructivist ideas to CNT education would suggest starting from the concepts held by the student and then possibly utilising commonly held concepts. Such commonly held concepts could be the computer or networked computer, and then proceeding to the components of the PC brought about by extensive hands-on exercises such as take place within the CIM unit workshops. Students can then develop an understanding of the next level down, which is the HDDs cards and Motherboard etc. Then the internal components of the HDD may be noted by observing inside of the device. This helps to build meaning from a student's perspective by placing new knowledge in an overall framework with respect to their previously held concepts, which implies a top-down rather than a bottom-up approach. However, from the perspective of some electronics engineering students, the experience of the student may be of digital logic gates, then registers and higher order components, in which case a bottom-up approach may accord with a constructivist approach.

Scragg has also suggested such a top-down approach (Scragg, 1991), and, as noted previously, many students now studying CNT units do not necessarily come from a technical background and would not be familiar with the basic digital logic devices, and so this may not be a suitable starting point even though the ACM recommend such an approach (ACM, 2001).

2.8.4 Summary

Constructivist theory is the dominant epistemological theory within education and has been used extensively and successfully in science education, but it has not been used to a great extent within CNT education. Constructivist educational principles suggest a starting point within a student's ZPD. Constructivism suggests teaching should take existing concepts of students into account. A good starting point could be the likely common concept held by many students of the computer and taking a top-down rather than a bottom-up approach.

2. 9 Constructivist View of CNT

Due to the need to attempt to provide a common starting point based upon commonly held student perceptions of PC and network performance that is in accordance with constructivist theory of taking students' existing concepts into account, then the major questions are:

- How do first year CNT students perceive PCs and computer networks?
- What is a suitable model of PCs and computer networks based upon such perceptions?
- What metric could such a model use?

Performance is one way in which students may perceive CNT operation because students can perceive performance differences by noting differences in response times, quality of output or both. The need for increased performance is the basis of much of the developments within this field and so student perception of this factor is a possible basis upon which they may build conceptual frameworks. Different underlying components such as various video and network cards, as well as different network and internetwork configurations would need to be used to allow students to perceive differences in computer and network performance. Then using a top-down constructivist model these perceptions could then be used to form the basis for understanding CNT theory. Such a top-down approach could also mean that these models could be independent of a particular implementation technology, providing some degree of future-proofing. However, such results based upon perception would also need to be scaled to be made meaningful and repeatable for comparison.

Performance can also be context dependant. Patterson and Hennessy note that better performance with respect to computers depends upon requirements (Patterson & Hennessy, 1998), a point reinforced by Lilja who states that:

"Metrics that measure what was done, useful or not, have been called 'means based' metrics whereas 'ends based' metrics measure what is actually accomplished" (Lilja, 2000, p.21).

What measures, or metrics, can be used that are relevant to both the high level abstract approach and the constructivist approach to CNT education? Users perceive performance differences in CNT technology, yet there are : wide variety of metrics in use for the evaluation of performance within the field of CNT. These include benchmarks, Millions of Instructions per Second (MIPS) Millions of Floating point Operations per Second (MFLOPS) (Hennessy & Patterson, 1996b). There is also the use of throughput, or bandwidth, in terms of rates of bps, Mbps or Gbps (Norton & Desmond, 1999; Shriver & Bennett, 1998).

However, the 'usefulness' of metrics with respect to judging the actual performance is a major point of contention in the field of computer benchmarks.

2.9.1 Benchmarks

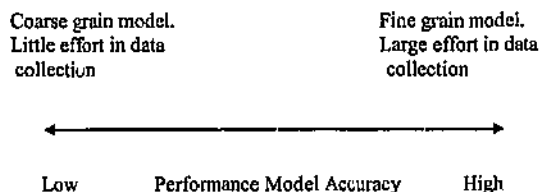
Benchmarks have different uses in the PC industry which can include system comparison, upgrade improvements and diagnostics (Bigelow, 2001). A computer benchmark is a test and may be used to indicate performance with respect to running a specified suite of commonly used software (Dujmovic & Dujmovic, 1998). These are known as application benchmarks (Hurwicz, 1998; Lilja, 2000). Weicker describes the use of benchmarks using floating point or integer calculations (Weicker, 1991). A judicious mixture of benchmarks is often chosen to use the strength of some measures to counteract the weakness of others in given conditions (Chen & Patterson, 1994).

Hurwicz suggests using synthetic benchmarks to obtain approximate computer or system performance measures, and the use of application mix benchmarks to refine any measurements obtained, if these are available (Hurwicz, 1998). Microbenchmarks can be used which emulate application activity (Chen et al., 1996; Rafael, Saavendra, Gaines, & Carlton, 1993; Staelin, 1999).

Chen and Patterson have developed 'self scaling benchmarks' (Chen & Patterson, 1994). Hennessy and Patterson note that a self scaling benchmark "automatically and dynamically adjusts several aspects of its workload according to the performance characteristics of the system being measured" (Hennessy & Patterson, 1996b, p.534).

Krishnaswamy, and Scherson use coarse grain and fine grain benchmark classification scheme (Krishnaswamy & Scherson, 2000), as noted by Menasce in figure 4.

Figure 4. Benchmark Classification by Granularity (Menasce, Almeida, Fouseca, & Mendes, 1999, p.196)



Menasce and Almeida place benchmarks within a more complete hierarchical system. Within this system, the innermost level contains synthetic benchmarks that perform only 'basic operations' such as addition and multiplication e.g. Dhrystone. The next level up are 'toy' benchmarks that are small programs such as the Towers of Hanoi. The third level up contains kernels that are parts of the essential code of actual programs that can affect performance eg Livermore loops (Menasce & Almeida, 2002). They then go on to note that:

"At the outermost level of the hierarchy is the workload composed of full-scale, real programs used to solve real problems. These programs make up benchmark suites, such as SPEC and TCP" (Menasce & Almeida, 2002, p.265).

Whilst Mueller notes that:

"Benchmarks can typically be divided into two types: component or system tests. 'Component' benchmarks measure the performance of specific parts of the computer system, such as a processor, hard disk, video card, or CD-ROM drives, whereas 'system' benchmarks typically measure the performance of the entire computer system running a given application or test suite" (Mueller, 2003, p.198).

The SPEC benchmarks are used internationally (Cvetanovic & Kessler, 2000; Henning, 2000; Seltzer, Krinsky, Smith, & Zhang, 1999; Sharp & Bacon, 1994).

Skadron et al note that: "No benchmark suite can be a one-size fits all solution" (Skadron et al., 2003, p.32).

2.9.2 Problems with Current Benchmarks

The use of benchmarks is not without problems, such as when programs are designed to achieve high benchmark ratings on specific benchmarks whilst being incapable of achieving such gains in actual performance. Hennessy and Paterson note that:

"A big factor influencing the usefulness of a benchmark is the ability of the benchmark to resist 'cracking' also known as benchmark engineering. Once a benchmark becomes popular there is tremendous pressure to improve performance by targeted optimisations or by aggressive interpretation of the rules for running the benchmark. Small kernels or programs that spend their time in a very small number of lines of code are particularly vulnerable" (Hennessy & Patterson, 1996b, p.48).

Many benchmarks age with time due to changes in technology and need either to be replaced or radically updated. There are also problems caused by lack of a methodical or a scientific approach as noted by Mueller who notes that when:

"... reviewers run a test of disk performance between two systems with the same disk and controller drives, and say (with a straight face) that the one that came out a few milliseconds ahead of the other wins the test. With the statistical variation that normally occurs in any manufactured components these results are meaningless" (Mueller, 1999, p.1436).

Such a lack of scientific approach can be found in the unreasonable number of significant figures used by some practitioners when quoting benchmark results and many benchmarks may not translate directly into user observable quantities. Different benchmarks, although purporting to measure the same quantities, may not give the same results when measuring the same quantities under the same conditions (Saavendra & Smith, 1996). This notwithstanding, Saavendra and Smith further note that:

“Standard benchmarking provides the runtimes for given programs on given machines, but fails to provide insight as to why these results were obtained” (Saavendra & Smith, 1996, p.344).

Such failings can make benchmarks unsuitable as a foundation on which to build a constructivist based understanding of CNT. Lilja notes that:

“Most fields of science and engineering have well-defined tools and techniques for measuring and comparing phenomena of interest and for precisely communicating results. In the field of computer science and engineering, however, there is surprisingly little agreement on how to measure something as fundamental as the performance of a computer system” (Lilja, 2000, p.xi).

In a chapter entitled “Metrics for performance” Lilja notes: “The bandwidth of a communication network is a throughput measure that quantifies the number of bits transmitted across the network per second” (Lilja, 2000, p.19). Hence bandwidth can be regarded as a performance metric.

2.9.3 Bandwidth as a Performance Measurement

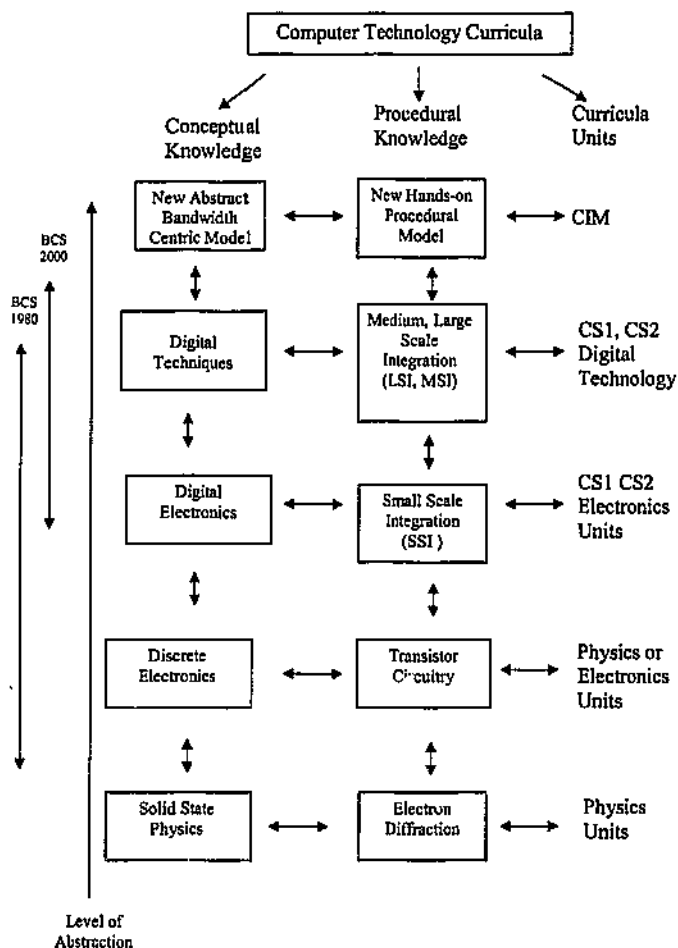
Bandwidth can be considered at a range of different levels of abstraction and hence has the possibility of being amenable to forming a basis for a top-down modelling approach. Such a model allows de-coupling from the particular underlying implementation technology utilised and has the possibility of providing some future proofing with respect to student learning. As an example, a HDD is composed of an HDD controller and platters and heads. The bandwidth of these components of these can be compared to the resultant bandwidth of both at level of abstraction, namely the bandwidth of the HDD. Therefore a bandwidth based model:

- Allows the possibility of being recursively decomposable into lower level abstractions due to its hierarchical nature.
- Can be described using diagrams and so is self documenting.
- Controls the level of detail due to the use of abstraction.

- May accord with student conceptual understanding as it would start with the PC and then move to lower level abstractions and may also accord with constructivist principles by proceeding from previously held student concepts.
- Allow the use of units such bits per second (bps) or Mega bytes per second (MB/s) from which derived units can be obtained, such as images per second or frames per second (fps), that are more relevant to the end user when, for example, evaluating full picture motion.
- A high level abstract bandwidth based model may allow decoupling from the underlying details of a particular implementation technology and help to provide some future proofing of student learning.

A high level abstract model based upon bandwidth provides an overarching framework for the new abstract model component shown in figure 5.

Figure 5. Conceptual and Procedural Levels in CNT Curricula



This leads to the need for a more in-depth consideration of bandwidth concepts and applications.

2.9.4 Summary

A computer benchmark is a test which can be used to assess performance. But different benchmarks may give different results when measuring the same quantity. Benchmarks change over time making it difficult to provide future proofing of student learning. Benchmarks may not use linear scales, and may not be based upon performance as perceived by users. From an educational standpoint, this means that the use of benchmarks to gain an overall understanding of the development and underlying principles of CNT technology is problematic.

From a constructivist perspective the existing perceptions of the students needs to be taken into account. Such experiences may be based upon performance and bandwidth may provide a suitable model based on these perceptions. A performance based model based on bandwidth requires a metric measured in bits per second or mps or MB/s. From these units more meaningful units can be derived with respect to performance units such as fps. A bandwidth based model may be particularly applicable to net-centric curricula due to the emphasis on bandwidth concepts. An abstract performance model could be advantageous as it could be decoupled from the underlying technological implementation which can be subject to rapid technological change. If it can be demonstrated that bandwidth is a persistent and valid metric then it could form the basis of a new high level abstraction model.

2.10 Bandwidth

Hennessy refers to bandwidth in Mbytes/s (Hennessy & Patterson, 1996b). Hudson et al note that: "... the real capacity of a network is known as throughput" (Hudson, Caudle, & Cannon, 2003, p.117). This can be defined as the file size divided by the download time. Cisco notes that "Throughput refers to the actual, measured bandwidth, at a specific time of the day" (Cisco, 2001, p.36). Oppenheimer notes the factors that constrain throughput, which include the following:

- End-to-end error rates
- Protocol functions, such as handshaking, windows, and acknowledgments
- Protocol parameters, such as frame size and retransmission timers
- The PPS and CPS rate of internetworking devices
- Lost packets or cells at internetworking devices
- Workstation and server performance factors
 - Disk-access speed
 - Disk-caching size
 - Device driver performance
 - Computer bus performance (capacity and arbitration methods)
 - Processor CPU performance
 - Memory performance (access time for real and virtual memory)
 - Operating systems inefficiencies
 - Application inefficiencies or bugs

(Oppenheimer, 2001, p.32)

Whilst Mueller states that: "... transfer rate is often called the 'bandwidth'" (Mueller, 2002, p.299). Bandwidth and throughput are often taken to be equivalent terms as is the case in this thesis.

2.10.1 Bandwidth as a Potential Performance Factor

Insufficient bandwidth can cause bottlenecks; the importance of reducing bottlenecks in computers has a long history. McCartney notes the importance of bottleneck avoidance on the ENIAC where: "To avoid other data slowing bottlenecks, Echart and Mauchy decided to use accumulators not only to store

numbers but also to be able to add and subtract them and to be able to transmit the result within the machine" (McCartney, 1999, pp.69-70).

The PC can be viewed as a complex collection of heterogeneous devices interconnected by a range of bus structures. However, from a user perspective, a PC is a low cost, storage device capable of processing data. Could bandwidth also be potentially useful from a constructivist perspective? Furthermore could this model also accord with the ACM criteria on abstraction namely that: "All computer science students must learn to 'integrate theory and practice, to recognize the importance of abstraction, and to appreciate the values of good engineering design'" (ACM, 2001, p.12).

PCs can be classified using Flynn's schema (Flynn, 1966) namely: "1. Single instruction stream, single data stream (SISD, the uniprocessor); 2. Single instruction stream, multiple data stream (SIMD), 3. Multiple instruction single data stream (MISD); 4. Multiple instruction stream, multiple data stream MIMD" (Patterson & Hennessy, 1998, p.748).

Using such a classification scheme the PC could be regarded as a MIMD architecture of sub-units (Clements, 1989) due to the fact of its sub-components are working on their own data and instruction streams. The rate of data flow between such sub-units then becomes an important consideration. This gives credence to the possibility of top-down abstract models based upon bandwidth considerations. Such models could allow comparison as between the bandwidth of sub-units at a particular level of abstraction and the bandwidth within these sub-units at a lower level of abstraction. This approach is further aided by the bandwidth of various devices being published quantities. Again, a higher level abstraction approach can de-couple a model from the underlying details of a particular technological implementation.

Commonly used PC devices with their associated bandwidths are shown in table 5.

Table 5. Bandwidths of Typical PC Devices (Patterson & Hennessy, 1998, p.644)

Device	KB/s
Keyboard	0.01
Mouse	0.02
Floppy disk	100
Laser printer	200
Scanner	400
Magnetic Disk	2000 – 10000
Graphics display	60000

All the major components of a PC that influence its performance will now be considered from a bandwidth perspective, starting with primary memory.

2.10.2 Primary Memory Bandwidth

Memory bandwidth has been investigated by Hennessy and Patterson, (1996) and this has long been viewed as a key characteristic of a computing system. Cragon notes that the Zuse Z3 computer built in 1944 which used approximately 2600 magnetic relays had a clock rate of 5.3Hz and a 22 bit data width and took one cycle to load (Cragon, 2000, p.23). This gives a bandwidth of $5.3 \times 22/8 \times 1 = 14.6$ B/s. Memory bandwidth has increased greatly over time and was also regarded as a distinguishing characteristic of the performance of a computer. For example the memory bandwidth increased from 0.5 MB/s for the cheapest model of the range up to 16 MB/s for the most powerful model in the IBM 360 family from the year 1964 (Pugh, Johnson, & Palmer, 1991; Stallings, 2003).

The importance of bandwidth limitations in primary memory, as this becomes progressively lower than the processor cycle time, is known as the memory wall (Flynn, 1999). Whilst Burger, Goodman and Kagi noted that: "The growing inability of memory systems to keep up with processor requests has

significant ramifications for the design of microprocessors for the next decade” (Burger, Goodman, & Kagi, 1996, p.78). They also added that pin bandwidth could become a severe physical limitation. However, a year later they noted that:

“Neither long latencies nor the increased bandwidth requirements constituted a ‘memory wall’ that will eventually inhibit improved microprocessor performance. Instead, designers will employ a range of design decisions and new technologies to produce balanced, cost effective systems” (Burger, Goodman, & Kagi, 1997, p.55).

Crisp notes bandwidth scaling problems of multi-media computers whereby the bandwidth demands of video and sound make provision of sufficient memory bandwidth critical (Crisp, 1997). Comparisons of a range of DRAM architectures have been undertaken (Cuppu, Jacobs, Davis, & Mudge, 1999; Katayama, 1997). Minasi observes the increasing significance of bandwidths for DRAM and how such bandwidth has increased in time in table 6.

Table 6. DRAM Bandwidth (Simplified) (Minasi, 2001, p.465)

Type	First Used	Clock Rate (MHz)	Bus width (bits)	Peak Bandwidth
FPM (60, 70ns)	1990	25	64	200MBps
EDO (50, 60, 70ns)	1994	40	64	320MBps
SDRAM (133MHz)	1999	133	64	1.1GBps
RDRAM (Direct Rambus)	1999	400 (x 2)	16	1.6GBps
DDR SDRAM (133MHz)	2000	133 (x2)	64	2.1GBps
SLDRAM	-----	400 (x 2)	16	1.6GBps

2.10.3 Secondary Memory Bandwidth

Disk drive bandwidth is also vitally important. Norton et al note, under a heading of “Key Specs” the transfer rate as being: “The rate at which the drive and controller pass data back to the PC system, measured in megabytes per second. A

higher number is better" (Norton & Desmond, 1999, p.289). Whilst Mueller notes the transfer rates for various secondary memory devices and that: "Most drive manufacturers now report up to five transfer rates. One is the interface transfer rate" (Mueller, 2002, p.602). Mueller further notes that:

"... the media transfer rate is more important than the interface transfer rate because the media transfer rate is the true rate at which can be read from the disk, which is how fast data can be read from the drive platters (media). It is the maximum rate at which that any sustained transfer rate can hope to achieve" (Mueller, 2002, p.603).

Disk Transfer rates or bandwidths have greatly increased over time Harker et al report that the data rate went up from 8.8 KB/s in 1957, to 68KB/s in 1962, to 312 KB/s in 1966, and to 1198 KB/s in 1976 (Harker, Brede, Patterson, Santana, & Taft, 1981, p.678). Furthermore, the bandwidth of IBM invented floppy disks rose from 33,333 bps in 1971 to 500,000 bps in 1977 (Pugh et al., 1991, p.521), and bandwidths of other secondary memory devices such as Digital Versatile Discs (DVDs) and CD-ROMs have also increased over time (Mueller, 2003).

Many authors have noted the importance of disk caching (Clements, 2000b; Stallings, 2003), as does Mueller who states that:

Many ATA and SCSI drives have cache memory built directly into the drive's onboard controller. ... These integrated caches are part of the reason many ATA (IDE) and SCSI drives perform so well" (Mueller, 2002, p.606).

Shriver has extensively investigated disk caching (Shriver & Bennett, 1998). Whilst Reddy has investigated a range of Disk I/O systems with different write back policies and caches sizes (Reddy, 1992), HDD bandwidths can also be derived via a consideration of the revolutions per second (rps) giving the time for a single revolution of the disks. Dividing this into the track capacity given in MB gives the bandwidth in MB/s. Hence this bandwidth can also be compared to the bus bandwidth of the HDD controller as well as the EIDE bus used to carry this data to the IO motherboard controller chip. This can allow an understanding of performance requirements of devices that the data passes through by considering the matching of their bandwidth requirements.

Although the bandwidths of the separate components that make up a computer system are important, the bandwidths of the buses that enable data to flow between these components at the required rates are also important.

2.10.4 Bus Bandwidth

Shiver and Bennet note that "As applied to buses this means to attempt to eliminate or reduce the number of bus transactions and transfers required Shiver and Bennet further note that this also reduces the need to purchase extra bus bandwidth" (Shriver & Bennett, 1998, p.468). Shiver and Bennet note that:

"The transfer of compressed data clearly permits available bus bandwidth to be used more effectively, but it requires special processing by both source and destination. ...Generally the system bus traffic is also reduced, increasing the available bus bandwidth for other tasks" (Shriver & Bennett, 1998, p.471).

The bandwidth of a range of buses has been noted by Mueller, as shown below table 7.

Table 7. Bandwidth comparison of PC Buses and Interfaces (Mueller, 2002, p.290) (Modified)

Bus Type	Bus Width D (Bytes)	Bus Speed (MHz) (C)	Data Cycles per Clock Pulse (E)	Bandwidth (MB/s) B = CDE
PCI	4	33	1	133
PCI 66MHz/64-bit	8	66	1	533
AGP	4	66	1	266
AGP x 8	4	66	8	2,133
RS 232 Serial	1/8	0.1152	1/10	0.01152
USB 1.1	1/8	12	1	1.5
USB 2.0	1/8	480	1	60
IEEE 1394b S1600	1/8	1600	1	200
SATA-600	1/8	6000	1	600
SCSI (Ultra 4)	2	40	1	80

"Burst mode transfers realize the highest transfer rates and make the most efficient use of the available bus bandwidth" (Shriver & Bennett, 1998, p.388). Whilst Finkelstein and Weiss note that "The bus bandwidth and transfer parameters place a limit on the system performance" (Finkelstein & Weiss, 1999), and Meyers note the importance of the Advanced Graphics Port (AGP) bus when using high resolution monitors with a large colour depth requiring high bandwidth (Meyers, 2001). Shriver and Bennet note that the "AGP is also a PCI Bus variation that is dedicated to a single high bandwidth peripheral" (Shriver & Bennett, 1998, p.395). This important point is also taken up by Halfhill who notes that AGP can extend the

life of the PCI bus by switching graphics into a dedicated pathway such as AGP (Halfhill, 1999).

Bus bandwidth is an important factor in PC performance (Messmer, 1997; Minasi, 2001; Wilkinson, 1996). However, measures of bus bandwidth needs to be taken in the context of an overall system. Paterson and Hennessy note the pitfall of: "Using the peak transfer rate of a portion of an I/O system to make projections or performance comparisons" (Patterson & Hennessy, 1998, p.688).

2.10.5 Microprocessor Bandwidth

This can be dependent upon clock speed, internal bus widths and the number of instructions and executions per cycle (Mueller, 2002). Suboptimal wait states can also be calculated via bandwidth considerations (Mueller, 2002). Microprocessor performance can also be affected by microprogramming. The use of microprogramming avoids the complexities of processor hardware design moving problems into software that can be changed at a later date if needed. However, Englander notes that: "A major disadvantage of the microprogrammed approach is that each step in the fetch-execute cycle now requires several clock cycles to achieve completion of the micro instructions that make up that step" (Englander, 2000, p.316). Microprogramming was suggested by Wilkes (Wilkes, 1951; Wilkes & Stringer, 1953). Bandwidth can therefore be increased by not using micro-coding. This is the approach taken by (Reduced Instruction Set Computer) RISC machines. For microprogrammed Complex Instruction Set Computers (CISCs), Minasi notes the importance of "Microcode efficiency: The number of steps required to multiply two numbers together" (Minasi, 2001, p.106). Shiver and Bennet note that at the micro-code level improvements can be made by the: "... use of parallel decoders significantly improves decode efficiency thereby increasing the decode bandwidth" (Shriver & Bennett, 1998, p.124).

Microprocessor bus interfaces and associated electronics come together in specific implementations in the modern PC via the use of chipsets.

2.10.6 Chipsets

The importance of bandwidth consideration in modern chipset design is noted by Mueller who states that:

“The Chipset contains the processor bus interface (called the front-side bus, or FSB), memory controllers, bus controllers and more... Because the chipset controls the interface or connections between the processor and everything else the chipset ends up dictating which type of processor you have; how fast it will run; how fast the buses will run; the speed type, and amount of memory you can use; and more” (Mueller, 2002, p.226).

Shriver and Bennet note that:

“At the chipset and motherboard levels there is a seemingly insatiable demand for bus demand for bus and memory bandwidth. The memory and I/O subsystems must be optimised to sustain the higher processor performance and higher bandwidth transfer rates required for access processing and display of 3D graphics” (Shriver & Bennett, 1998, p.508).

Intel’s Northbridge chip is the connection between the high-speed processor bus and the slower AGP and PCI buses while Intel’s Southbridge is the bridge between the PCI bus and the even slower ISA bus (Bigelow, 2001). Mueller also describes how the buses fit together in terms of bandwidth using the diagram as noted in figure 6. The appropriate device bandwidths can be matched to the bus bandwidths which can be used to emphasise to students the importance of bandwidth to PC design by requiring them to calculate the bandwidth of the devices and their buses in MB/s and getting the students to annotate such diagrams as shown above with the devices along with their corresponding bandwidths. For example, a monitor with requirement of 3 bytes per pixel and a resolution of 800 x 600 pixels would require a frame memory of 480,000 x 3B with a refresh rate of 80 fps this would result in a bandwidth requirement of 28.8 MB/s. Other devices and buses can be matched and compared in a similar fashion. A monitor with a resolution of 1200 x 1000 and 3 bytes per pixel and a refresh rate of 80 fps would require a bandwidth of $1.2 \times 3 \times 80 = 288$ MB/s, which is greater than the PCI bus bandwidth. Hence the need for greater bandwidths for buses supporting video

applications which can be supplied by the AGP bus. For Pentium 4 with a 100MHz 8 B wide data and 4 data clock cycles per clock pulse (Mueller, 2003, p.427). Its bandwidth can be given by:

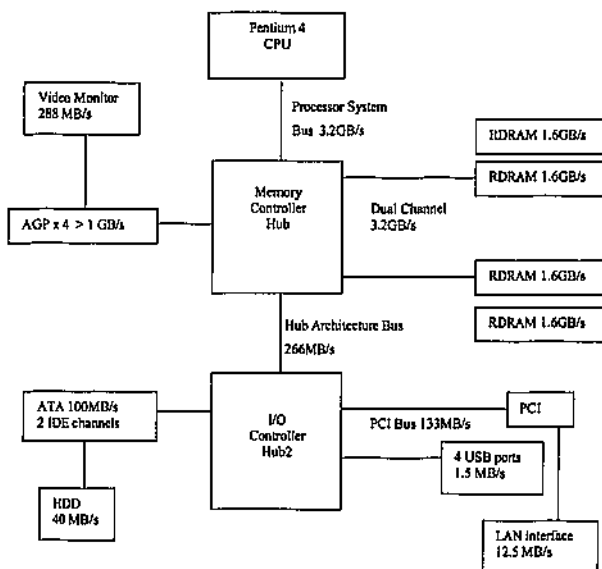
$$B = CDE = 100 \times 8 \times 4 = 3,200 \text{ MB/s} = 3.2 \text{ GB/s}.$$

The RDRAM has a data width of 2B and a frequency of 400MHz with 2 data clock cycles per clock pulse (Mueller, 2003). Its bandwidth is given by:

$$B = CDE = 400 \times 2 \times 2 = 1600 \text{ MB/s} = 1.6 \text{ GB/s}.$$

Furthermore the hierarchy of buses in terms of bandwidth with added typical bandwidths delineated in figure 6.

Figure 6. Pentium 4 System with Intel Chipset (Mueller, 2003, p.275) (Modified).



2.10.7 Bandwidth and Multimedia

The need for bandwidth can perhaps best be exemplified by real time realistic graphics systems that need to be able to handle complex geometries, high resolution images, textures and live video streams, hence the need for graphics accelerators. Anderson notes two basic design variations whereby:

“Low end workstations tend to rely on the host CPU for graphics-compute tasks such as geometry calculations, which require processing or floating point power. For the other type of accelerator, local compute power is added inside the graphics accelerator itself” (Anderson, 1999, p.74).

There are, however, trade offs between fidelity and bandwidth (Shriver & Bennett, 1998, p.334). Examples of video adaptor memory bandwidth requirements for different fidelities are shown in table 8. This table has an additional column added,

with a heading of $\text{Bandwidth} = \text{Memory} \times 80 \text{ fps} = (\text{MB/s})$, which assumes a frame per second rate (fps) of 80fps. Requirements for increased multimedia realism have led to increasing demand for bandwidth.

Table 8. Video Display Adaptor Memory Requirements for 2D Operations (Mueller, 2003, p.887) (Modified)

Resolution	Colour Depth (bits)	No of Colours	Memory required (B)	Bandwidth = Memory x 80 fps = (MB/s)
640 x 480	8	256	307,200	24.6
640 x 480	16	65,536	614,400	49.2
800 x 600	8	256	480,000	38.4
800 x 600	16	65,536	960,000	76.8
1024 x 768	16	65,536	1,572,864	125.8
1024 x 768	24	16,777,216	2,359,296	188.7
1280 x 768	16	65,536	2,621,440	209.7
1280 x 768	24	16,777,216	3,932,160	314.6

It should be noted that the resolution, the refresh rate, and number of colours all contribute to the bandwidth requirement. The tendency over time is for this to increase. Boyce notes a typical early monochrome monitor providing 25 lines and 40 characters per line. Each character is formed by using an $8 \times 8 = 64$ pixel cell. This gives a memory requirement per frame of $25 \times 40 \times 64 \text{ bits} = 8000\text{B}$ (Boyce, 1979). Assuming a 60 fps refresh rate, this would result in a bandwidth of 0.48MB/s. This is considerably less than that required for modern colour monitors. This is in accordance with an assumption of increasing demand for more bandwidth over time. Hence, a performance measure based on bandwidth criteria could prove a useful model as bandwidth induced effects can result in performance differences,

which can be observable by students, e.g. fundamental units in MB/s can be expressed in derived units of images per second.

2.10.8 Networks with respect to Bandwidth

Clarke and Pasquale note that the: "Integration of low-power, high-capability microprocessors and digital signal processing will provide the possibility of high-bandwidth communications on the move everywhere" (Clarke & Pasquale, 1996, p.688). In the field of computer networking, bandwidth has a well established history as papers such as 'The Bandwidth Famine' by Wilkes (Wilkes, 1996) can attest. Clarke and Pasquale note that: "... there never seems to be enough bandwidth. As more bandwidth is provided, users conceive new applications that consume it" (Clarke & Pasquale, 1996, p.681). Hudson et al note the importance of bandwidth utilization on network performance noting it can be reduced by:

"Reducing the number of devices on a segment. Reducing the number of protocols in use on the segment. Disabling bandwidth intensive applications of protocols, such as those that support video or audio streaming. Relocating the systems consuming the most bandwidth on the segment" (Hudson et al., 2003, p.118).

Whilst Goldman and Rawles note that: "Bandwidth management, often used interchangeably with the term traffic shaping, can be the appropriate allocation of bandwidth to support application requirements" (Goldman & Rawles, 2001, p.548). However, bandwidth remains an important consideration at each of the layers of the International Standards Organisation (ISO) Open Systems Interconnection (OSI) seven layer model and can provide a possible starting point for network performance models. Each layer will now be considered individually.

2.10.8.1 OSI layer 1 Bandwidth Considerations

Hudson et al note that: "Frame relay uses Statistical Multiplexing to allocate bandwidth to virtual connections" (Hudson et al, 2003, p.167). This enables sharing of bandwidth based upon need and opportunity for such sharing using Statistical Time Division Multiplexing (STDM) (Dennis, 2002). Menasce and Almeida list a bandwidth hierarchy as shown in table 9.

Table 9. Network bandwidth hierarchy (Simplified) (Menasce & Almeida, 2002, p.164)

Network connection	Theoretical Bandwidth
56 Kbps Modem	56 Kbps
ISDN BRI (phone line)	64 Kbps
DS1/T1 (dedicated connection)	1.5 Mbps
DS3/T3 (dedicated connection)	45 Mbps
Ethernet	10 Mbps
Fast Ethernet	100 Mbps
OC-12	622 Mbps
OC-192	10 Gbps
OC-48 with WDM	40 Gbps
OC-768 with DWDM	6.4 Tbps

McGregor notes that:

"When a remote site's bandwidth demands outstrip its link's capacity, the best solution is the provision of more bandwidth. However, in some cases an additional line or additional circuits might not be practical, especially if the bandwidth demands are sudden or unexpected" (McGregor, 2002, p.325).

Ballew notes the use of Bandwidth Allocation Protocol (BAP) to automatically add or remove extra links using extra dial-up or Integrated Systems Digital Network (ISDN) lines when extra bandwidth is required (Ballew, 2001), whilst with respect to 100BaseT Local Area Networks (LANs). Bruno notes:

"The 4B/5B coding takes 4 bits of data and expands it into a 5 bit code for transmission on the physical channel. Because of the 20 percent overhead, pulses ran at 125 MHz on the wire to achieve 100 Mbps" (Bruno, 2003, p.118).

McGregor also notes the use of queuing which enables the storing of data, sent or received, until it can be dealt with (McGregor, 2002). This enables a more

efficient use of available bandwidth. Different classes of queues can be employed to minimise specific types of delays (Lewis, 2003; Morgan & Dennis, 2001; Thomas et al., 2000). Furthermore, Coccetti and Percacci have noted that bandwidth can be strongly influenced by queue configuration (Coccetti & Roberto, 2002).

The importance of using available bandwidth is emphasised by the Voice over Internet Protocol (VoIP) default usage of Voice Activity Detection (VAD) as described by Bruno who notes that:

"Because you listen and pause between sentences, typical voice conversations can contain up to 60 percent of silence. In plain telephone networks, all voice calls use fixed-bandwidth, 64-kbps links, regardless of how much is speech and how much is silence. In multi-service networks all conversation and silence is packetized. Using VAD, packets of silence spurs can be suppressed. Instead of sending VoIP packets of silence, VoIP gateways can interweave data traffic with VoIP conversations to more effectively utilize network bandwidth. Bandwidth savings are at least 35 percent in conservative estimates" (Bruno, 2003, p.551).

The importance of having sufficient bandwidth of Wide Area Network (WAN) interfaces not just on high speed LAN interfaces is important as described by Bartell who notes that: "High speed links as well as low speed links need to be able to provide users with enough bandwidth to survive network bursts of traffic, just as interstate highways do" (Bartell et al., 2001, p.345).

2.10.8.2 OSI layer 2 Bandwidth Considerations

With respect to layer 2 switches Minasi notes that: "Switching makes it possible to connect multiple LANs to get all the advantages of being linked without the disadvantages of sharing bandwidth" (Minasi, 2001, p.1220).

Spanning Tree Protocol (STP) prevents loops at layer 2. Such loops could use up all available bandwidth by endlessly cycling the same frames (Hucaby & Boyles, 2001; Ratliff, 1999).

Lewis notes: "... implementing VLANs improves bandwidth utilization" (Lewis, 2003, p.126).

With respect to Frame Relay traffic shaping Morgan and Dennis make extensive use of bandwidth concepts such as Committed Information Rate (CIR), and Peak Information Rate (PIR), all expressed in units of bits per second (bps) (Morgan & Dennis, 2001).

2.10.8.3 OSI layer 3 Bandwidth Considerations

The use Round Trip Time (RTT) of packets can be used for analysing network performance using PING as has been mentioned by many researchers (Bovey, Mertodimedjo, Hooghiemstra, Uijterwaal, & van Mieghem, 2002; Carbone, Coccetti, Dini, R., & Vespignani, 2003; Coccetti & Roberto, 2002).

Some routing protocols help to conserve bandwidth in many different ways such as finding the shortest route in terms of combinations of hop count, bandwidth, and reliability (Doyle 1998, 2001; Forouzan, 2000; Zinin, 2002). Furthermore, bandwidth can also be conserved by using triggered updates instead of more frequent regular updates. McGregor notes that:

“Some routing protocols, such as OSPF and EIGRP, send routing updates that contain only information about routes that have changed. These incremental routing updates make more efficient use of bandwidth ...” (McGregor, 2001, p.19).

As well as potentially enhancing security, Access Control Lists (ACLs) based on source or destination layer 3 address can prevent packets unnecessarily consuming bandwidth, traversing a network or internetwork, by being applied on appropriate router interfaces (Hudson et al., 2003; Odom, 2002). Davis notes that:

“Using access lists for route filtering is CPU intensive. Overuse of routing filtering can slow the flow of packets. Typically your router uses net flow or fast processors for fast switching. When you use route filtering, you use the slowest mode of process switching. The router usually has but one processor available for process switching” (Davies, 2002, p.371).

In an article entitled “The Cost of Security on Cisco Routers” it is noted that:

“there are significant performance penalties once you enable ACLs, especially long ones that we used in our tests, because an access list cannot always take advantage of the fastest switching technique that might otherwise be available on the router” (Morrissey, 1999, p.3).

Dramatic performance reduction after implementing 200 line ACLs have also been noted. Bandwidth degradation can be reduced by using hardware based Private Internet Exchange (PIX) firewalls (Bruno, 2003).

Table 10. Throughput of PIX firewalls of Increasing Power (Lusigan, Steudler, & Allison, 2000, p.39)

Model	Throughput	Simultaneous Sessions
506	10Mbps	N/A
515-R	120Mbps	50,000
515-UR	120Mbps	125,000
520	370Mbps	250,000

Bandwidth measurement via packet delay using pairs of packets and noting tailgating effects has also been both simulated (Lai & Baker, 1999) and undertaken (Lai & Baker, 2000).

Ogletree notes the use of high bandwidth routers on the Internet core (Ogletree, 2002)

2.10.8.4 OSI layer 4 Bandwidth Considerations

The ability to control bandwidth within intranets has been noted by Minasi et al who state that: “Windows 2000 allows you to control bandwidth within your intranet using Quality of Service (QoS) control in TCP/IP” (Minasi, Anderson, Smith, & Toombs, 2002, p.463). As Cisco note:

“TCP uses sliding window techniques which results in more efficient use of bandwidth because a larger window allows more packets to be transmitted pending acknowledgement” (Cisco, 2001, p.684).

When considering delays on WAN links with connection orientated protocols at transport layer, the bandwidth delay product can be important (Katabi, Handley & Rohrs, 2002). This is the product of the bandwidth in bits per second with the round trip delay in seconds which gives a measure of the pipe's capacity in both directions to transfer bits (Tanenbaum, 2003). Tanenbaum further notes that: "... the receiver's window must be at least as large as the bandwidth-delay product, preferably larger since the receiver may not respond instantly. For a transcontinental gigabit line at least 5 megabytes are required" (Tanenbaum, 2003, p.559). Jain has conducted experiments to measure the available bandwidth with respect to TCP throughput (Jain & Dovrolis, 2002).

The central importance of bandwidth can also be seen from the need to reserve it. RSVP, operates at layer 4 of the OSI model and reserves bandwidth for network applications by working in conjunction with access control lists (Bruno, 2003).

2.10.8.5 OSI layer 5 Bandwidth Considerations

Checkpoints are used at the Session layer to provide a rollback point should a crash occur (Forouzan, 2000). This can prevent the need to re-send all of the data as only part of the data going back to the last checkpoint needs to be resent, which again helps to conserve bandwidth (Cisco, 2001, 2002).

2.10.8.6 OSI layer 6 Bandwidth Considerations

Data compression is also important in utilizing available bandwidth Goldman and Rawles note that: "Data compression replaces large strings of repeating characters with special code which represents the pattern" (Goldman & Rawles, 2001, p.120). Compression can also help reduce bandwidth loads but increases latency of routers due to the time taken for compression and decompression (Fage et al., 2000). Morrissey notes the cost of encryption with respect to bandwidth on routers (Morrissey, 1999).

2.10.8.7 OSI layer 7 Bandwidth Considerations

The choice of Layer 7 services using either TCP or UDP can effect bandwidth utilisation depending upon the need to avoid error in transmission, or the likelihood of such errors (Comer, 2000; Forouzan, 2000). Oppenheimer notes:

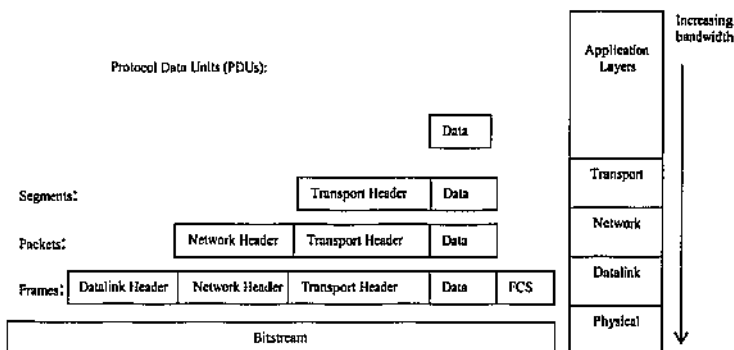
"Most end users are concerned about throughput rate for applications. Marketing materials from some networking vendors refer to application-layer throughput as 'goodput'. Calling it 'goodput' sheds light on the fact that it is a measurement of good and relevant application-layer data transmitted per unit time... When specifying throughput goals for applications, make it clear that the goal specifies good (error-free) application-layer data per unit of time. Application layer throughput is usually measured in kilobytes or megabytes per second" (Oppenheimer, 2001, p.32).

Hence, bandwidth considerations can be important at all levels of the seven layer OSI model, as well as within the computer itself. If bandwidth is such an apparently central measure in electronic systems could, it also possibly be important in non-electronic systems? Is it not the data transfer rate that is important not necessarily the means used to undertake such a transfer?

2.10.9 Bandwidth and the OSI Model

With respect to the OSI seven layer model. Bandwidth can be considered at each of the layers (Coccetti & Roberto, 2002). Due to extra encapsulated information added at each layer when descending the protocol stack (Cisco, 2001), it may be seen that the bandwidth should increase when going from the session layer down to the Physical layer with each layer increasing the encapsulation overhead (Thomas et al., 2000) as is illustrated in figure 7.

Figure 7 OSI Seven Layer Model Protocol Data Units
(Thomas et al., 2000, p.14) (Modified)



Again there exists the possibility of an abstract top-down model based on bandwidth considerations, and such a model would be based upon a given OSI model layer. Different data transfer protocols operate at different layers in the OSI model causing the bandwidth results to be layer dependant. This is because higher layer encapsulation is considered as part of the data to be encapsulated at lower layers.

This model could also be verified using of performance monitors available under modern PC operating systems (such as Windows 2000 and Windows XP) to measure throughput rates at layers 3, 4, and 7 of the OSI model (Minasi et al., 2002).

2.10.11 Non-Electronic Bandwidth Applications

Non-electronic devices may also store data in a digital form so the concept of bandwidth could also be applied. Examples of non-electronic devices using digital data are Jacquard looms (Schoenherr, 1999) and musical boxes. One version of a musical box has a cylinder with pins over its curved surface that makes contact with the teeth of a comb as the cylinder is rotated. Tallis notes that "The comb

having 250 teeth ... the cylinder of a grand overture box probably has up to 50,000 pins... because of the size of the cylinder many overtures could be played in their entirety" (Tallis, 1971, p.47). The more complex and detailed the musical score, the more pins and higher speeds of rotation required (Tallis, 1971), hence the need, even with these mechanically based devices, for higher bandwidth capabilities. However, a higher bandwidth alone does not necessarily make a higher performance machine.

With both non-electronic and electronic devices there are problems associated with using bandwidth to denote performance, and one of them is latency. For a Jacquard loom this could include the setting-up time between runs.

2.10.12 Potential Problems in Using Bandwidth as a Performance Indicator

Bandwidth can be used as a performance indicator where there is extra bandwidth produced, but this may not necessarily lead to increased performance. McComas notes the problems associated with using bandwidth with respect to PC related devices as the sole performance measure (McComas, 2001a), as do Buzen, and Shum (Buzen & Shum, 1996a). This point is also made with respect to network technology by Openheimer:

"It is possible to improve throughput such that more data per second is transmitted, but not increase goodput, because the extra data transmitted is overhead or retransmissions. It is also possible to increase throughput by not using compression. More data is transmitted per time, but the user sees worse performance" (Oppenheimer, 2001, p.32).

Furthermore, Hennessy and Patterson, under a heading of "Fallacies and Pitfalls" note the:

"... pitfall of using bandwidth as the only measure of network performance. ... this may be true for some applications such as video, where there is little interaction between the sender and the receiver, but for many applications such as NFS, are of a request-response nature, and so for every large message there must be one or more small messages ... latency is as important as bandwidth" (Hennessy & Patterson, 1996b, p.622).

Coccetti and Percacci also note that: "Network performance cannot be expressed by a single parameter". Nonetheless, they go on to note that: "packet loss, delay and bandwidth are in principle some possible independent measures of a network's performance" (Coccetti & Roberto, 2002, p.1).

2.10.13 Bandwidth as a Basis for an Abstract Model

The questions to be considered are about the importance of the bandwidth factor: could it become a guiding principle in conjunction with a new bandwidth-based model to aid student understanding of developments in the field of CNT? This form of abstract model could potentially be used across different age groups, various course units and at different educational levels, freeing students from the need to re-learn the basis of the models as they progress through the educational system. The use of derived units could aid this process. To avoid becoming bogged down in the minutiae of low level details, a bandwidth-orientated model may well need to be based upon high level abstractions. The importance of abstraction has been a common theme in the context of aiding conceptual understanding (ACM, 2001; Ramsden, 1992; Staggers & Forcio, 1993). It should be noted that different subjects have their own appropriate models at differing levels of abstraction dependant upon the area of use. Floyd notes that "Models should be specific to the research question being investigated" (Floyd & Kohler, 2002). Whilst Cooling notes the importance of high level abstraction to reveal important system features (Cooling, 1991). Importantly, the use of abstraction is recommended as a recurring theme by the ACM:

"Levels of Abstraction: the nature and use of abstraction in computing; the use of abstraction in managing complexity, structuring systems, hiding details, and capturing recurring patterns; the ability to represent an entity or system by abstractions having different levels of detail and specificity" (ACM, 1991b, p.75).

Bandwidth may be used at all layers in the OSI seven layer model. For example bandwidth concepts can be applied to layer 3 routers layer 2 switches and layer 1 hubs (Cisco, 2001, 2002).

2.10.14 Summary

Although it is difficult to deny the crucial importance of bandwidth there are problems with latency. Digital devices working on bits can be limited in their speed of operation by the rate at which bits can be moved around for their operation. Bandwidth concepts may be applied across a very large range of situations both within and between digital devices, as well as allowing the use of both fundamental and derived units. Bandwidth concepts can be applied to electro-magnetic relay devices and non-electronic mechanical devices. This exemplifies the extent of application of the high level abstraction bandwidth centric model and its potential for de-coupling from the underlying technological implementation. A salient characteristic of all of the uses of bandwidth discussed is that over time there is a marked increase in bandwidth as the technology develops, which is indicative of its importance in the provision of an overarching theme in the development of computer and computer networking technology.

An important potential advantage of de-coupling from the underlying technological implementation is that this could help to future proof learning from the rapid rate of technological change. The bandwidth centric model also allows the possibility of being recursively decomposable into lower level abstractions as it is hierarchical; being self documenting due to being diagrammatic, as well as allowing for the controlling of detail due to the use of abstraction.

Bandwidth can be useful at each the OSI model's seven layers. However, bandwidth should be higher at lower levels in the OSI model due to encapsulation overhead.

If a bandwidth based model may also accord with student conceptual understanding as it would start with the PC and then move to lower level abstractions and may also accord with constructivist principles. Measurements need to be preformed to test such ideas both in the technical and the educational domains.

2.11 Overall Literature Search Summary

Many students now demand an employment relevant university education. Such a demand is supported by governments and employers, yet there is a tendency for university courses to become more academic and less practically relevant. There is also a tendency towards qualification spirals, or credentialism, resulting in higher academic requirements than those strictly necessary to perform actual job functions.

The university as a place for gaining vocationally relevant skills has been hotly debated. The EU now accepts that the university does provide vocationally based education or training for a vocation.

Surveys have indicated that relevant employment skills include hands-on skills and experiences. Attainment of such practical skills requires assessment for both the students and potential employers. CBAs can be used for hands-on assessments.

CBAs have come under attack both as encouraging minimal attainment due to the difficulties and expense in more advanced forms of testing or from behaviourist assumptions that may underpin such assessments.

There is a need for additional safety requirements to those normally required in non hands-on environments. This presents extra problems in situations where staff may not have had prior experience in potentially hazardous environments.

Within Australia, TAFEs were established specifically for employment based education and training. Up-to-date hands-on relevant retraining can be expensive as well as susceptible to rapid change. Increasingly, university graduates find it necessary to undergo training at TAFEs to gain job relevant skills and qualifications. The university sector has lost control of content of units based upon vendor based and vendor neutral curricula.

Debates about the suitability of vocationally orientated education within a university context have led to a renewed focus on the role of the university, and also on different types of knowledge.

Understanding the epistemology of 'knowing-how' and 'knowing-that' are both required to achieve mastery over a subject, as is the experience of knowing when and why to use them. Such integration can be especially important in SMEs where new recruits in the IT and IS fields may be expected to have hands-on skills and knowledge across a range of topics.

Yet vocationally relevant skills can be subject to obsolescence because of the rapid rates of change in technology. Meanwhile students may well need the skills and knowledge acquired through education courses to equip them for careers going on for decades after their graduation, hence the need to attempt to future-proof student learning.

A possible candidate for such future-proofing could be based upon high level abstract performance models. Abstraction is an important theme within computer science education. An example of a successful abstraction that has been used across a broad range of educational levels and topic areas within electronics and computer science are digital logic gates. From a computer architecture perspective digital logic gates form a starting point for a bottom-up model, making it unsuitable from a constructivist perspective for many students as it may well not be in accordance with their previous concepts and general understanding. This model could, however, be useful for engineering students.

For many students a high level model with a top-down approach is required on which to base learning, starting from commonly held understandings and experiences. A high level abstraction would de-couple the model from the underlying technology and be potentially useful across a range of such technologies, regardless of its particular implementation.

Basing an abstract model upon benchmarks could be problematic due to the inconsistent results from benchmarking programs, which claim to measure the same quantities using identical data. Furthermore, such programs may only give a number, and may not yield results based upon meaningful units.

Simulation has been used to model PC and network performance, as have analytical models based upon queuing theory. However, such models are often based upon complex mathematics, making them unsuitable for a large number of CNT students who may not possess the mathematical knowledge required to use them effectively.

However, an abstract model could be based upon bandwidth as this is crucial to both in PC and computer network performance. Bandwidth considerations are important at each of the seven layers of the OSI seven-layer model. Increased bandwidth can be seen as vital to developments within these areas. Furthermore, bandwidth comparisons may be applicable to non-electronic but nevertheless digitally based devices such as musical boxes or Jacquard looms. Bandwidth concepts are used across a range of CNT topics.

The use of such a bandwidth based model may also be based upon a top-down approach using different levels of abstraction and based within a constructivist framework of the student's own observation of PC and network performance. Such abstraction could help educational institutions to more quickly respond to changes in the CNT area and could also help to introduce an element of future-proofing in the education of IT students.

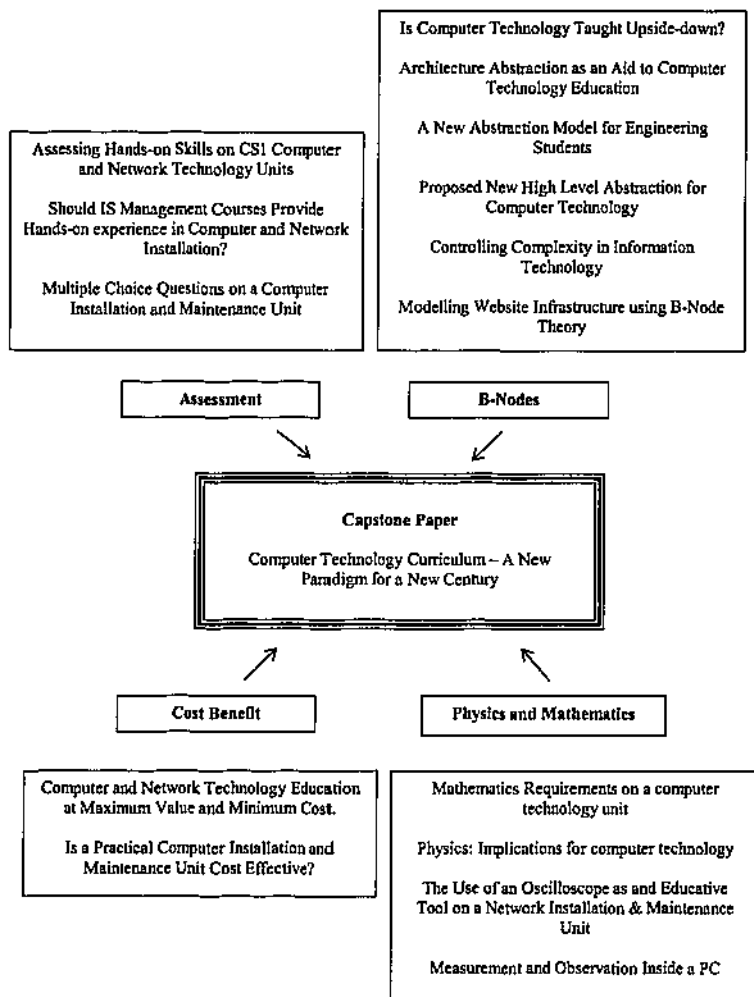
CHAPTER 3

PUBLISHED PAPERS

3.1 Introduction to the Published Papers

The need for a computer science curriculum more relevant to the needs of potential employer expectations and student needs has been discussed. The case for a lack of hands-on skills has been made, and associated curricula introduced and evaluated. The introduction of these new curricula required a top-down approach that highlighted the need for high level abstraction. The B-Node model is proposed as such a model. Both the practical hands-on approach, with the need for hands-on skills and understanding, and the new high level abstractions via B-Node modelling, to help students to place developments of CNT in context and to provide some future-proofing of student learning in this rapidly changing field, are both core components of this approach. It should be noted that there is some inevitable repetition in these papers that was required to 'set the scene' and to explain the problems in the units and the work undertaken up to the point in time when the paper was written.

Figure 8 Publication Structure Diagram



3.2. The Published Papers

These papers have been assessed by blind peer review for publication in international journals or in conference proceedings.

3.2.1 Assessment

3.2.1.1 Assessing Hands-on Skills on CS1 Computer and Network Technology Units

This paper (Veal, Maj, & Duley, 2001) was presented in 2001 at the 32nd Technical Symposium on Computer Science (CS) Education held at Charlotte, North Carolina. The symposium is a peak international forum on computer science education. The symposium is the flagship event of the Special Interest Group for Computing Science Education (SIGCSE) which is a group within the Association for Computing Machinery (ACM). The ACM is arguably the world's foremost body in the field of computing science and SIGCSE is most likely the world's foremost body in CS Education

This paper describes how Edith Cowan University (ECU) in Perth Western Australia, introduced a new curriculum in computer and network technology in response to an analysis of employer expectations.

The survey of employer expectations had revealed that employers were seeking an assurance that IT graduates could actually perform in the workplace.

The new curriculum at ECU required that students achieve standards in a workshop environment that closely reflected the reality they were likely to meet as graduates in the actual workplace, including how to deal with potential Occupational Health and Safety Hazards.

The research question asked was: can an effective, efficient and meaningful assessment be undertaken to test students' hands-on skills and understandings?

The authors therefore designed a Competency-Based Assessment (CBA) to measure procedural knowledge and skills. The hypothesis was: Could a CBA be

designed that was simple, easy to use, and meaningful and that could also be implemented as part of a standard workshop without interrupting student activities? The results confirmed that this was possible. The resultant CBAs were probably the first in this field within Australia in a university context. The initial implementation found that the lack of safety practice was highlighted via the CBA and could not easily have been determined otherwise. Significantly the CBA also provided a necessary audit trail in case of a student complaint, and allowing further analysis of a student's individual workshop session, or unit results if this was required. There was a need for a range of PC architectures to enable vendor independence, and to encourage generic maintenance skills, and a consideration of issues of professional practice and hands-on skills within a CS unit.

The results to date suggest that the hypothesis: "CBAs can measure hands-on skills on a unit such as CIM within a university context without significantly interrupting student activities" was confirmed. It was found that there was a need for effective highlighting of safety issues via use of CBAs.

Assessing 'Hands on' Skills on CS1 Computer & Network Technology Units

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Abstract

Edith Cowan University (ECU) introduced a new curriculum in computer and network technology based upon a market analysis of employer expectations. Uniquely, within Australia, this curriculum has extensive workshop exercises that require students to work on equipment they are likely to meet in the workplace and as such the workshop environment is potentially hazardous to students. It was found that prospective employers often required both an assessment and an assurance that students following this curriculum could work to an acceptable industry standard. The traditional forms of assessment (examinations and assignments) did not fulfil this requirement. The authors therefore designed a Competency-Based Assessment (CBA) to measure procedural knowledge and skills. The CBA designed was simple, easy to use and can be implemented as part of a standard workshop without interrupting student activities.

Keywords

Computer Technology, Constructivism, Competency Based Assessment

Introduction

According to the 1991 ACM/IEEE-CS report, *'The outcome expected for students should drive the curriculum planning'*. Within Western Australia an exploratory market audit was conducted of a wide range of companies. From this survey a set of guidelines were developed for the type of skills expected of computer science graduates entering the field of computer and network support.

Using the criteria developed, a random selection of ten final year ECU computer science undergraduates were interviewed from a graduating population of approximately one hundred. The computing science degree at ECU is level one accredited, the highest, by the Australian Computer Society. According to Maj, *"I 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."*[8]

Interviews conducted with five ECU graduates employed in computer and network support clearly indicated that they were, to a large degree, self-taught in many of the skills needed to perform their job. Preliminary investigations indicated a similar situation with computing science graduates from other universities in

Western Australia. According to Campus Leaders, *"... the predominant reason why they (the 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"*. [15]

The initial ECU student questionnaire, first used in 1993, was also conducted in 1999 at two universities within the UK [3]. Both universities have well established degree programs that are British Computer Society (BCS) accredited. Both these degree programs offer students the opportunity to examine a PC in the first year however they never take a PC apart. Students are taught network modelling, 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. The survey indicated that any practical knowledge students have of hardware is largely a result of experience outside the course. Furthermore, there is considerable potential demand from students of other disciplines for instruction in computer technology. According to a study of Multi-media students by Maj, *"It is significant that every student interviewed expressed the view that It would be extremely beneficial to have a much better knowledge of computer and network technology"* [8]. In order to meet this demand a new curriculum was designed, introduced and evaluated.

Curriculum Development

Four units were introduced to address the above problems by use of a practical, inter-disciplinary, problem oriented approach – Computer Installation & Maintenance (CIM), Network Installation & Maintenance (NIM), Computer System Management (SCM) and Network Design & Management (NDM). The two units initially introduced were CIM and NIM [8]. Rather than lowering academic standards Professor Lowe argues, *"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"* [2]. By example in the CIM unit, rather than consider the technical detail of one particular type of PC architecture, a range of PC architectures is used thereby ensuring vendor independent and generic maintenance skills.

The principles of computer operation along with an emphasis on the skills associated with installation, fault diagnosis etc. provides skills that are readily portable between different PC architectures. Given the rapid changes in technology this emphasis on generic skills is a non-trivial issue. Accordingly a systems engineering approach is employed i.e. a top down, hierarchical, modular analysis. According to Sragg *"most (perhaps all) first courses in computer hardware are created "upside down" - both pedagogically and pragmatically"*. [12]

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. 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 in which students must install a variety of memory devices and conduct simple fault diagnosis exercises.

Furthermore, it is anticipated that on completion of this curriculum students will be able to manage a computer and network systems support team. Safety in the workplace both as employee and employer mandates that the principles of Health & Safety be taught, both in principle and in the context of computer and network support and management.

Curriculum Evaluation

Since their introduction the units CIM and NIM have been oversubscribed with a low student attrition rate. According to Maj,

"The student demand has consistently exceeded possible places. The initial quota of 100 students for the unit CIM was exceeded with 118 students enrolling and even then demand exceeding possible places. The student attrition rate was 8.5% with a subsequent unit failure rate of less than 10%. An independent unit review of the unit found: 80% would recommend this unit; 75% found the practical sessions useful; 70% found the unit relevant to their needs". [9]

These units attract cross-institutional enrolments from students at other universities within the state and they are consistently highly rated in mandatory evaluations by students. Independent investigation by an educational expert found that the CIM unit

"... 'is perceived as very valuable by students from different disciplines; supports learning in other units; increases students' understanding of computers and computing; And also that it 'generates a demand for further curriculum in this field; is enhanced by the series of lectures and workshops given by an experienced computer support technician and is about right in terms of difficulty". [9]

Given the success of the two units CIM and NIM, two subsequent units, SCM and NDM have been introduced. However problems existed with respect to workshops skills and knowledge.

Practical Skills Assessment

Students with a wide range of physical dexterity and skills attend these units. For many it is the first time they have worked on computer equipment. This problem is addressed to a limited degree by using decommissioned equipment for the introductory CIM unit. In the subsequent unit, CSM, students have the opportunity to work with 'state of the art' equipment that includes: installation and testing of: Digital Video Disc (DVD), flat bed scanner, PC video camera, Infra-red communications link, Zip Disc etc. Other workshop exercises include establishing and testing a videoconference communications link via a local area network. [10] The main problems are therefore safety of the students and to minimise damage to equipment. It should also be noted that the students who claimed to have prior

experience in this field damaged more equipment than the novices. Clearly 'self evaluation' of skills is inadequate. It was found that students needed to repeat many of the tasks to acquire the necessary skills. Even though two earth leakage detection circuits were installed (10 and 20mA) in the workshop such circuits afford no protection to the individual when a PC is mistreated. Hence, 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 electrocution must always be considered. Accordingly, high tension devices, the VDU and power supply, are never opened. According to Maj,

"One of the main problems that we have faced is that students are accustomed to 'soft systems' in which it is always possible to re-compile or use the 'undo' button in order to correct a mistake. This type of work is, however, very unforgiving and accordingly a fundamentally different approach was needed and must be taught. We adopted a mastery learning approach where students had to learn the basic skills to a 100% level. One wrong connection made during a live experiment can destroy a motherboard". [10]

Furthermore, it was found that prospective employers often required both an assessment and hence assurance that students of this curriculum could work to an acceptable industry standard. The assurance being that students not only had the necessary theoretical knowledge but also that their standard of practical skills was such that they would not endanger either the safety of themselves or others and that expensive equipment would not be damaged. In this context the traditional forms of assessment (examinations and assignments) were inadequate. These assessment methods do not provide any measure of how well students perform in an employment workshop environment. To address this problem the authors investigated the different types of knowledge and associated assessment methods.

Professional Practice and Practical Skills

It is submitted that technical expertise is an enhancement of theoretical knowledge. According to Cervero, *'the popular wisdom among practicing professionals is that the knowledge they acquire from practice is far more useful than what they acquire from more formal types of education'*. [3] Cervero further argues that the *'goal of professional practice is wise action' and that 'knowledge acquired from practice is necessary to achieve this goal'*. [3] Both declarative and procedural knowledge are necessary for professional practice. Declarative knowledge is knowledge that something is the case; procedural knowledge is knowledge how to do something. Cervero clearly makes the point that, *"A major difference between experts and non-experts in any field is that experts have far more procedural knowledge. That is, they know how to perform their craft."* [3] According to Goldsworthy, skill *"... refers to a person's ability to do something well. It relates to expertness, a practiced ability, dexterity in performing a task. It is an outcome that flows from knowledge, practice, inherent abilities and an understanding of the task to be performed"*. [5]

The curriculum introduced demands both declarative and procedural knowledge. *"Declarative knowledge is knowledge that something is the case; procedural*

knowledge is knowledge how to do something. Both declarative and procedural knowledge are essential for professional practice". [3]

However, even though students are taught both procedural and conceptual knowledge only conceptual knowledge is assessed by means of traditional assignments and examinations. None of these assessment methods provides any measure of how well students perform in a workshop environment that is designed to simulate working practices. According to Havard, *"The world of work requires people who 'know how and not just know what. Graduates invariably fall into an 'information gap' of having knowledge about a specific subject area but do not necessarily know how to operate in the working environment". [16]*

It is necessary to be able to measure competency thereby providing essential feedback to students and information to prospective employers. The authors therefore examined competency within a university context.

Competency Issues

Competency has been defined as *"The ability to perform in the workplace."* [5] According to Karmel evaluation of competencies, *'provide a check on the performance of students and on the success of institutions and teachers in training them. In this sense, they are instruments of accountability and are attractive to those responsible for funding public education". [11]*

Competency Based Assessments (CBAs) have themselves come under attack as leading to a too narrow a perspective on the skills part of the equation. According to Goldsworthy, *"Competency based standards in effect are an ad hoc measure of skills they measure performance after the event. The activity is performed and measured after the skills, experience and knowledge have been acquired".[5]* However a written examination, the assessment activity is also performed and measured after the acquisition of the skills, experience and knowledge and does not necessarily provide a prediction as to how well students might perform in the workplace. Both written assessments and CBAs may be required.

Another critique of CBAs is that they often only assess minimum levels of competency. This is often due to the practicalities of both limited assessment time and resources. However, standard driving tests are also minimum level assessments and yet they considered useful in checking basic driving skills and understanding. This is surely better than no assessment whatsoever. However, not all competency tests are limited in this manner. Abelman notes that:

"The most demanding is probably the Certified CISCO Internetwork Expert (CCIE) assessment, which in addition to the two-hour written exam, requires a two-day lab exam that 'pits the candidate against difficult to build, break, and restore scenarios.' Those in higher education who talk glibly about performance assessment don't really know what it means until they are up against the CCIE". [1]

Within a university context the competency debate will no doubt continue. However, the new curriculum introduced at ECU requires students to work in a potentially hazardous environment. Pragmatically there is the requirement to ensure that those students are able to work competently within the workshops in a manner that is not hazardous to themselves or others. In an attempt to provide the necessary assurance of acceptable workshop practices Maj introduced workshop rules, *"the first workshop was concerned entirely with workshop practice and students were required to read both the university and workshop regulations - it was emphasized that misconduct would not be tolerated"*. [8] However, this fails to provide the necessary assurance mechanisms to determine whether or not students work at an acceptable level of competency to a clearly defined and recognized standard. The authors therefore attempted to design CBAs, at university level, for the new curriculum that should be:

- Meaningful to students, staff and employers.
- Scaleable, so that they could eventually cater for both small and large groups of students at many different sites should the need arise.
- A part of the normal workshops.
- Easily repeatable by other members of staff.
- Easy to manage and does not cause excessive extra work for both staff and students.
- Checkable, in case of student complaint. There should be a signed and dated paper 'audit trail'.

Furthermore, in any fully implemented assessment scheme, each competency would need to be tested more than once as a consistency check and to afford students sufficient opportunity to demonstrate their skills and understanding. [4]

Fully implemented CBAs would also need to check for inconsistencies between assessors. Two or more assessors assessing the same student at the same time should produce the same results. For a competency classification to be consistent the same competency being assessed by using different workshop exercises, yet close in time to each other, should produce similar results for the same students. Likewise two different CBA schemes used to assess the same sets of competencies for the same workshop exercise should give consistent results when tested on the same students at the same time.

CBAs can also be used to flag student misunderstanding in areas of the unit relevant to the workshop exercises. Moreover should students in a particular tutor's workshops have difficulties not experienced to the same extent by students attending the workshops of other tutors then this can be used to indicate possible problems with an individual tutor's workshop delivery.

CBA Design and Implementation

Within the new curriculum offered at ECU students are currently assessed by means of a standard written examination and two written assignments. It is possible however, for a student to successfully pass these units without ever attending any workshop. However both declarative and procedural knowledge must be assessed.

Different forms of assessments have both advantages and disadvantages. Written examinations can enable students to demonstrate a greater depth of knowledge while at the same time they may also test a limited breadth of their understanding. Whilst written assignments can give students an opportunity to search literature and show understanding, multi-choice questions provide the means to test students with minimum effort across a large portion of the syllabus, but may not allow students to show their in-depth knowledge. However, CBAs may be used to test practical skills not tested via other forms of assessment. It can be concluded that no single assessment technique is sufficient if both procedural and conceptual knowledge are to be assessed. Veal notes with respect to CBAs that, *"merely because the higher order skills may not be capable of measurement this should not of necessity exclude measuring other very important and potentially commercially relevant skills"*. [13]

Accordingly the authors designed and tested CBAs for two units in the new curriculum - CIM and NIM. The workshops are typically implementations of the preceding lecture. All workshop details are provided including objectives of exercise, learning outcomes, equipment checklists and details of each experiment. At the start of each workshop the tutor provides a demonstration of the experimental procedures. The required outcomes from the workshop tasks were grouped under appropriate headings, thereby defining a set of competencies. The defined set of competencies for the CIM unit were:

- A. Testing and checking
- B. Safe work practices and protection of equipment.
- C. Manipulative awareness and skills
- D. Interpretation of instructions. Knowledge of systems
- E. Fault diagnosis and correction.

To ensure that the CBA was easy to use the authors elected to use simple binary evaluation criteria i.e. pass or fail. By example for the unit CIM the checkpoints used for set B of competencies were:

- 1 Mark: Disconnects from mains when appropriate.
- 1 Mark: Takes power lead out of back of system box.
- 1 Mark: Uses Anti-static strap at appropriate times.
- 1 Mark: Re-assembles computer correctly.
- 1 Mark: Polarity of all cables correct.

During the CBA the assessor moved around the workshop checking off the sheet for each student being evaluated. The assessor had a separate sheet for each student with a standard clear and simple layout for ease of marking. A similar method and assessment sheet layout was employed for the NIM CBAs. [14]

Results

It was found that the CBAs used were easy to manage as part of normal workshops. No extra time was taken during the standard two-hour workshop period yet it was

possible to assess all twenty students in each workshop. According to Veal for the CIM unit

"At no point was the workshop interrupted, or extra time taken. Ten students were evaluated. Despite the fact that considerable emphasis is placed on ensuring that students are provided with the highest possible standard of good workshop practices to underpin Health & Safety the results clearly indicated that some students did not demonstrate a satisfactory competency in basic safety practices. It would not have been possible to determine this result without a CBA". [13]

Conclusions

Competency within a university context is subject to considerable debate. The new curriculum in computer and network technology at ECU requires students to work on equipment in a manner that simulates a typical commercial environment. For some units these environments are potentially hazardous to students. This mandates that students be assessed for their competency. The simple CBAs used in this study were straightforward to design and test. Furthermore they could be implemented as part of a normal workshop with minimum interruption to normal student activity.

Fully implemented CBAs require the inclusion of both consistency checks and provision of 'audit trails'. The authors are currently conducting further tests of CBAs on a larger number of students on a range of different units.

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3.2.1.2 Should IS Management Courses Provide Hands-on Experience in Computer and Network Installation?

This paper (Veal & Maj, 2001) was presented at the Americas Conference on Information Systems. (AMCIS) 2001, held at Boston Massachusetts from 2nd to the 5th of August. This conference is one of the leading Information Systems (IS) conferences worldwide. The paper includes the results of a questionnaire administered to a group of Management IS (MIS) students all of whom were attending an Australian university. The research question asked was: Were hands-on experiences in computer and networking installation and maintenance appropriate for IS management courses, and what were student opinions concerning these issues? These students, who were either studying, or had studied, e-commerce, networking or computer programming units in the faculty of business, were interviewed whilst completing a questionnaire. Students were asked to express their opinion on a number of issues relating to their course. Questions were asked using an open PC and associated equipment as a reference. Students were also asked a range of questions on topics such as the setting up of Internet sites, LANs, including typical hardware and software requirements, costs and expected capabilities for a range of typical business scenarios.

Significantly nearly all of the students interviewed thought that hands-on practical experience in computer networking and PC hardware would be either required by employers or would enhance their confidence as IT professionals, and should be included as a course component. Such hands-on experiences such as upgrading PCs and maintaining computer networks were not provided as part of their curriculum. Yet these issues could be particularly relevant as IS managers are increasingly taking on responsibility for Internet implementation and need a good understanding of computer networks and their management. The suitability, importance and associated problems with hands-on components within IS Management and e-commerce units was considered.

Additional new knowledge includes a consideration of the problems of implementing a hands-on computer installation and networking components within an IS management unit and the problems experienced by students in such a unit.

Also included are the results of interviews with students that were currently studying on an IS management unit at an Australian university and the results of the questionnaire undertaken these students, many of whom were employed in IS management positions. Hence it is likely that these participants were in a position to know the job requirements with in their company.

Students were questioned with an open PC with network interface card and asked to describe common processes and computer and network installation and maintenance. The relevance of practical skills to MIS students is considered. A conclusion was that there were a range of opinions of the need for CNT installation and maintenance hands-on experiences, although that most students felt that there was a need for such experiences.

Should IS Management Courses Provide Hands-On Experience in Computer and Network Installation?

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Abstract

Recently a group of IS Management students attending an Australian university either studying, or had studied, e-commerce, networking or computer programming units in the Faculty of Business were interviewed whilst completing a questionnaire. These students were asked to express their opinion on a number of issues relating to their course. Some questions were asked using an open PC and associated equipment as a reference. Students were asked a range of questions about the setting up of Internet sites, LANs, including typical hardware and software requirements, costs and expected capabilities for a range of typical business scenarios. Significantly nearly all of the students interviewed thought that 'hands on' practical experience in computer networking and PC hardware would be either required by employers or would enhance their confidence as IT professionals, and should be included as a course component. Such experiences were not provided as part of their curriculum and these issues could be particularly relevant as IS managers are increasingly taking on responsibility for Internet implementation and need a good understanding of computer networks and their management. The suitability, importance and associated problems with 'hands on' components within IS Management and e-commerce units are considered.

Introduction

Recent years have seen an enormous increase in the number of university students enrolled on business IS and e-commerce units. Such units are often regarded as distinct from those in computer and network technology traditionally provided by computing science departments. It might be thought likely that computing science students would possess skills required in such areas as computer and network support. However, nearly all 3rd year computing science students investigated at Edith Cowan University (ECU) did not possess the skills demanded by employers in this field despite the fact that they had successfully completed all of their units (Maj Robins Shaw and Duley 1996). These findings are consistent with those of Nwana who noted that: "Perhaps most worrying of all is the persistent view that computer science graduates are not suitable for some employers, who appear to distrust computer qualifications" (Nwana 1997).

The lack of student 'hands-on' skills in PC hardware and computer networks led to the development and the successful introduction within the Computing Science department at ECU of two new units, Computer Installation & Maintenance (CIM) and Network Installation & Maintenance (NIM). Both units have been consistently oversubscribed and attract students from other faculties within ECU and from other universities within Western Australia. Both are single semester full credit units with

a weekly two-hour lecture and an associated two-hour 'hands-on' workshop. CIM and NIM have a significant 'hands-on' practical component and been successfully independently evaluated (Maj Fetherston Charlesworth and Robbins 1998). Identical studies by Maj, Fetherston, Charlesworth, and Robbins (1998) were undertaken on an international level and revealed a similar lack of 'hands-on' skills in PC hardware and computer networks.

A corresponding situation was also found amongst local multi-media students (Maj Kohli and Veal 1999). These findings led the authors to consider the possibility that a comparable situation could be occurring within IS Management courses. Such a possibility was given particular credence, as IS Management students from local universities were also enrolling in the CIM and NIM units. Research by Trauth had shown the existence of an expectations gap between IS Industry and the academic preparation undertaken by IS Students (Trauth Farwell, and Lee, 1993).

The Questionnaire

A questionnaire was designed to determine IS Management students' 'hands on' skills, knowledge, and practical experience in computer networking, Internet and PC hardware and software, and their provision via the IS management units. Each questionnaire was completed as a part of an interview session that lasted between 20 and 50 minutes. Thirteen students participated. These were either on undergraduate or graduate programmes. Some of the graduate students interviewed already held managerial positions and were upgrading their qualifications. Others were engaged in employment and wished to move into IS management. A number of those interviewed either were, or had been, employment in the IS area. All were volunteers. Just under half (46%) of those questioned said that they had never opened a PC to replace parts, or that it had not been successful. However, 3 students who had stated that their part replacement had been successful failed to note the use of an anti-static or ground strap whilst taking the PC apart. Only 31% of students interviewed noted this requirement. Good workshop practice mandates the use of an antistatic strap or comparable measures. Managers in the field of business IT need to know this. Should these students have attempted replacing parts without any anti-static protection then there would have been good chance of damaging the PC. Such results are in line with findings from Maj whilst observing computer science students initially undertaking similar tasks: *"Students who claimed to have prior experience in this field damaged more equipment than the novices. Clearly 'self evaluation' of skills is inadequate. It was found that students must be given the opportunity to repeat many of the tasks in order to acquire the necessary skills"* (Maj Robins Shaw and Duley 1996).

Questions were asked regarding their previous studies, IT related employment, and what sort of computer related skills prospective employers might want them to possess. When asked whether they considered that the IS Management Curriculum units they had undertaken adequately prepared them to meet such employer expectations the answers given fell into two roughly equally sized groups. Within the group who answered 'yes' some noted that they were intending to seek a higher managerial level post that would require some background IS and IT knowledge although not at a high level of technical detail, or that their programming and web

page authoring skills were sufficient. Students from the other group noted that the units that they had studied were useful and provided some of the 'hands on' skills required by employers. However, this second group also expressed the opinion that there was a need for 'hands-on' practical skills in the area of networking, including Internet-working, the physical realities of putting together an actual working network, as well as the skills required to make changes within a PC. Asked whether their IS Management course should provide a practical component such as 'hands on' workshops in networking and computer installation 77% of the all students interviewed replied that it should. Replies given included "Employers are looking for such skills" and "I would feel more confident in the role of an IT professional".

Just over half those questioned (54%) responded that they could set up a simple Internet presence, i.e. a web presence only, for a company of less than 10 people (both hardware and software). However, a student working in the field noted that they thought it unlikely that students could achieve this task solely as a result of their IS Management units. Significantly 85% of all respondents thought that the IS Management curriculum should provide the opportunity for them to obtain the necessary theoretical and practical skills be able to do this task. This could be particularly relevant at the present time as IS managers are increasingly taking on responsibility for Internet implementation and need a good understanding of computer networks and their management. Some students had already undertaken similar tasks as part of their employment. When questioned about the installation and management of a more complex web interactive Internet presence, allowing information exchange, for a legal firm of about 100 staff only 15% thought that they had the necessary skills. It should be noted that there are many technical management issues associated with this case study e.g. distributed architectures, scalability, security etc. Of the students interviewed 69% thought that the IS Management curriculum should provide the necessary theoretical and practical skills and knowledge to enable them to be able to perform these tasks. Those disagreeing with the need for such provision cited reasons such as "*being too complex for the course they were undertaking*", or "*specialists should do this work*".

Student Concerns

Most of the students interviewed felt that there was a need for 'hands-on' experience in computer networking and PC hardware. Notably 3 students believed that such 'hands on' experiences could help to reinforce their theoretical understanding of the subject area. Such concern is in line with statements by Havard "*The world of work requires people who 'know how and not just know what'. Graduates invariably fall into an 'information gap' of having knowledge about a specific subject area but do not necessarily know how to operate in the working environment*" (Havard Hughes and Clarke 1998). Todd whilst investigating job skill requirements from newspaper advertisements "*concluded that organizations are looking more to technical requirements in the hiring process*" (Todd McKeen and Gallupe 1995) cited in (Crook and Crepeau 1997).

Many undergraduates may not be aware of the needs of industry in their field of study. Harvard also noted that: *"On completion of their academic programme the graduate was given no way of knowing how their skills compared to the requirements of industry"* (Harvard Hughes and Clarke 1998). The results of a study specifically concentrating upon the perceptions of IS Students of the needs is the IS Industry found that: *"students are in remarkable agreement with employers"* (Mawhinney Morrell Morris Helms 1999). Furthermore, Dunn notes that: *"Higher Education, while vocationally orientated, is often viewed as focusing on theoretical bases of professional practice. However, contemporary graduates are required to be able to practice with effect as soon as they begin their profession"* (Dunn and Carson 1998). An Australian government commissioned report entitled: *"Employer satisfaction with Graduate Skills"* noted specific problems in the IT and electronic communication area: *"In regard to course content, we found very few complaints by employers except in regard to more advanced areas of information technology and electronic communications"* (DETYA 2000). Whilst the MSIS 2000 Model curriculum notes that one of its objectives is to *"overcome the skill shortage that exists and is expected to continue in the years ahead. Students graduating with an MS degree should possess enough skills that they can take responsible rather than entry-level positions and serve as mentors to people with lower levels of education"* and that *"to make students more employable students take a related set of courses (reinforced by practical experience within information systems)"* (Gorgone Gray Feinstein Kasper Luftman Stohr Valacich and Wigand 1999).

Another Australian Government commissioned report commenting the recruitment of new graduates also noted that employers: *"recruit on the assumption that graduates have satisfied the academic requirements of each institution, thus allowing them to focus on the particular skills and attributes they believe are most essential for the particular work environment. Generally, employers' emphasis skills and attributes which are more difficult to evaluate than academic skills"* (NEEB, 1995). An earlier Australian government report had found that *"90% of employers surveyed indicated that they used academic results as part of their criteria to select new graduates and only 36% used previous job experience"* (NEEB, 1992).

A large proportion of the students interviewed in our investigation had either undertaken or were undertaking the Business Studies Network Management unit. One student stated that this unit was *"very informative as to the physical realities associated with networks"*. Whilst another student noted that *"The unit failed to provide a description of the facilities provided by the Novell or NT network operating systems, neither did it include a discussion about their relative strengths and weaknesses"*. Notably one student interviewed stated they also stated: *"there were no practicals involved in assigning rights to users, or setting up new users on to a computer network"*. A unit description stated that it *"will give students the skills and knowledge necessary for managing computer networks"*.

Further classification needs to be made regarding the level of expected of initial employment of undergraduate students upon graduation. Maybe this is predominantly at initial entry level? However, with respect to the postgraduate

students the situation can be very different. One postgraduate student noted with respect to their units that: *"Postgraduate students are often employers themselves and quite often already in management roles."* And further that: *"I found, apart from the overseas students, most people in level 5 (Postgraduate) units were quite experienced in the management of IS/IT. They were either from the technical staff that had moved to management positions or managers who have had to take on the role of managing the resource. At that level of experience one tends to have a good idea of what one needs to know to make decisions."* With respect to the expected size of the enterprise that graduating students would enter they further noted that: *"It appeared to be assumed by the university that students would work for a large company and so not need to know how upgrade or set up a network as an IT manager. Whereas most businesses within Western Australia are Small to Medium sized Enterprises (SMEs)."*

Such views are also in line with a paper entitled *"A profile for the IT manager within SMEs"* Gramignoli stated that *"the deeper the IT manager's technical knowledge, the more effective will be the end users training programme and day-by-day support"*. And they further add that: *"Within SMEs the traditional IS management activity is often replaced by the management of the relationship with the technical partners: because of the shortage of IS dedicated staff, the IS design, implementation, and development are often outsourced. In such a context, in-depth technical knowledge is essential to correctly weigh up the technical validity of the partners' proposals"* (Gramignoli Ravarini and Tagliavini 1999).

The crucial importance of IS managers in assessing proposals is noted by O'Brien in the article *"SMEs blame suppliers for solutions failures"* notes: *"Most feel let down by poor relationships, misleading advice and inadequate support"* He goes on to state that: *"SMEs miss out on Internet opportunities because suppliers do not provide them with appropriate business solutions, according to a new report. Mind the Gap, compiled by the University of Durham Business School and IT solutions vendor Flexion Systems, revealed that more than three-quarters of the 300 SMEs questioned found relationships with their information and communication technologies (ICT) suppliers frustrating or disappointing"* (O'Brien 2000). Many large companies are out-sourcing their IT and IS department functions and their IS manager become contract and negotiation managers who require strong technical knowledge to control the out-source partner (Willcocks and Fitzgerald 1996).

'Hands-on' PC and Computer Networking Skills for Business IT Students.

The provision of 'hands-on' skills in computer networking, PC hardware and setting up internet sites, including hardware and software, can be both time consuming and expensive it could be vitally important in enabling students to at least gain entry level admission into many organizations. Without such skills students may not get that important first job in their field. Even if most students succeed in this aim under present conditions, should there be a downturn in demand then the additional possession of these skills could become a deciding factor. Exposing the students to 'hands-on' experiences in PC networking and hardware could also enable them to participate more effectively in IT decisions in their employment, particularly as managers making decisions about IT/IS investment.

One graduate student interviewed noted that on the programming unit students are informed that as managers in the IT field they needed to experience programming to aid their understanding of the processes involved, even though in the final analysis they would not become programmers. This student made the observation that similar reasons were not used when considering 'hands-on' experiences in the fields of PC hardware or networks. Furthermore this student stated that: *"At university Business Management Courses include at least one accounting unit. You don't teach a manager how to read a balance sheet or Profit & Loss without teaching them basic accounting principles. They need to understand fundamentals for good decision-making. So too it should be for computer and computer networking skills"*

Some students expressed a concern that they will need to incur yet more expense immediately after completion of their Business IT course to order to gain practical experience and qualifications in the IT field from TAFE or a private provider. In Australia TAFE is a federally funded vocational education and training provider. Werner (1998) has noted that in South Australia more students went from university to TAFE than from TAFE to university. The increasingly popular trend of enhancing employment prospects via private training providers as an addition to higher education study, or as an alternative pathway, has been noted by Abelman (2000).

The CIM and NIM Units.

The use of dedicated workshop and storage space demands a large allocation of resources compared to conventional IT laboratories, which will incur extra cost. Tutors are often postgraduate students who have previously attended the CIM and NIM units. Tutors must be present whenever students are using the 'hands-on' workshops for safety, insurance and legal reasons, as well as to help to prevent possible damage to equipment. The costs of student 'hands on' damage to equipment and its replacement due to the rapid pace of technological advancement can be expensive (Veal Maj Fetherston and Kohli 1999). Without sufficient time and money devoted to updating lectures and 'hands on' workshops then such units will become rapidly outmoded. The CIM unit has recently been updated to include Windows 2000 professional exercises in setting up peer to peer networking, Linux dual boot installations, security and resource allocation, whilst the NIM unit has included Windows 2000 Server workshops in addition its Novell based workshops.

A Business Studies student who had been a consultant to companies changing their financial systems, which also involved upgrading the computer and network infrastructure, stated that: *"Personally I often have felt at the mercy of the computer technicians and suppliers, relying upon their, (often conflicting!) advice in order to make decisions about spending large sums of \$\$\$\$. Hence units, such as CIM and NIM, give me the basic understanding of what it is all about"*. Both the CIM and the NIM Unit were designed to be technical management units. In addition to forming part of the standard undergraduate options as first year units within the computing science department at ECU they have been run as short intensive courses on a commercial basis.

The CIM and NIM workshops are based on standard PCs. Each two-hour workshop consists of a set of tasks for the student to undertake and all students undertake the same set of tasks in a given workshop. The CIM workshops require students to install and test a range of components such as, Master-slave hard disk drive; Network interface card installation; CD-ROM installation etc. The CIM unit is often the first opportunity that many students have had to work with computer hardware.

The problem of lack of training in observation techniques is also of initial concern as many students do not correctly note how a piece of equipment is put together before proceeding to take it apart. Allowance must also be made for students to acquire experience in applying correct levels of force and attainment of the manipulative abilities required in the assembly and disassembly processes. The use of decommissioned equipment for the first few workshops can help minimise the financial cost of initial mishaps. Students in the NIM unit have the opportunity to design, install and test a small Local Area Network (LAN). This includes establishing a file server, client, construction and testing of cabling, and the design and installation of the directory tree. (Veal and Maj, 2000). The CIM and NIM unit workshops cost AUS \$35K for the initial equipment plus the cost of technical support and a dedicated laboratory. In the subsequent unit, Computer System Management, students have the opportunity to install and test Digital Video Disks (DVDs); flat bed scanner; PC video camera; Infra-red communications link; Zip Disk; and establishing and testing a video conference communications link via a local area network (Maj Kohli and Veal 1999). In this subsequent Network unit more emphasis is put upon NT systems. These two units required AUS \$60K in initial equipment costs plus the cost of technical support and a dedicated laboratory.

Within the CIM unit Safety & Health are important from a safety and a legal perspective as both employees and employers have legal responsibilities, which cannot be delegated. Students are given practical safety demonstrations as well as being informed and examined on the legal aspects of safety. Sets of multi-choice questions have also been designed in an attempt to further test and extend student appreciation and understanding of safety issues.

Competency Based Assessments (CBAs)

The IS'97 Model Curriculum Guidelines note that: *"The basic idea is that graduates of IS programs should have competencies, skills and attitudes that are necessary for success in the workplace and life-long learning as an IS professional or provide the basis for graduate programs"*. (Davis Gorgone, Couger Feinstein and Longnecker 1997 pp37). Both CIM and NIM were designed to integrate theoretical understanding gained through lectures with practical exercises. Assessment of 'hands on' skills could prove to be a cause of concern for the staff involved. However, CBAs have been found to be more suitable for testing aspects of students' 'Hands on' skills and knowledge than written assignments. Competency has been defined as *"The ability to perform in the workplace"* by Goldsworthy (1993).

CBAs have been described as: *"an approach to establishing occupationally-relevant standards of competence. The emphasis is on demonstrated competence in the skills relevant to an occupation"* (DEET 1992). Within a university context, CBAs are somewhat unusual according to Ashenden (1990): *"Training for many occupations is conducted in universities and colleges where the standards set often have more to do with educational or scholarly performance than performance as an engineer or doctor or accountant. It is in this context that the idea of 'competency assessment' has grown up"*.

Under a heading of *"Education v Training"* Denning notes *"Learning the professional practices of a specialty of information technology is every bit as important as learning the intellectual core of computing. The mark of a well-educated professional will be a balance of the two, earned perhaps through partnerships and training companies. The current academic inclination to disdain skill-specific training does not fit a profession"* (Denning 1998).

The intended use of CBAs within the CIM and NIM units is not to supplant but to supplement the more conventional means of student assessment. Student's theoretical understanding and knowledge on the CIM and NIM units are assessed via a conventional three-hour end of semester written examination and two written assignments.

Were such "hands-on" units as described above to be included in IS management courses then time spent on this provision would need to come from somewhere else in the curriculum. The updating of curricula knowledge often leads to similar situations where topics need to change if courses are to remain relevant. Furthermore, the unit cost of providing these "hands-on" experiences to large number of students, for example 200, is diminished by economies of scale as only one set of exercises need to be developed for each workshop and one set of equipment need be used with only one dedicated laboratory required. A potential downside is that the workshop equipment would also be more likely to suffer from the effects of increased usage as has been discovered on the CIM unit which has now has 125 currently enrolled students.

Conclusions

Most business IT students who volunteered to be interviewed felt that employers would expect 'hands on' practical skills such as upgrading computer hardware, and network implementation but did not think that their course had provided them with those experiences. Most students interviewed thought that their course was worthwhile and did provide some useful 'hands-on' IT skills in the form of programming and web authoring.

Due to the limitations of a single investigation with only 13 participants in a business faculty of a single university in one country these results, though certainly cause for attention, do not constitute a definitive study. More extensive investigations need to be undertaken to determine both the source of the concern about employer exceptions and their extent. It is vital to interview potential

employers of IS management to determine their expectations regarding the 'hands-on' skills and experiences highlighted in this paper.

Setting up 'hands on' workshops in computer networking and PC hardware can be expensive over and above the general demands of more conventional IT or IS units. CBAs offer a means to efficiently and meaningfully assess 'hands-on' skills. Workshops in PC hardware present additional problems such as Safety & Health implications and possible damage to equipment. However, the potential benefits might be great and could include students graduating from IS and business IT courses with a wider range of skills and abilities within their field along with improved employment prospects. Furthermore enhanced faculty reputation amongst both potential students and potential employers could result from the additional provision of 'hands-on' skills and experiences in the vital areas of networking and PCs. The IS and Business IT fields change rapidly whilst changes in unit provision take a relatively long time to bring on stream. A potential scenario resulting from the omission of such 'hands on' provision, or of leaving the introduction of their provision too late, is that students along with reputations could go elsewhere.

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3.2.1.3 Multiple Choice Questions on a Computer Installation and Maintenance Unit

This paper (Veal, Engel, & Maj, 2001) was presented at the UICEE 5th Baltic Region Seminar on Engineering Education, held from the 17th to the 19th of September in Gdynia, Poland. The UNESCO International Centre for Engineering Education (UICEE) is based in the Faculty of Engineering at Monash University, Melbourne, Victoria, Australia. The mission of the UICEE is to facilitate the transfer of information, expertise and research on engineering education. It facilitates international conferences worldwide where peer reviewed papers are presented and published.

The unit Computer Installation and Maintenance (CIM) had been running for 5 years at ECU at the time of this research and had been consistently oversubscribed attracting students from other faculties within ECU, and from other universities within the Perth area. It was discovered that many CIM students came from non-computing, non-technical backgrounds. The CIM unit, of necessity, covers a wide range of technical topics. The testing of students' knowledge before the final examination to provide feedback for staff and students was perceived as desirable by both the staff involved and by many of the students. The research question was; did the students perceive the use of testing to provide them with feedback on their progress in a range of topic areas in the CIM unit via Multiple Choice Questions (MCQs)? MCQs relevant to the CIM unit were developed and subsequently tested on students in the CIM unit as a pilot process. After answering the MCQ paper, students were encouraged to complete an anonymous questionnaire asking if they regarded MCQs as useful. The answers to the MCQ paper were later worked through in tutorials and the reasoning behind both the correct and incorrect answers was explained. This paper details the results of the survey of student opinions regarding the use of MCQs. It considers the possible advantages and disadvantages of their application within the CIM unit. This included things such as, the use of MCQ as an aid to revision; MCQ question bank; cueing; and a student survey as well as anti-guessing formats. Criticisms of MCQs such as the Trivial Pursuit Theory of Knowledge are also considered. Use of MCQs

in commercial certification programmes and the use of adaptive testing are also considered.

Additional new knowledge resulted from surveys to students in the CIM unit and the implementation of MCQs on a hands-on university CNT unit. The results of a survey revealed that most students thought that feedback before the main examination via MCQ results was a good idea. It was also found that some students believed that MCQs were easier than standard written examinations, at least from the perspective of causing less language difficulties for some students for whom English was not their first language. It was also discovered that some students thought that there was a 'trick' aspect to some MCQs.

Multiple Choice Questions on a Computer Installation and Maintenance Unit.

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Abstract:

The unit Computer Installation and Maintenance (CIM) has been running for 5 years at Edith Cowan University (ECU), has been consistently oversubscribed and has attracted students from other faculties within ECU and from other universities within the Perth area. Many CIM students come from non-computing, non-technical backgrounds. The CIM unit, of necessity, covers a wide range of technical topics. The testing of students' knowledge before the examination to provide feedback for staff and students was perceived as desirable. Multiple Choice Questions (MCQs) were developed and subsequently tested on students in the CIM unit as a pilot process. After answering the MCQ paper students were encouraged to complete an anonymous questionnaire asking if they regarded MCQs as useful. The answers to the MCQ paper were later worked through in tutorials and the reasoning behind both the correct and incorrect answers was explained. This paper details results of the survey of student opinions regarding the use of MCQs. It considers the possible advantages and disadvantages of their application within the CIM unit. The use of adaptive testing using MCQs is considered.

Introduction

The unit Computer Installation and Maintenance (CIM) was set up in response to findings by Maj et al [5] who identified a mismatch between the skills and knowledge required by employers in the field of CIM, and the skills and knowledge possessed by third year computing science students who had successfully passed all of their previous units in computing science. Maj et al note 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" [6].

As there are no prerequisites for CIM, students come from a wide range of backgrounds with respect to technological education [16]. Assessment is currently based on two written assignments and a three-hour written examination. Staff noted that the assessments did not cover the entire syllabus and that there was also a lack of timely feedback. MCQs could be set to cover those parts of the syllabus not covered by the present assessment practice. It was thought that MCQs could also provide timely feedback, without excessively increasing staff workload. Staff and students could then address problem areas revealed by the MCQs. Additionally,

MCQs could be used for end of semester revision. A short MCQ test could highlight topics students need to revise.

The addition of MCQs to the final written examination paper would provide an opportunity to examine student understanding across a broader range of topics than would be possible with only a written examination.

Staff feedback to students could include explanations of why answers chosen were correct or incorrect. This can encourage the promotion of discussion, both to resolve misunderstandings and to enable students to put their point of view.

Ambiguity in MCQs can be a problem. Having another member of staff checking the MCQs for ambiguity can help to avoid this situation.

Previous Use of MCQs

MCQs had been successfully used in previous semesters to test CIM students' understanding of basic Physics [16].

MCQ Question Bank

To ascertain the potential usefulness of MCQs in the CIM unit, a question bank was developed to test student understanding across a wide range of the CIM syllabus. An MCQ paper of 25 questions was chosen from this question bank and students were given 35 minutes to complete the test. All managed to complete the paper within the allotted time with no students noting that they required extra time

The Student Survey

An anonymous survey was conducted immediately after the MCQ test. Students were asked whether they would like to see MCQs as a part of the end of unit examinations. Three students thought this was bad idea, 30 were neutral and 67 considered it a good idea. Student statements included: *"Those trick questions really make you think"*, *"The questions would give a more challenging approach since questions can be phrased in ways to test knowledge"*, *"Word English is the problem for us (International students) Multi-choice helps us to understand questions"*, *"I don't understand the theory so including it I would be just as confused. Although if we had had multi-choice each week then this would have helped a lot"*.

Another survey question asked whether MCQs would be useful as a revision aid. In response 84 students replied yes, 16 were neutral and none replied no. Statements included:

- *"it shows what your strengths and weaknesses are"*
- *"It will help in most aspects of revision"*
- *"because I just did pretty bad, so I know what I have to study"*.

As the student response to the sample MCQ test was positive, MCQs are being developed for further use in the CIM unit.

Criticisms of MCQs

MCQs can be used to assess across a broad range of a curriculum. Within the CIM unit the use of MCQs is not to replace more traditional forms of assessment but to enhance them by providing both timely and cost effective revision and feedback to students. Scouler notes that different forms of assessment can promote different forms of learning [12], whilst Lazarus observes that: *"Even more than their teachers, students know that the test is what matters most. 'Are we responsible for this on the test?' is the student's way of asking 'Is this worth my trouble to learn?' when the answer is no, attention is turned off as if it were the flick of a switch"* [4]. Therefore, the inclusion of MCQs as an additional form of assessment could aid the learning process. Farthing notes common objections to MCQs: *"they may be answered simply through guessing; they assess only trivial recognition of facts, rather than high-level thinking, such as exercising judgment and synthesis; they offer a choice of answers, rather than of ask the candidate to construct and answer"* [3].

Swanson et al note that: *"Critics of MCQs often focus on 'cueing' inherent in MCQ format: they argue that examinees need only recognize the correct answer, rather than work through the problem and construct it. This is a legitimate concern, but it is generally straightforward to reduce cueing by increasing the number of response options"*. However, they point out that: *"Critics of MCQs also argue that in real-world situations, physicians must consider more than a single best answer"* [14].

A similar case is made by Christianson and Fajen who note that: *"Some critics assert that a single multiple-choice test can't tell you whether a person can handle real-world problems using a particular product... Furthermore, the multiple-choice tests that vendors use are typically designed - by teams of practicing and skilled 'prometricians' (professionals in testing and measurement) - to assess knowledge and abilities as will be needed in real-world applications"* [2].

Situations requiring 'more than a single best answer' were addressed in the CIM unit by the use of competency-based assessments (CBAs) [17]. CBAs are also known as 'hands-on' performance-based tests. Real world situations are simulated, in part, by extensive 'hands-on' workshops each of two-hours duration per two-hour theory lecture. As in medical diagnosis, a particular PC malfunction symptom, presented to students during a workshop, is not always indicative of the same fault, and further investigations may be required.

With respect to commercial certification, Christianson and Fajen also note that: *"Certification is not without its detractors... It is true that not all certification programs involve hands-on performance-based testing. Many programs do and the general trend is to move certification programs in that direction"* [2].

Suskie in a paper entitled *"Fair Assessment Practices"* notes that to be as fair as possible to students in the assessment process we should use many kinds of measures noting that *"One of the most troubling trends in education today is the increased use of high stakes assessment - often a standardized multiple-choice test - as the sole or primary factor in a significant decision, such as passing a course,*

graduating, or becoming certified. Given what we know about the inaccuracies of any assessment, how can we say with confidence that someone scoring say, 90 is competent and some scoring 89 is not?" [13].

However such criticisms could apply to most forms of testing, not just MCQs.

To address the problem of merely guessing answers, Farthing et al have developed permutational MCQs making successful guessing statistically unlikely [3]. The UK Open University has made extensive use of MCQs as an integral part of some of their programmes. For example, MCQs can be used that have answers 'A' to 'H' inclusive and each of these possible answers can themselves depend on a combination of up to 6 factors [10]. Farthing et al also note that a common objection to MCQs is that: *"they assess only trivial recognition of facts rather than high level thinking"* [3]. McPeck calls this *"The Trivial Pursuit Theory of Knowledge"*. He goes on to state that: *"Like the game Trivial Pursuit, knowledge is assumed to be the kind of thing which can be fitted into one-sentence questions, with one-sentence answers"* [8].

However, McCurry states, with respect to MCQs, that: *"they can also assess higher order skills when they are well written"* and notes that *"MCQ tests are described as 'objective' because their scoring can be mechanical and unambiguous. However, there is always an element of subjective judgement about what to include in a multi-choice examination and about what constitutes adequate performance on such a test"* [7].

Pithers notes the difference between select-type questions, where students need to select answers from a range of alternatives and supply type questions, where they need to provide the answers. Pithers states: *"Supply-type items have typically been shown to have the capacity to tap deeper levels of cognitive understanding and application. It should be noted however, that if well thought out, sometimes select-type multi-choice items can achieve this as well"* [11].

Advantages of MCQs

McCurry notes that MCQs have the special advantage of being able to assess candidates' mastery of a wide variety of facts and procedures within a limited time period [7]. Whilst Farthing notes that: *"Well formed distracters can present candidates with options that they may not have otherwise considered. This can challenge woolly thinking in a way that open-ended questions do not"* [3].

Adaptive Testing

Where a large bank of questions is available adaptive testing can be part of the MCQ process. IT trainers and assessors have used adaptive testing as part of their certification processes. Novell's examinations for Certified Novell Administrator (CNA) and Certified Novell Engineer (CNE) are well-established examples of combining MCQs with adaptive testing. Another example of this type of combined MCQ/adaptive testing is the A+ Technicians exam. Under the heading of "test taking hints" Brooks notes that "the A+ Exam is an objective-based timed test", and that students should "be aware of A+ questions that have more than one answer"

[1]. Brooks also notes that the organisation responsible for the delivery of the A+ examinations, CompTIA, will eventually convert all of its exams into adaptive mode [1]. Adaptive tests are sometimes provided on an accompanying CDROMs included with training packages.

The adaptive testing process can be quite complex and can be used both for MCQs and for other forms of assessment. Under the heading of *"Frequently Asked Questions About Adaptive Exams"* on a Microsoft Training and Certification web page, it is noted in response to the question *"What does an adaptive exam look like?"* that *"An adaptive exam appears the same as a fixed form exam but presents questions targeted to the examinee's level of ability. This ultimately results in fewer questions for the examinee... An adaptive exam uses a statistical process of discovery. It first presents a question of moderate difficulty. When the examinee responds the question is scored immediately. If correct, the test statistically re-estimates the person's ability at a higher level. The exam delivery algorithm then finds and presents a question that matches that higher ability. (If the question is answered incorrectly the opposite occurs)... This process continues with the test gradually targeting the examinee's target level. The exam ends when either the accuracy of the examinee ability estimate reaches a statistically acceptable level or when the maximum number of items has been presented"* [9].

Adaptive testing is useful to probe students' understanding. However, its use as a replacement for university examinations is problematic if only due to the present requirement that all students sit an identical examination. In view of the extensive use of adaptive testing by commercial accreditation providers, adaptive testing may nevertheless be useful for those students who intend to sit for commercial certification.

Conclusion

The relatively steep learning curve experienced by many CIM students, especially those students from a non-technological background, means that staff need to actively monitor student understanding. MCQs can be used as part of the final examination, for end of unit revision, or as diagnostic tests to provide feedback for staff and students.

It was found that once banks of MCQs are set up they could be modified and reused, hence providing a valuable assessment and revision resource. The trial MCQ paper taken by CIM students included questions that encompassed a range of levels of difficulty. For student revision it is intended to initially ask questions of fact, graduating to more difficult questions once the students have gained a better understanding of the fundamental principles.

Adaptive MCQ testing at present appears to be limited to providing practice for students' intending to sit for commercial certification. However, the future potential of adaptive testing within universities ought not to be ignored, particularly if computer-aided testing were to become more widespread.

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3.2.2 Cost Benefit

Hands-on in CNT education mandates a different approach and results in components of cost different from traditional computing science units.

3.2.2.1 Computer and Network Technology Education at Maximum Value and Minimum Cost

This paper (Veal & Maj, 2000b) was presented at the American Society for Engineering Education (ASEE), Computers in Education Division, 2000 Annual Conference, (held in St Louis, Missouri, USA). The ASEE is one of the leading engineering education bodies within the USA. Its annual conference is its leading forum for publication and presentation.

This paper presents an international comparison of employers' skill expectations of students. The Network Installation and Maintenance (NIM) and the Data Communications & Computer Networks units were compared. The Digital Technology and Computer Installation and Maintenance (CIM) units are also compared. Factors considered in the selection of the initial PC used for students to work with in the CIM unit are considered. The use of switchable faults as part of the fault finding exercises are also described. Students' experience of a range of PC architectures to develop their skills and the importance of systematic observation to enhance the benefits of these hands-on experiences is emphasised. It was found that it is important to retain a classroom set of working PCs, which is vital from an instructional perspective. The value of a working class set of PCs exceeds the actual monetary value of a particular PC. Students are presented with a graded range of tasks of increasing difficulty to enable them to gain the initial skills and understandings required. Simple tasks were performed before students were faced with more difficult tasks. It was found that students needed plenty of practice to develop their hands-on skills in this unit. The importance of safety is raised as well as the costs of running the NIM and CIM units. Low attrition rates with respect to student continuation with these units are also noted and the results of student interviews and survey are presented.

Additional new knowledge includes findings of the costs, and problems involved in the implementation of this hands-on networking unit within a university context. Whilst it may be concluded that the CIM and NIM units are cost effective, they also incur some additional costs when compared to more conventional CS units. However, savings can be made by using discarded equipment to help offset the additional expenses incurred.

Computer and Network Technology Education at Maximum Value and Minimum Cost

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Abstract

Rapid advances in technology place considerable demands on computer and network curriculum. A market analysis clearly demonstrated that the standard approach to teaching computer and network technology failed to meet the expectations of both students and employers. A subsequent, preliminary international market analysis endorsed this finding. Accordingly a new curriculum was designed, implemented and evaluated at Edith Cowan University. The student demand for this curriculum has always exceeded possible places and student attrition rate has been consistently very low. An independent review of one unit found: 80% would recommend this unit; 75% found the practical sessions useful; 70% found the unit relevant to their needs and 55% think this should be a compulsory unit. Significantly, this curriculum attracts students from a wider range of disciplines (Computer Engineering, Computer Science, Business IT, Multimedia, etc) and also students from other universities within the state.

This portfolio of new units provides each pair of students with their own client-server network connected to the Internet, a wide range of PCs and associated equipment. Workshops include the installation and testing of: master-slave Hard disc, CD-ROM, Digital Video Disc (DVD), flat bed scanner, PC video camera, Infra-red communications link, Zip Disc etc. Other workshop exercises include establishing and testing a video conference communications link via a local area network. With nearly over two hundred students every semester the logistics associated with supporting this type of laboratory are non-trivial. Issues include: initial equipment cost, student safety, damage to equipment and technical support. This paper presents details of how this new curriculum was designed and implemented at a minimum cost.

Introduction

Reports such as the 1991 ACM/IEEE-CS *Computing Curricula*¹ provide the foundations of computer science curriculum world wide and set benchmarks for accreditation by professional bodies. The computer science degree at Edith Cowan University (ECU) is level one accredited by the Australian Computer Society (ACS). According to the 1991 ACM/IEEE-CS report, "*The outcome expected for students should drive the curriculum planning*". Within Western Australia an exploratory market audit was conducted of a wide range of industrial and commercial companies. This was complemented by a further detailed analysis of the IT department of a state wide rail company. From this survey a set of guidelines

were developed for the type of skills expected of computer science graduates entering the field of computer and network support. Using the criteria developed 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.

The computer architecture and communication engineering units were: Computer Technology, Microprocessors, Data Communication & Computer Networks. These units follow the standard approach taken by most universities. The Computer Technology unit introduces students to computer systems and hardware i.e. number codes, assembly language (Motorola 6800), machine architecture etc. The Microprocessor unit is a detailed examination of microprocessor technology and an in-depth treatment of assembly language (Intel). The Data Communication & Computer Networks unit provides an understanding of the physical and logical elements of data communications with a detailed discussion of the ISO OSI model. Furthermore, interviews conducted with five ECU graduates employed in computer and network support 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. This problem is exacerbated not only by the constant and rapid changes in technology but also the requirement to teach technology to students from a wide range of discipline such as multimedia, e-commerce etc. The authors therefore attempted to find an alternative approach to teaching introductory computer and network technology. 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.

Other countries similarly have professional accreditation. In the United Kingdom (UK) the British Computer (BCS) accredits university courses and has an internationally recognized examination scheme in two parts with Part II at the level of a UK honors degree in computing. The initial ECU student questionnaire, first used in 1993, was also conducted in 1999 at two universities in the UK. A similar study is currently being undertaken in Sweden. The first university has well established degree programs and is fully BCS accredited. The second university recently redesigned their IT awards, some of which are now BCS accredited. The degree programs at the first university offer students the opportunity to examine a PC in the first year as part of a module in Computer Organization. However they

never take a PC apart. 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. The survey indicated that any practical knowledge students have of hardware is largely a result of experience outside the course. At the second university the results demonstrate that these students had a broad, hobbyist's understanding of the PC but no knowledge of health and safety law. Significantly, the students interviewed identified that their skills and knowledge of PCs and networks came from self-study or employment, not from courses at university. Again student responses indicated that such knowledge would be useful. We therefore examined developments in computer and network technology curriculum.

Computer and Network Technology Curriculum

The problems associated with teaching computer technology are not new. Units in microcomputer systems are fundamentally important to students^{3,4}. These address issues that include: computer organization, memory systems, assembly language, digital logic, interrupt handling, I/O and interfaces. Mainstream computer science education is well supported by journal articles on various aspects of re-programmable hardware for educational purposes⁵ and assembly language⁶. Simulation has proved to be a very useful tool^{7, 8, 9}. Reid used laboratory workstations to allow undergraduate students to "build a complete, functioning computer - in simulation"¹⁰. The simulation is so complete that it:

*"extends down to the gate and signal levels, with effective modeling of delays and transitions, so reasonable assurance of the validity of the designs can be achieved. The computers constructed in this laboratory are complete with peripheral equipment including tapes and discs, and the students furnish a rudimentary operating system"*¹⁰.

Pilgrim [10] took an alternative approach in which a very small computer was designed in class and bread-boarded in the laboratory by students using small and medium scale TTL integrated circuits. Thereby, according to Pilgrim, providing students with the "knowledge and experience in the design, testing and integration of hardware and software for a small computer system"¹¹. According to Parker and Drexel simulation is a preferred approach because: "In the past we used separate and usually unrelated, bread-boarding labs to demonstrate basic system elements: decoders, multiplexers, sequential logic etc. However, students often do not see the big picture"¹². The difficulty of providing a suitable pedagogical framework is further illustrated by Coe and Williams:

*"In trying to understand the detailed operation of the computer, the student must consider the constantly changing state of its individual components. One natural way to represent this state information is by means of components. However even for the simplest uni-processor the set of data to be conveyed by such means is very large and subject to rapid change"*¹³.

And further that: *"This presents the scientist with a problem – how to represent a large, ever changing set of state information with sufficiently fine time resolution of be useful"*¹³

Coe et al address this problem by means of simulation. Barnett¹⁴ suggests that standard computer architecture is too complex for introductory courses and that *"One alternative is to define a simple computer with a limited instruction set and use this computer as an example"*. Similarly the problems with teaching network technology are not new and various approaches have been employed. Primarily software approaches have been advocated by^{15, 16, 17, 18}. The dominance of the TCP/IP standard being addressed^{19, 20}. Advocates of simulation as a primary tool for curriculum design include^{21, 22, 23}. According to Engel simulations and demonstrations, though valuable, do not provide students with procedural skills such as how to actually install, maintain and manage a network²⁴.

However, it is possible to consider the PC and network technology from a different perspective. The PC is now a (relatively) low cost consumer item. This has been possible due to design and manufacturing changes that include: Assembly Level Manufacturing (ALM), Application Specific Integrated Circuits (ASICs) and Surface Mounted Technology (SMT). The result is PCs with a standard architecture and modular construction – so simple that high school students take them apart. However, traditionally computer technology education is typically based on digital techniques, small scale integration IC's, Karnaugh maps, assembly language programming etc. Operation on PCs at this level simply does not exist any more within the field of computer and network support. Valuable though simulation and breadboarding may be a typical PC support environment demands other knowledge and skills that include: upgrading PCs, fault identification and correction procedures, safety, ability to recognize different system architectures etc. Simulation provides no experience of practical problems such as inserting a new input/output card into a PC and the associated skills that are needed.

Procedural Skills – Conceptual Knowledge

The authors submit that that despite interest from students the standard curriculum in computer and network technology does not provide students with the opportunity to acquire the necessary skills recognized as either relevant to their needs or those of potential employers²⁵. This opportunity to develop technical expertise is an enhancement of theoretical knowledge. According to Cervero: *"the popular wisdom among practicing professionals is that the knowledge they acquire from practice is far more useful than what they acquire from more formal types of education"*²⁶. Cervero further argues that the *"goal of professional practice is wise action"* and that *"knowledge acquired from practice is necessary to achieve this goal"*²⁶. Both conceptual and procedural knowledge are necessary for professional practice. Procedural knowledge is knowledge *how* to do something. The 1991 ACM/IEEE-CS report states that, *"undergraduate programs should prepare students to apply their knowledge to specific, constrained problems and produce solutions"*¹. A good case can therefore be made to provide students with the opportunity to perform workshop exercises such installing and maintaining networked PCs in an

environment that mimics standard commercial/industrial practices and is more directly relevant to student needs.

Curriculum Design – Computer Technology

At ECU a new curriculum was designed consisting of four units – Computer Installation & Maintenance (CIM) and Network Installation & Maintenance (NIM) both prerequisites to Computer Systems Management (CSM) and Network Design & Management (NDM). The units CIM and NIM were introduced first. The success of these two units led to the introduction of the other two units.

The unit CIM provides a practical, inter-disciplinary, problem oriented approach. Rather than lowering academic standards Professor Lowe, as cited by Armitage, argues, *"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"*²⁷. There are no unit pre-requisites for the CIM unit, hence one of the main problems is to control complexity as PC architecture can become complex very quickly. 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'. This has the consequence that '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"*²⁸.

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.

Rather 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.

Twenty-five IBM model 50z PCs were selected for two reasons. Firstly cost, they were decommissioned and obtained at minimum cost. Secondly, even though they are about 10 years old, they are highly modularised with only two connecting wires

in the entire machine - it is difficult to plug modules in the wrong way. They have, to date, proved to be an ideal 'trauma free' PC for this introductory unit thereby allowing complexity to be introduced in a safe and controlled manner. It is essential to be systematic with respect to workshop procedures; for example, always use an 'earth' strap and only change one variable at a time. Observation skills are needed; for example, never disassemble a device that you cannot reassemble and if necessary take notes. Safe working practices are mandatory. Accordingly a simple mnemonic was devised - 'Systematic Observation and Safety' (SOS). Experience to date has shown that all students could disassemble an IBM 50z, however about one third of all workshop groups could not initially successfully reassemble a PC. Quite simply they did not understand the principles of systematic observation. In this case they failed to ensure the edge connectors were properly seated.

Rather than consider the technical detail of one particular type of PC architecture, a range of PC architectures are used thereby ensuring vendor independent and generic maintenance skills. The principles of computer operation along with an emphasis on the skills associated with installation, fault diagnosis etc. provides skills that are readily portable between different PC architectures. Given the rapid changes in technology this emphasis on generic skills is a non-trivial issue.

It should also be noted that the students who claimed to have prior experience in this field damaged more equipment than the novices. Clearly 'self evaluation' of skills is inadequate. It was found that students must be given the opportunity to repeat many of the tasks in order to acquire the necessary skills. According to Cervero *"procedural knowledge underlies skilled performance, and that procedural knowledge is acquired through practice"*²⁶.

Commercial equipment is not designed for repeated disassembly and reassembly. Even with the most rigorous workshop practices, equipment was damaged. We submit that this can only be accepted as a natural consequence and budgeted for accordingly. The use of decommissioned equipment significantly minimizes this expense. After satisfactorily completing the basics, students were then required to work on a range of different and more complex PC's with extensive and complex cabling prior to using new equipment. A range of PC architectures were used: Intel (286, 386, 486) based Micro Channel Architecture (MCA), Industry Standard Architecture (ISA), Video Electronic Standards Association (VESA) Local Bus and Peripheral Components Interface (PCI).

An essential feature of the workshops is that not only are the PCs disassembled but also some experiments employ 'live' testing. It should be noted that even though two earth leakage detection circuits were installed (10 and 20mA) in the workshop such circuits may afford no protection to the individual when a PC is mistreated. Hence, 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 must always be considered. Accordingly, high tension devices, the VDU and power supply, are never opened.

One of the main problems that we have faced is that students are accustomed to 'soft systems' in which it is always possible to re-compile or use the 'undo' button in order to correct a mistake. This type of work is, however, very unforgiving and accordingly a fundamentally different approach was needed and must be taught. One wrong connection made during a live experiment can destroy a motherboard. It should be noted that all workshops were supervised.

All the IBM model 50z PC's were modified with 'switchable faults', designed and constructed 'in house', thereby allowing the controlled selection and de-selection of known fault conditions. Using these switches, discretely placed on the motherboard, it was possible to selectively enable a variety of fault conditions affecting : individual VDU guns (red, green and blue), horizontal and vertical synchronization, BIOS, keyboard, fan, floppy disc drive motor and index pulse.

The CIM unit is followed by a second unit, Computer Systems Management (CSM), in which students are introduced to more advanced technologies. Accordingly workshops include installation and testing of: Digital Video Disc (DVD), flat bed scanner, PC video camera, Infra-red communications link, Zip Disc etc. Other workshop exercises include establishing and testing a video conference communications link via a local area network. The workshops are based on typical Multimedia applications. It must be stressed that CIM is a pre-requisite to CSM. The equipment used in CSM is expensive, 'state of the art' technology. The prerequisite link helps to ensure that students are able to correctly handle expensive equipment in a safe manner. We suggest that even with the higher level units there is no requirement to teach electronics or digital techniques.

Computer Design – Network Technology

Novell have internationally recognized professional development program - the Novell Certified Network Engineer (CNE) which consists of a number of courses. The unit NIM is based on three courses from the CNE program i.e. Administration, Advanced Administration and Networking Technologies²⁹. The course Administration is intended for NetWare systems administrators responsible for the day-to-day operational management of the network such as basic network services, login scripts, file system management etc. Advanced Administration introduces more complex tasks that include planning the directory structure, tune performance and troubleshooting. The course Networking Technologies provides the basic concepts of network technology i.e. transmission media, OSI model etc. It must be stressed that the NIM unit is not simply a collection of three CNE courses. Rather the NIM unit uses Novell as the target Network Operating System for workshop exercises in conjunction with more theoretical lecture material. In the NIM unit workshops each pair of students are allocated their own client-server Local Area Network (LAN). At the conclusion of the NIM unit students are able to take three Novell courses. To study for these three Novell courses commercially would cost approximately \$A3,000. Students can therefore obtain commercial certification for university fees. The subsequent unit NDM is NT based and includes topics such as proxy server, DNS server, RAS server etc.

Laboratory Design and Technical Support

A dedicated laboratory for the units CIM and NIM was designed, constructed and equipped at an initial cost of \$A35,000. The extensive use of decommissioned equipment and the in-house development of switch faults significantly helped to reduce the cost. With this budget it was possible to provide each of the 10 workplaces within the laboratory with three different types of PC of increasing cost and complexity. For maintenance purposes it was found essential to have at least 15 of each type of PC. In addition to this class sets of equipment were provided (Network cards, CDROMs, PCI video cards etc). The CIM laboratory therefore consisted of 45 different PCs. For the NIM unit each workplace consists of a client (Intel 486), a server (Intel 486) and a ten-port hub i.e. a self-contained network. The cabling in the laboratory (Category 5, Unshielded Twisted Pair) allows all the hubs to be connected together to a switch or hub, located in a patch panel, and hence connected to the worldwide web with protection by means of a firewall.

At the conclusion of each two-hour workshop all the equipment must be checked and where necessary reconfigured. Experience dictates that two hours of support is needed between successive CIM workshops. For the NIM unit only one hour of technical support is needed between successive workshops. However experience has shown it is advantageous to allow two hours for maintenance hence allowing for the occasional, catastrophic failure of equipment. For all other units at ECU only the first hour of each workshop is supervised, for the second hour students are guaranteed access to the laboratory – but no supervision. During the semester they have unrestricted access to any vacant laboratories 24hours a day, 7 days a week. Given the nature of the CIM, NIM units, workshop access is restricted to the allocated workshop periods, all of which are fully supervised. Prior to the start of each workshop each pair of students must complete and sign a checklist of equipment. Students are not permitted to leave the workshop until the equipment is returned.

The number of students for CIM and NIM is restricted to eighty for each unit. This allows four workshops per unit with two students per workplace. The CIM lecture is given Monday evening (5-7pm) followed by a two-hour workshop (7-9pm). There are three workshops on the Tuesday (9-11am, 1-3pm and 5-7pm). The NIM lecture is given on Wednesday evening (5-7pm) followed by a two-hour workshop (7-9pm). There are three associated workshops on Thursday (9-11am, 1-3pm and 5-7pm). This arrangement allows the whole of Wednesday to remove the CIM equipment and replace it with the NIM equipment. Monday and Friday are used for change over and development work. Experience had clearly demonstrated that no other arrangements are possible, furthermore it is essential to have an adequate, secure and convenient storage location. The CIM, NIM curriculum is supported by a technician for 2 days full-time equivalent. The evening classes provide the opportunity for part-time students to attend these units.

The success of the curriculum was such that two other units were introduced (CSM and NDM). Accordingly another dedicated laboratory was designed and constructed at a cost of \$AUS 60,000 and operates on similar principles to the

CIM/NIM laboratory. However in this laboratory students are provided with 'state of the art' and hence expensive equipment.

Equipment must continually be replaced. Strict workshop practices minimizes, but does not prevent, damage and general 'wear and tear'. Given the rate of PC development many companies decommission equipment which typically can be obtained at no cost. The main criterion for selection is that for a given type of PC it is essential to have at least 15 identical machines thereby sufficient for a class set of PCs with spares. Both laboratories can be maintained with a budget of approximately SAUS 5,000 per annum. This is sufficient to replace items such as network cards etc.

Health & Safety

Arguably the most important theme in the CIM unit is Health and Safety - employees and employers have non-delegable legal responsibilities. The principles of Health & Safety are introduced at the start of the unit. The first workshop was concerned entirely with workshop practice and students were required to read both the university and workshop regulations - it was emphasized that misconduct would not be tolerated. Misconduct is taken to include failure to observe good workshop practice. Compulsory attendance at the first lecture and workshop were verified by a signed declaration. Failure to comply being an automatic disqualification from continuing the unit. Many students have little or no knowledge of legal issues. The unit therefore includes a lecture on law and technology in order to fully appreciate the significance and importance of Health & Safety legislation. After a brief overview of the legal system, the tort of negligence is addressed with reference to negligent misstatement. However, particular emphasis is placed on negligent acts and the associated Duty of Care and Standard of Care of both employee and employer. The examination has a compulsory question on health and safety worth 20%.

Results

The units CIM and NIM were piloted in semester 1, 1996. The majority of students who attended the unit CIM had never taken apart a PC - quite simply they were too intimidated by the complexity of a PC and were concerned about the consequences of making a mistake. Typical comments were *"I have never opened a PC before. I always wanted to but I was too frightened"*. The minority who had did so without knowledge of and due regard to good workshop practice to ensure safety both to themselves and the equipment. At the conclusion of the unit CIM students had the confidence and ability to disassemble, upgrade and perform first line maintenance on a PC to a professionally acceptable standard - they knew how to approach the problem, what you must always do and what you must never do. Whilst lacking in experience that comes with time, they could operate with safety in the role of computer support and solve the many of the more common problems. The majority of students who attended the unit NIM had never installed a LAN. At the conclusion of this unit students were able to install and manage a simple network. The initial quota of 100 students for the unit CIM was exceeded with 118 students enrolling and even then demand exceeding possible places. The student attrition rate was 8.5% with a subsequent unit failure rate of less than 10%. Since they were

introduction both units have always been oversubscribed, had a very low attrition rate, attracted students from other faculties and also other universities by means of cross-institutional enrolment.

An independent unit review of the CIM unit found: 80% would recommend this unit; 75% found the practical sessions useful; 70% found the unit relevant to their needs and 55% think this should be a compulsory unit. The majority of students enrolled were computer science majors with many in their final year. Three students were enrolled in an MSc in Computer Science. There were students from a wide range of disciplines and significantly, some final year B.Eng. (Computer Systems Engineering) students.

An educational expert independently evaluated the unit CIM in order to assess students' perceptions of the unit, the educational approach taken and the educational value of the unit. Interviews were conducted with students at the start and end of the course. Results presented here are from interviews conducted at the end of the course³⁰. Five students, chosen at random, were interviewed. Interviews were semi-structured consisting of a number of closed and open ended questions and respondents were encouraged to comment on any positive or negative aspect of the course and its effect on their learning. Students' responses were grouped into common themes, reported below and substantiated by quotes. All students perceived the unit as being very valuable. They thought it was "excellent, really good" and especially liked the "hands on stuff" and the "logical, sequential presentation of content". One student thought that "the practical side was really good and I learnt a lot". A fourth year engineering student described the unit as "very helpful" explaining that all the rest of his course was theoretical, with nothing practical dealing with the "components with which I have to work". He said, "I never see the component in the whole four years of my course" so to actually work with the components "was helpful to my understanding". He stated that this unit should be in first year "to help students visualise what they are working with". A business student described it as "a very good unit" saying "it taught me many, many things I did not know despite my background in information processing". Another student with a poor background in computing also liked the unit saying "It's a great unit, I liked it very much" and felt that he would "benefit very greatly from it". One student appreciated the way in which this unit effectively "demystified the machine and took me behind the scenes" and "gave an understanding of how computers work". All students stated that their understanding of computers and computing was increased by this unit. According to Maj, "Based on the above interviews it can be stated that this unit (CIM): is perceived as very valuable by students from different disciplines; supports learning in other units; increases students' understanding of computers and computing; generates a demand for further curriculum in this field; and is about right in terms of difficulty"³⁰.

Digital Techniques

According to the report of the 1991 ACM/IEEE-CS Joint Curriculum Task Force report computer science curriculum includes: digital logic and systems, machine level representation of data, assembly level machine organization, memory system

organization and architecture, interfacing and communications, and alternative architectures¹. The authors do not suggest that the bandwidth node model should replace the teaching of this traditional computer technology curriculum. Rather, it may serve as a useful introduction that provides both interesting and useful skills. This point is reinforced by Ramsden: *"Material should preferably be ordered in such a way that it proceeds from common-sense and everyday experiences to abstractions and then back again to the application of theoretical knowledge in practice"*³¹.

Conclusions

PCs now play a dominant role in commerce, industry and entertainment. In this context the standard computer and network technology curriculum designed for computer engineering and computer science students is in danger of becoming perceived as increasingly irrelevant – both by students and potential employers. This paper presents the results of implementing one possible solution to providing an introductory computer and network technology curriculum suitable not only for students from other disciplines but also as a basis for Engineering and Computer Science majors. The workshops of this new curriculum provide students with the opportunity to perform workshop exercises such installing and maintaining networked PCs in an environment that mimics standard commercial/industrial practices and is more directly relevant to student needs. Though more expensive than more traditional workshops it is still possible to be done in a cost-effective manner. The success of this new curriculum is such that since the first two units were introduced both units have always been oversubscribed, had a very low attrition rate, attracted students from other faculties and also other universities by means of cross-institutional enrolment. Furthermore demand has been such that two other units have recently been introduced with the expectation of the curriculum being expanded even further.

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3.2.2.2 Is a Practical Computer Installation and Maintenance Unit Cost Effective?

This paper (Cikara, Veal, Watson, & Maj, 2001) was presented at the UICEE 5th Baltic Region Seminar on Engineering Education, held from the 17th to the 19th of September in Gdynia Poland. The UNESCO International Centre for Engineering Education (UICEE) is based in the Faculty of Engineering at Monash University, Melbourne, Australia. The mission of the UICEE is to facilitate the transfer of information, expertise and research on engineering education. It facilitates International conferences worldwide where peer reviewed papers are presented and published. Although there are many topics that may be taught on-line, there remains the problem of the effective and safe provision of hands-on experiences in units such as CIM, as well as the need to provide an adequate and timely level of technical support. The nature and particular problems involved in the provision of the support is also described. Such units require specialised equipment, and this paper examines the cost and details of such provision. Also considered is the use of decommissioned equipment; setting up and repair time costs; inventory controls; development time, and student demand for hands-on units. The importance of providing sufficient bandwidth on the network during re-imaging times is also noted. This paper concludes with a cost benefit analysis.

Additional new understanding includes an up-to-date knowledge of the costs of running the hands-on unit, plus costings from a management perspective. It was found that there were higher overheads due to extra hardware and software provision. It was also found that effective and timely technical support on this unit is of critical importance, as is the knowledge of technical support staff in other areas in respect to copyright, hardware and software advice.

Is a Practical Computer Installation and Maintenance Unit Cost Effective?

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Introduction

A popular theory among practising professionals is that knowledge acquired from practise is far more useful than what they acquire from more formal types of education [1]. Ramsden notes that *"Many students can juggle formulae and reproduce memorised textbook knowledge while not understanding their subjects in a way that is helpful for solving real problems"* [2].

According to Goldsworthy, *"Skill refers to a person's ability to do something well. It relates to expertness, a practised ability, a dexterity in performing a task. It is an outcome that flows from knowledge, practise, inherent abilities and an understanding of the task to be performed"* [3].

Theory alone may be inadequate, so practical application and implementation can be applied to reinforce such skills. Professor Lowe argues, *"the complexity of the real world is more intellectually taxing than living in imaginary worlds of frictionless planes, perfectly free markets or rational policy analysis"* [4].

Computer Installation & Maintenance (CIM) is a single semester unit at ECU that enables students to gain employable skills and experience in this field, as determined by market-based analysis of potential employers within Western Australia [5]. Students acquire skills that are commercially relevant, and these can be highly regarded by prospective employers. It has a weekly two-hour lecture and an associated two-hour practical session.

Dedicated laboratories are required because students reconfigure, disassemble and assemble PCs [6]. Extra costs are incurred because safety and equipment concerns mandate that a tutor must always be present when there are students in these laboratories, which means that they cannot be in continual use by students or used for other units. Furthermore, the wide range of PC hardware used requires additional nearby storage space [7].

Effective and timely technical support is vital for this unit and normally takes place outside of the two-hour laboratory sessions. The setting up and repair time required for the technical support of laboratory sessions can vary considerably, requiring time flexibility from technical support staff. Such staff also need to take part in the ongoing development of the laboratories, as these units need regular updating due to the rapid advances in both hardware technology and software.

A test of the effectiveness of these units is that students who have successfully completed them should be able to undertake a technical support role. However, staff performing maintenance for the CIM unit may need to maintain contact with the school's regular technical support personnel. This enables them to solve problems requiring more extensive experience and so avoid expenditure of excessive extra time.

The extra ongoing costs entailed in providing this unit is offset by the extensive use of the school's own decommissioned equipment. The challenge is to provide students with extensive 'hands-on' experience without incurring extensive additional expenditure due to 'hands-on' student damage [5]. Maj has noted that: *"Students who claimed to have prior experience in this field damaged more equipment than the novices. Clearly 'self evaluation' of skills is inadequate. It was found that students must be given the opportunity to repeat many of the tasks in order to acquire the necessary skills"* [6].

STANDARD COMPUTER LABORATORIES

Computer Science laboratories are generally based on late model PC compatible systems, with a collection of applications ranging from Microsoft Office to graphical packages and Oracle. These are based on the server set up and deliver model, allowing for reasonably fast, efficient and cheap recovery after any student problem in a laboratory. The principal expenditure occurs up front in setting up the environment with the larger financial gains made with reduced maintenance costs.

Standard laboratories require backend imaging servers and a support network. The imaging servers are powerful Small Computer System Interface (SCSI) sub-system computers and are dedicated systems. They are used for different image deployment and do not get congested while workstation(s) pull down images of systems to reconfigure or install a workstation. The associated support network must also not get congested while workstations pull down an image. This requires a significant overhead and guaranteed availability.

Software installations (independent of imaging) can require the BIOS to be updated and the operating system, drivers and other applications to be installed. This process can take up to a week depending on applications and configurations needed. Once this infrastructure is in place, a complete reinstall for an entire lab from disk can take as little as 4 minutes, to a maximum of 1 hour, depending on software used and image size. This practise is executed on a weekly basis.

COSTING FOR A STANDARD LABORATORY

The set up costs for a standard teaching laboratory includes the computers (typically numbering 20 with identical hardware in each system), networking infrastructure, the backend servers as well as software and maintenance costs amortised over a two year period.

Hardware

The estimated cost of the hardware per workstation including the computer, backend servers and networking infrastructure is approximately \$4000 each, or \$2000 per workstation per year.

Software

Monitoring and imaging software, operating system and application software per unit is about \$2000 each or \$1000 per year.

Maintenance

Amortising the support salaries across the multi-campus and multi-laboratory environment results in a figure of \$25000 per annum per laboratory, or \$1100 per workstation (taking into account varying sizes of laboratories).

Total cost

The total estimated cost per workstation per year for support, upgrades and replacement is \$4100.

COSTING FOR A CIM LABORATORY

The CIM laboratory is specialized and is especially constructed for reconfiguration of computers. One would anticipate that the associated cost for such an environment would significantly exceed a standard computer laboratory. Maj notes that: *"in the CIM unit, rather than consider the technical detail of one particular type of PC architecture, a range of PC architectures is used thereby ensuring vendor independent and generic maintenance skills"* [8].

To remonstrate this, a range of PC architectures are employed, such as Intel (286, 386, 486 and 586) based Micro Channel Architecture (MCA), Industry Standard Architecture (ISA), Video Electronic Standards Association (VESA) Local Bus and Peripheral Components Interface (PCI). These include a class set of 10 machines and associated spares.

Hardware

To set up the workshops originally *"the CIM and NIM unit workshops cost AUS \$35K for the initial equipment plus the cost of technical support and a dedicated laboratory"* [9]. The school has an upgrade policy designed to keep the standard laboratories current with technology, with a major upgrade every two years. The CIM lab requires modern, rather than leading edge computers to support the activities undertaken in that environment. Using conventional write down calculations, the value of a two year old computer is approximately \$800 each, or \$400 per annum.

The CIM unit makes extensive use of decommissioned machines. The initial PC the students have contact with is the IBM 80286 based 50Z. This is due to its high degree of modularity and robustness, as well as the fact that they can be easily taken apart and put together. The student has the opportunity to: *"acquire necessary skills in applying correct levels of force and the manipulative abilities needed in the assembly and disassembly processes"* Furthermore: *"the choice of*

the introductory PC can have far reaching consequences with respect to the maintenance and longevity of the machines" [10].

The unit attempted to use modern machines as the introductory computer. In the first workshop, four of these machines were damaged, demonstrating the need for a simpler, more robust computer, hence the suitability of the IBM 50Z as the introductory computer. It was found that by steadily increasing the complexity of computers, the manipulative skill of the student also increases. The benefits of this approach have lead to increasing the longevity of machines and decreasing the severity of faults and hence the maintenance time required.

Additional components (for the more modern machines) are purchased new and are used to enhance and add to the workshop. This incurs additional expenditure to the written down value of these decommissioned machines. Therefore, an additional \$500 is allowed per CIM computer per year giving a capital hardware cost of in the order of \$900.

Software

Although minimal, there are still software requirements that need to be addressed, and standard licensing arrangements apply. This adds an average cost per CIM workstation of \$100 per year. This figure is minimised through the use of shareware or freeware programs and utilities. Expenses are reduced through the downloading, rather than the purchase of such programs.

Maintenance

Due to the intensive creation of hardware faults and set up activities by support staff, the laboratory has a slightly higher maintenance cost. An essential aspect of CIM is the disassembly and assembly of PC's. As students are inexperienced in such tasks, it has been noted by Maj that: *"all students could disassemble an IBM 50z, however about one third of all workshop groups could not initially successfully reassemble a PC. Quite simply they did not understand the principles of systematic observation"* Furthermore: *"the students who claimed to have prior experience in this field damaged more equipment than the novices. Clearly 'self evaluation' of skills is inadequate"* [6]. Consequently, enabling 'hands-on' student experience runs the risk of 'hands-on' student damage. It is only through systematic maintenance after each class that potential problems can be detected and rectified. Although the time invested in such activities can be large, the financial benefit can be offset through the replacement of components. It is noted by Veal that: *"Should too many donated machines of the same model be damaged then this could mean the loss of a class set. This could far outweigh the associated financial cost"* [10]. The annual cost per machine of physical maintenance is approximately \$2500 per workstation.

Safety

Safety is another facet that is of paramount importance in the labs, as directed by legal and university requirements. As a result, certain measures have been implemented to fulfil these obligations, such as the installation of Earth Current Leakage Detectors also known as Residual Current Detectors (RCDs) and fire

extinguishers. They are used comply with Occupational Safety and Health guidelines as well as safeguard students from potential hazards. These however do come with their own associated maintenance costs. RCDs are tested by the university electrical department and fire extinguishers are tested on a yearly basis. All these add to the costs of running the workshops.

Development

Due to the dynamic nature of technology, there is considerable demand for computer and network curricula to adapt to these changes, resulting in a never ending cycle of research and design. As noted by Maj, there is a significant lack of relevance of university curricula within the field of computer and network technology [5]. Therefore time must be set aside to continually improve and develop new workshops in reaction to student and employers' expectations and demands. Liaising with additional resources incurs added time involvement that provides highly beneficial results in terms of support structures and expertise. People involved can be roughly divided up into three main categories; lecturing staff and tutors, school support staff and other third parties.

Staff not directly involved in the unit, but who are experts in other areas, can provide a valuable pool of knowledge. Lecturers and tutors in subjects as Novell Netware, Windows 2000 and UNIX who have a good understanding of how such systems operate, and can provide valuable advice on the implementation of support structures for increased efficiency in maintenance.

School support staff are the primary source of advice and knowledge. Essentially the work that is performed in CIM is a subset of the jobs that they perform. They have the experience and expertise to complete the work, and so they are naturally the logical choice for information. Advice on hardware (pros and cons, information on existing hardware, etc) software (both as a source of programs, documentation and copyright information) as well as general maintenance suggestions are provided by these staff.

Other third parties mainly involve vendors and sales staff. These people have information on new products and technologies that are emerging. They are a primary source for data and pricing for these products. Regular dialogs with such people can greatly reduce the workload on technical support staff and make them aware of further emerging technologies in their field.

Inventory Controls

Efficient stock control techniques for all hardware and software are essential for future investment concerns. Auditing current stock levels as well as damaged stock can indicate an opportunity to modify a workshop to reduce hardware casualties or highlight possible areas for additional investment.

Implementing and maintaining a technical reference library is another consideration. In most cases, associated documentation arrives with the product. However, in the case where decommissioned equipment is used, documentation is inadequate or in most cases non-existent. Manuals, configuration data, or even

datasheets must be located in order for some equipment to become operational. There are other miscellaneous items that must also be referenced and archived. These can include device drivers, BIOS updates and test programs

Total Cost

The total estimated cost of a "hands-on" laboratory as CIM is around \$3500 per workstation per year amortised over a two year period.

STUDENT DEMAND

The CIM unit consistently achieves high demand with enrolments exceeding quotas. Student attrition rates are low (8.5%) as well as unit failure rates (less than 10%). There is cross faculty and cross institutional enrolment, high levels of satisfaction, with independent reviews finding 80% of students would recommend this unit [7].

Conclusion

Computers now play an increasing role in all facets of modern society. Standard computer and network curricula are increasingly irrelevant in commercial or industrial situations that require installation and maintenance. To cover this area of opportunity, specialized units that give students a greater practical component were introduced. Although it may be perceived that such a dedicated environment would have a significantly increased cost over a standard computer laboratory, this does not occur in reality. In contrast, various methods can be utilised, such as the extensive use of decommissioned equipment, to reduce the expense. The amortised cost over a two year period for a standard computer laboratory is \$4100 per workstation per year, while the cost for a computer installation and maintenance unit is \$3500 per workstation per year. We then conclude that the introduction of such a unit can compare favourably with a standard computer science laboratory.

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3.2.3 Physics and Maths

3.2.3.1 Mathematics Requirements on a Computer Technology Unit

This paper (D Veal, S. P. Maj, & G. I. Swan, 2001) was presented during a session of the mathematics division of the American Society for Engineering Education (ASEE) at the 2001 Annual Conference in Albuquerque, New Mexico USA. The ASEE is one of the leading engineering education bodies within the USA. Its annual conference is its leading venue for publication and presentation.

The unit CIM attracts a wide range of students which include both cross-faculty and cross-institutional enrolments from other universities within the Perth area. Its wide appeal across a broad spectrum of students has meant that many of those who enrol may not possess an appropriate technological, scientific, and mathematical background. Hence the need for a new pedagogical framework based upon B-Nodes. This framework required students to be able to solve simple formulae; convert to and from SI magnitudes and to transpose simple equations. The problem was that many students were unable to use basic mathematics and mathematical concepts to allow them to use utilise this model.

The need for basic mathematical skills and knowledge is considered as a significant percentage students found the above mathematical requirements problematic. The testing of students' mathematics on this unit, the results, and the reasons for the response chosen to address these problems along with the necessary mathematics required on this unit, are outlined.

The paper includes Constructivism as a starting point for the new model and points out student difficulties with basic mathematics in using the B-Node model and with bandwidth calculations.

Additional new knowledge includes problems that students that students on the CIM and NIM units have experienced in using basic mathematics in the context of understanding to operation of PC hardware and computer networks. There is also a consideration of the problems in implementing use of a simple abstract model with students experiencing difficulties with basic mathematics. The results of

student survey of how they would like the extra mathematics provided were this to be possible is included and the chosen method of delivery described. The problems associated with the chosen method of delivery are also described. In conclusion it was found that extra mathematical practice was required to enable some students to benefit more fully from the CIM and NIM units and that students wished this provision to take place within the normal workshop setting and time periods.

Mathematics Requirements on a Computer Technology Unit

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Abstract

Computer Installation & Maintenance (CIM) is a 'hands on' unit run by the Computing Science department at Edith Cowan University (ECU). CIM was designed and introduced as a direct result of an analysis of job advertisements in newspapers in Western Australia and interviews with potential employers in the field of computer and network installation and maintenance. This first level unit consists of a weekly two-hour lecture with an accompanying two-hour 'hands on' workshop, and does not have any mandated entrance prerequisites and yet CIM attracts a wide range of students, has been consistently oversubscribed, and attracts both cross-faculty and cross-institutional enrolments from other universities within the Perth area. Its wide appeal across a broad spectrum of students has meant that many of those who enrol may not possess an appropriate technological, scientific, and mathematical background. Hence a new pedagogical framework was required. However led to the use of a model required that students to be able to solve simple formulae, convert to and from SI magnitudes and to transpose simple equations. The need for basic mathematical skills and knowledge is considered as many students found the above mathematical requirements problematic. The testing of students' mathematics on this unit, the results, and the reasons for the response chosen to address these problems along with the necessary mathematics required on this unit, are outlined.

Introduction

Computer Installation & Maintenance (CIM) and are 'hands on' units run by the Computing Science department at ECU. This unit was designed and introduced as a result of surveys of job advertisements in papers in Western Australia. Subsequent interviews with potential employers in the computer and network support who had recently advertised for staff lead to a list of employer requirements. Testing of 10% of third year computer science students, who had successfully passed all of their previous units, subsequently revealed that none could fulfil these requirements¹⁴. Those who could partly fulfil the employer requirements had been self-taught. International studies have revealed that a similar situation also exists in other countries¹⁴. Similar findings were discovered from testing multi-media students¹⁵. CIM is a single semester first level unit. It consists of a weekly two-hour lecture with an accompanying two-hour 'hands on' workshop. During the CIM workshop students perform a set of tasks such as installing and testing hard drives, network cards, video cards, upgrading memory and simple faultfinding exercises. The CIM unit is an option within the ECU computing science degree requirements however it is a full credit unit. This unit has consistently been oversubscribed and attracts students both from other faculties

within ECU and from other universities within the Perth area. Students on this unit have included IS management students, Multi-media students,¹¹ as well as students studying dance and drama. The lack of any mandated prerequisites may have helped to widen the appeal of the CIM unit in attracting a broad range of students²².

Constructivism

As the CIM unit had no prerequisites it is necessary to proceed from the assumption that students had no previous computer hardware technology education. Constructivism suggests the starting point for the explanations was the student's own experiences. A top down approach was used rather than proceeding from basic electronics concepts upwards¹⁶. For example storage and throughput requirements are made initially from concepts such as files, and filing cabinets are equated with computer secondary memory. Freeways and slower roads are compared to computer buses and slower data paths within a computer. Students also note the changes wrought by upgrades and check these changes against expectations based on bandwidth considerations.

This is in line with parts of Constructivist theory that is based upon enabling students to build increasingly complex scaffoldings of understanding upon their current scaffolding. The Zone of Proximal Development (ZPD), which is the phase at which a task can be mastered given appropriate support.²⁴ Benson notes that "*Vygotsky*²³ claimed that the larger the zone the better students will learn in school"² Matching leaning tasks within student's ZPD is an important part of the teaching process from a constructivist viewpoint.

The B-Node Model

A new pedagogical model has been developed to enable students to compare and contrast PCs with different internal components using bandwidth nodes. Bandwidth or throughput calculations were seen as an important in enabling students to assess whether a computer has the appropriate hardware configuration to handle a particular job. The underlying measure of bandwidth enables a minimum performance criterion that is independent of the underlying technological implementation¹⁶. Likely bottlenecks can be detected found via a sequence of B-Nodes where obvious 'weak links' can help highlight potential problems.

B-Node models are independent of the basic underlying technological implementation. This is analogous to the use of digital logic gates symbols. Digital logic gates may be based on electromagnetic relays, thermionic valves (or tubes), discrete transistors, or silicon chips. Hence using the B-Node model means that students do not to relearn the underlying digital electronics for every major change in technology. Such methods could be especially useful for multimedia and business studies students. B-Node analysis is achieved via calculations of throughput or bandwidth. However, this requires that students are able to solve the associated mathematics. From the results of a student questionnaire 37 out of 40 students thought that B-Nodes should be taught on the CIM unit.¹⁶ A significant advantage of the B-Node model is that simple and meaningful diagrams can be used. Circuit diagrams, even at the chip level, can be confusing for students with little previous technological education.

Student Difficulties on the CIM Unit with Basic Mathematics

Staff on the CIM unit noted that students were having difficulties with basic mathematics in particularly in the area of bandwidth calculations and number base conversions. Particular problems included:

1. Rounding, significant figures and decimals places.
2. Estimation ("Ball park" figures to detect obvious errors)
3. Standard scientific notation in particular, and indices in general.
4. Binary, hexadecimal to denary conversions.
5. Simple transposition of formulae.
6. Derivation of a result given facts about the storage or transmission rates of data.
7. Being able to solve problems using appropriate formulae.
8. S.I. units. Appropriate use of SI magnitudes such as Giga, Mega, nano etc.

These findings were in line with the findings of Armstrong and Croft who noted that: *"Many entrants to undergraduate mathematics dependant programmes are being disadvantaged because they lack sufficient skill in basic mathematical techniques"*. And that: *"University tutors should not assume that all their students have wide-ranging basic knowledge and skills in mathematics"*¹. The following example illustrates the type of calculation that students are required to undertake. It should be noted that the concept of bandwidth used here is bits or Bytes per second and not Hertz or Mega Hertz from Telecommunications theory.

*"Bandwidth = Clock x Data Path Width x Efficiency. The early Intel 8088/86 required a memory cycle time of 4 clocks cycles (Efficiency = ¼) however, for the Intel 80x86 series, including the Pentium, the memory cycle time consists of only 2 clocks (Efficiency = ½) for external DRAM (Results, 1999). A 100MHz Pentium, with a data path of 8 bytes has a therefore bandwidth of 400Mbytes/s"*¹⁷.

In regard to performing such calculations it was implicitly assumed by staff on the CIM unit. However, the assignment and examination results strongly indicated this was not the case for a significant number of unit participants.

The Bandwidth Calculation Test

In order to quantify potential difficulties in performing bandwidth calculations by students, a short test was given. This involved the use of scientific notation, Units, significant figures, the use of basic formulae and SI magnitudes. A total of 46 students took part, which was approximately 50% of the students on the CIM unit. The mean mark was 60% however as the test was designed to also test very basic calculations this result meant that there was a significant problem with regard to many student's mathematical skills and understanding in the areas covered by the test. The test was given to students before such topics were introduced in lectures to help to ascertain their knowledge and skills on entry into the unit. Only 31% of students tested could successfully state how many nanoseconds there were in a millisecond. Less than 30% could correctly state the number of bits in a Gigabit and only 15% could perform the necessary calculations to convert a periodic time to a frequency and frequency to a bandwidth measured in bits per second. However,

67% could correctly convert 1000 bytes per second into bits per second. Many students did not appreciate ideas of significant figures; others experienced problems with substitution or the choice of an appropriate equation. The students' calculations of bandwidth were noted, these involved converting between time periods and frequencies; frequencies to bits per second and bytes per second; multiplying the bandwidth for one line with the number of lines used to carry the data. Again many students experienced difficulty in converting between S.I. magnitudes. CIM students also require algebraic substitution and formula selection skills to assess whether particular power supplies were sufficient to handle the power requirements at particular output voltages. It can be concluded that most students had insufficient mathematical skills to enable them to benefit fully from their participation in the CIM unit. It was then decided to investigate possible methods to help overcome this problem.

Possible Solutions to the Lack of Basic Maths Skills

In order to attempt address the problem of lack of basic maths skills amongst many of the students on the CIM unit the following possibilities were considered:

1. A short maths unit.
2. Extra basic maths practice as part of lectures.
3. Extra basic maths practice as part of the workshops.
4. The use of Pre-recorded Material
5. The use of a computer based tutorial either via CDROM for pre-recorded tutorials, or via the web.
6. A drop-in Maths surgery.

A Short Maths Unit

A similar problem had arisen in respect to the possibility of an extra physics unit. It had also been discovered that students on the CIM unit lacked basic physics skills via a simply physics test and questionnaire²⁵. Asked whether they would like an extra basic maths unit most students replied that they did not wish to undertake an additional unit to help rectify this situation. This was due to:

1. The extra cost involved.
2. Not being able to fit in the lectures due to extra time available.
3. Not wanting to become involved in yet more study.

It was thought likely that a similar result would result in this case and so the question was not asked.

Extra Basic Maths Practice as Part of Lectures

As an additional part of the lectures there would be very little chance for staff to deal with individual problems as they arose. Furthermore, the quantity of detail covered by these lectures, partly due to the necessity of covering much of the background from a perspective of no previous technical knowledge, means that there is little or no time available for extra material.

Extra Basic Maths Practice as Part of the Workshops

Considerable time, effort and expense had gone into securing the workshop rooms facilities and maintenance support of two hour for each CIM workshop. This was in addition to the initial setting up and taking down periods at the start of a weekly series of sessions. If much of this time was to be spent in maths work then this could have been seen to use most of the time in such expensive workshops as not requiring these extra facilities. However, there was often some time available near the end or after such sessions. The time at the end as due to the fact that not all workshops took the same time and yet the longest was designed not to exceed the two-hour limit. The time after the workshop was available, as it would not otherwise be used, as there was a two hour checking and resetting time allowed for the technical staff to prepare for the next workshop. However, with some of the longer workshop session some students may need to take the full two hours normally available and the proposed extra maths practice could reduce the time available to spend on the practical exercises.

Pre-recorded Tutorials

These could include sound recorded sections talking students through the more difficult exercises and notes. An advantage of such an approach is that most students have ready access to a tape recorder. A major disadvantage is that it is not interactive. The Open University (OU) in the UK often used this approach. On some OU units the use of taped recorded audio as well as video instruction included self assessed questions as well as the use of reading material. However due to the both the size of the student base for many of the OU Units and the ability of this university to spend many staff hours for each student hour spent studying it was not felt to be an effective use of staff time to attempt develop such a system.

Computer-Based Tutorial

The computer based tutorial was not felt to be a possibility or from a staff point of view the development of Computer-Based Learning (CBL) materials was considered to represent a large input of extra effort that could be better spend in developments with respect to these units. However there are many commercially available packages that could have been of use. However cost and time constraints have initially limited investigation of these packages on the CIM and NIM units.

Caccetta et al have noted that: *"The problems encountered in teaching first year mathematics are not unique to Australia. Universities worldwide are utilising computer assessed learning to help overcome the problems"*. They further note that: *"Computer technology can be used both for diagnostics and for supplementary material for a unit"*⁴.

In a study of the use of a computer based tutorial system by Faye and Scott students noted that: *"The main advantage of the computer based tutorial in the students opinion was that the you could work at their own pace and the deadlines and strict monitoring forced students to complete work and stay up-to-date"*. They also mentioned the *"the ability to obtain help quickly"*⁶. Whilst Roisin Donnelly and Gorman have noted that:

"Each student can work at an appropriate level of difficulty and proceed in the lesson at a pace that is appropriate for them. Such individualised instruction is a significant feature of CAL." However, they go on to note: "The major weakness of the computer based tutorial identified by the students was the lack of help needed to make conceptual jumps and for understanding a concept thoroughly". Interestingly they found that: "While students felt comfortable in asking questions in both tutorials they were more comfortable asking questions in the computer-based tutorials" ²⁰.

Further research in developing maths multi-media tutorials in higher education by Harding, Lay and Moule noted the importance of being able to alter the sequence of student's viewing of material to encourage exploratory learning. This meant that the materials were arranged in small blocks ⁸. The courseware was designed to be used across a range of curricula and they note that video and sound clips can now be readily included thus gaining many of the advantages of pre-recorded materials as noted above. They also noted the importance of being able to provide a 'kit of parts' that "individual teachers can take apart and re-assemble in the order they wish" ⁸.

A Drop-in Maths Surgery

Armstrong notes that at Loughborough University "Drop in surgeries are open to all engineering students four afternoons and one evening each week during term time" ¹. Such surgeries can also expand the tutor's experiences with an extremely diverse range of students seeking help. The first author found when helping to run such a surgery in a further education college in the UK, and that the problems brought to his attention in the same session ranged from basic addition and subtraction to 2nd order partial differential equations. There was also a large variation in the usage patterns of this surgery by students. Some students would just come into the surgery as needed and leave when they had found how to solve particular types of problems. Other students would regularly attend each week and would work through exercises in the surgery and seek help if and when problems that they were unable to solve on their own.

A drop-in maths surgery would have needed to be a faculty, or campus wide, initiative. This would have required extra resources and reallocation of staff commitments within a short time frame, which may well have not been possible under the present prevailing circumstances. Furthermore with 50% of undergraduate assessment being via assignment, care would need to be undertaken to ensure that this facility was not used for answering assignment questions.

The Delivery Method Chosen

It was therefore concluded that each potential method of delivery of the basic maths theory and practice had its strong and weak points. From a practical short term feasibility perspective the mathematics was delivered via a short session at the start of the workshop period. A requirement was that this should not take up more than twenty minutes at most of the two-hour workshop. As much as was feasible the maths work was in the context of the work in the lectures and the practical session. However, some maths work had to commence well before the use of the topic in

the lectures due to the time needed for the students to gain familiarity with the subject matter. For the workshops, where it was thought that students would need most of the session to complete the practical work, the mathematics component was significantly reduced.

Initially during the maths section of the workshop periods, examples of binary and hexadecimal and denary conversion and their practical uses was undertaken. Then work on estimation, and significant figures were attempted. Exercises in scientific notation and conversions to and from SI magnitudes were given. Bandwidth calculations standing with basic time period to frequency calculations and bit to byte Megabyte and Gigabyte calculations were shown. Students then attempted to solve these problems in the tutorial group and simple transpositions of formulae. Although important, merely using drill and practice was regarded as insufficient and all problems were all given in the context of units and involved calculations that would be used in computer and network support. Problems, such as bandwidth calculations, were used to check on the minimum throughput requirements of PCs and could be used to compare and contrast some of the strengths and weaknesses of actual computer systems. The use of equations was demonstrated in situations likely to arise in the CIM unit.

The assignment results for the unit indicated that there was a significant improvement in student's abilities to calculate bandwidth compared with those of the previous year before the implementation of the extra basics maths teaching and practice. However this was not always the case as a minority of students were still not able to successfully perform the bandwidth calculations exercises. These students appeared to have problems in deciding what parts of the data in a given hardware specification to utilise in their calculations. A possible way of flagging such difficulties could be to give example questions as homework during one tutorial and show solutions during the following tutorial hence giving students a week to work on the problem and then checking student's progress. It should be noted that those who were experiencing difficulty during the tutorials had the opportunity to stay behind after the tutorial or could ask to see the tutor later, for extra examples and practice. However it was mostly the mature aged students who chose to attend these extra sessions.

Are there Fundamental Mathematical Requirements for School Leavers?

The problems encountered with students' level of basic mathematics on the CIM unit pose the following questions, which are a part of many basic maths debates:

1. What standard of basic mathematics should students possess on leaving school?
2. Should the main concentration in school maths education be on a practical sense or on an appreciation of the subject of mathematics?

However Keitel has noted that:

"Mathematics teaching can no longer be perceived as a bound to a model of transmission or broadcasting. New perspectives for the teaching and learning processes have to be developed, such as those offered by constructivist theory or

*the psychology of content-related activity. A dynamic view of mathematics and the teaching and learning of mathematics must replace the existing conception of mathematics as a series of compartmentalized tasks and prescribed actions"*¹⁰.

Keitel goes on to state that: *"Applications and structural insight, technological and systemic aspects are no longer regarded as contradictory aspects of mathematics education, as they were in some reform debates"*¹⁰. Furthermore, there have been many complaints internationally about students' deficiencies in basic mathematics³. Whilst McHenry has noted with respect to the quantitative understanding, that *"It is clear that this need for a workforce able to think quantitatively is much more of a challenge to school mathematics, science and engineering than the nurturing of the best students toward careers in mathematics, science and engineering"*¹⁷. Maybe these approaches need not be mutually exclusive. A major challenge for today's education systems are to be able to effectively serve a broad cross-section of student needs in the areas of mathematics, science, and technology. McHenry has also noted with respect to the lack of quality mathematics education reaching the broad mid-range of students: *"without such an outcome, the student must seek the opportunity of remedial mathematics education in college, trade school, or on the job. None of these is particularly satisfactory,"*¹⁷ Magrid, in an article entitled *"America's real skills shortage"* makes the point that maths is one part of a collection of basic skills increasingly required in the modern workplace: *"When thinking about future jobs, its important to focus on the basic skills of reading, writing and math, as well as increasingly important skills such as critical thinking and public speaking"*¹³.

However, deficiencies in mathematics can be seen as a wide-ranging problem from basic maths skills to mathematical understanding at a higher level such as amongst full time students in engineering faculties. Kumar notes *"It is the widespread opinion and belief among engineering faculty that undergraduates enrolled in any engineering field could be better prepared in mathematics when taking courses related to their professional field of study"*¹². In respect to students' basic skills and knowledge requirements Goldsmith and Mark note the need for mathematical literacy and that:

*"Literacy involves understanding mathematical principles; developing mathematical ways of thinking; and acquiring fluency with number, geometry and data. Students develop this literacy by activity doing mathematics, using their skills and knowledge to solve problems and to investigate mathematical ideas"*⁷.

However, there are problems with the notion of mathematical literacy. Pugalee notes that: *"Both in the United States and abroad, the task of creating a coherent vision of what it means to be mathematically literate has not been sufficiently realised"*¹⁸. Whilst Confrey notes that the call for an understanding of mathematics to prepare students to take part in technological based occupations different from those made previously: *"The call is for a technological workforce, and this call to my mind differs from either of the previous mandates those prepared to the preparation of mathematicians or to improving standards to create a quantitatively*

literate public". Confrey also notes that "this obligates us to view mathematics as fundamentally a tool"⁵.

Mathematics is used as a tool on the CIM unit and this is basically the approach that is taken. The aim on these units is not to provide a general understanding of basic mathematics, but to use only specific parts of the subject as necessity dictates. However, a higher level of mathematical literacy attainment by students enrolling on the units would, no doubt, help their understanding of some of the subject matter. No doubt this debate will continue. Students' motivation to learn mathematics can be of vital importance in the learning process, and when they are perceived as relevant to their needs, as on the CIM unit, they can be prepared to undertake the extra work and effort required.

Conclusions

Two new units were introduced based upon job advertisements, employee requirements. The teaching of mathematics was certainly not a part of the original intention of these units. However, due to a lack of basic mathematics skills amongst many of the students involved, it was found necessary to include some mathematics tuition as part of the unit. Basic mathematics was found to be an essential requirement of this technological based study. With these non-perquisite units extra mathematics practice was required to enable some to appreciate the numerical aspects presented in this unit. Such mathematics was also necessary to enable students to gain the understanding to successfully complete their assessed work and to be able to apply such skills in possible future employment. The use of computer hardware maths based modeling and calculation necessary for this unit could be undertaken from a converse direction by using 'hands on' experiences with computer hardware to demonstrate vocationally relevant uses of mathematics.

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3.2.3.2 Physics: Implications for Computer Technology

This paper (Veal, Maj, & Swan, 2000) was presented at the American Society for Engineering Education (ASEE), Physics and Engineering Physics Division 2000 Annual Conference, held in St Louis, Missouri, USA. The ASEE is one of the leading engineering education bodies within the USA. Its annual conference is its leading venue for publication and presentation.

The B -Node model coupled with the need for hands-on experiences in CNT education led to the requirement for students to understand basic physics principles. This research investigated the basic physics knowledge requirements on the CNT units Computer Installation and Maintenance (CIM) and Network Installation and Maintenance (NIM). The importance of health and safety is also discussed as are the problems for students on the CIM units in understanding formula derivation and application. CIM and NIM are compared to conventional networking and computer hardware units. Distinctive groupings of physics topics within the CIM and NIM units are listed and the results of physics test and survey are included. The CIM and the NIM units at ECU had implicitly assumed that student's possessed a basic knowledge of physics, which included basic electric circuits, voltage, electrical current, resistance, power, AC, DC and EHT as well as electrostatics and light emission. This was subsequently revealed to be unfounded.

In the CIM unit the effects of electrical current on the body is considered, as is application of magnetism in the operation of VDUs and HDDs. The results of a test based upon basic electric circuits had been administered to CIM students which clearly demonstrated that many students lacked sufficient physics knowledge in this area to fully support their learning. A questionnaire given to students revealed large variations in previous levels of physics education.

Given that students must work in a potentially hazardous environment, knowledge of physics was deemed important by the authors for students to understand the potential hazards underpinning Health & Safety practices. The importance of a basic knowledge of physics, particularly as a foundation for understanding technology and its curriculum implications are discussed. An outline of the use of the basic principles of physics on the CIM and NIM units is provided

which includes the use of the concepts of voltage current, resistance, power, AC, DC, EHT as well as the effects of electrical current on the body.

New knowledge includes the results of interviews with graduates as well as the results of physics test and survey which found that many students lacked sufficient knowledge of physics to enable them to benefit fully from the CIM and NIM units. Furthermore, distinct groupings were found within the student groups investigated in respect to their physics background with large differences in relation to their previous study of physics. It was found that there was a need for extra physics provision within the CIM unit.

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, 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.

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. Random selections 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.

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 success⁴ led to the subsequent development CSM and NDM.

The unit CIM provides 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 than 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 Armitage, 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 i.e. 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: *"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.

Physics

CIM and NIM attract students from a wide range of disciplines. The students differ greatly in respect to both their physics and technology backgrounds⁴. 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:

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 Extremely High Tension (EHT) devices is essential.

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 field is important in understanding monitor operation.

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.

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.

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 fiber optical cable, coaxial cabling and twisted pair cabling. An appreciation of electromagnetic radiation and sources of electrical interference is also considered as well as throughput calculations applied to computer networks.

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 to their hand and resulting in burns and scarring. 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.

Physics Education

A questionnaire developed 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 comparison purposes¹². 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 children¹¹. 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 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.

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 ¹³. In this study learners solved physics problems by working at a distance via a computer network and an audio link via pre and post test 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 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 real life contexts 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.

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 student's 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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3.2.3.3 The Use of an Oscilloscope as an Educative Tool on a Network Installation & Maintenance Unit

This paper (Veal, Maj, & Swan, 2001) was presented at the Experimentation and Laboratory Oriented Studies Division, American Society for Engineering Education (ASEE) 2001 Annual Conference, held in Albuquerque, New Mexico, USA. The ASEE is one of the leading engineering education bodies within the USA. Its annual conference is its leading venue for publication and presentation.

This paper discusses the critical importance of a good knowledge of networking for many types of computer work. It further notes student demand for knowledge of networking to improve job prospects. The NIM unit is described. However, this unit has no prerequisites and is a full credit unit that attracts students from a wide range of backgrounds many of whom may have had little previous education in technology or physics. Hence many NIM students have experienced difficulties in conceptualising effects such as signal degradation along media, or even what a wave shape or wave train represents when drawn on a board or displayed upon a Cathode Ray Oscilloscope (CRO) screen. The CRO was also used to measure voltages. Measurements of time periods were also subsequently used in frequency and bandwidth calculations. These investigations were undertaken as part of a normal NIM workshop, and effects such as signal attenuation, crosstalk, phase shifting, and pulse spreading were observed via CRO.

New knowledge includes the results of a survey gained after introducing students, many of whom were from non technical backgrounds, to the concepts of signal degradation via use of a simple CRO and signal generator, and by using other inexpensive equipment. These students were also introduced to CRO concepts such as time-base signal attenuation, crosstalk, phase shifting, and pulse spreading. A survey guaranteeing anonymity of participating students found that these students unanimously believed that the CRO should be included as a part of the NIM unit, and that most students thought that their understanding of the lecture material had improved as a result of the CRO exercises.

The use of the Oscilloscope as an Educative Tool on a Network Installation and Maintenance Unit

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Abstract

Network Installation and Maintenance (NIM) is a first year single semester unit in the School of Computing at ECU. This unit consists of a two-hour lecture and two-hour hands-on workshop. The creation of the NIM unit was based upon a survey of the needs of employers in the field of network installation and maintenance and its workshops consist of extensive hands-on exercises necessary to provide students with the initial practical background skills and understanding required. The NIM unit has no prerequisites and is a full credit unit that attracts students from a wide range of backgrounds many of whom may have had little previous education in technology or physics. Hence many NIM students have experienced difficulties in conceptualising effects such as signal degradation along media or even what a wave shape or wave train represents when drawn on a board or displayed upon a cathode ray oscilloscope (CRO) screen. The CRO was also used to measure voltages. Measurements of time periods were also subsequently used in frequency and bandwidth calculations. These investigations were undertaken as part of a normal NIM workshop and effects such as signal attenuation, crossover, phase shifting, and pulse spreading, were observed via CRO.

Introduction

The single semester, level 1 unit, Network Installation and Maintenance (NIM) is a hands-on unit that is based on employer expectations in the field of Computer and Network support. NIM's companion unit is Computer Installation & Maintenance (CIM) which was designed to fulfil the basic hands-on requirements where students need to make changes to the insides of PCs to upgrade machines or to replace suspected faulty machines. Prior to its implementation investigations had revealed that nearly all of the final year computing science students surveyed had failed to fulfil the employer-based requirements.⁴ Nelson and Morales have noted that:

"It is becoming evident that a good knowledge of networking is critical for success in many kinds of computer-based work. Understanding enough to be able to troubleshoot network problems could become a significant bargaining chip in the job market in the 21st century"⁷.

Whilst Molina III notes that:

"... we polled our junior and senior computer science students to see what they felt would help them most in a networking course. Students indicated that they desired to obtain an applicable knowledge of networking that would lead to immediate employment opportunities after graduation".⁶

NIM assumes the knowledge and experience of CIM however due to safety prerequisites internal change to the PC system are not undertaken on this unit as NIM students may not have attended the relevant CIM safety practical.

The economic and other problems associated with the delivery of a hands-on unit such as NIM is described by Veal et al.¹⁰ Maj has noted the importance of hands-on experiences in such units³. The NIM unit covers the installation of both clients and servers. During the NIM workshops students install their own server and client and link them together. Students assign right to users as the network administrator and then log on as various users to test their system. Shull and Vescovi have noted that: *"Unlike most physical sciences where laboratory instruction is accepted as integral to the student's education, data communications and networking are often taught without the practicality of the laboratory section"*⁸.

Each workstation consists of a client and a server although students can connect to two servers in the labs and also to the outside world via the Internet connection, when this is enabled by NIM staff. Each two-hour theory lecture is accompanied by an associated two-hour hands-on workshop where some of the ideas presented in the lecture can be put into practice.

Many NIM students had problems with bandwidth and throughput calculations typically leading to results in Megabits or Megabytes per second. The lectures also include information about network media such as twisted pair coaxial and optical fiber cabling. It was noticed by staff on the NIM unit that some students did not appear to have an appreciation of representations of the waveforms and of signals described in the literature and unit material. Students drawing signal sloping backwards confirmed such suspicions as this indicated that part of the signal was undergoing a time reversal. When questioned further on this matter it transpired that it was not due to poor artistic skills on the part of the student but rather a lack of understanding of the representation. Methods were sought to give students an understanding of the meaning of waveform representation. Simulation was considered as a possible candidate to fulfil this role. Simulation has been used for computer network education^{1,9}. However, Engel et al have noted that although the simulation approach can be valuable it does not provide students with some important hands-on skills and experiences². In keeping with the hands-on practical nature of this unit it was decided to use a Cathode Ray Oscilloscope (CRO) to demonstrate signal degradation after traversing network cabling.

The Use of the Oscilloscope

It was decided to make the initial introduction as simple as possible. The students were first given a demonstration of the use of the oscilloscope to measure simple low voltage torch light cells. With the scan set to a low frequency so that the students could observe the trace slowly traversing the CRO screen connection of

the CRO probes to the cell were made on broken. This showed the students that the CRO could be used to measure a voltage that varied over time. Using a signal generator set on square wave low frequency output extended this theme. Similarly sine and triangular waveforms at different frequencies and voltages were also demonstrated. The students then performed these measurements in small groups of three or four per group using a worksheet. The students were encouraged to read the same voltage using different Volts/Division settings so that the shape of the waveform was not seen as an absolute but depended on these settings. The students also made further changes in the Time/Division settings. They were informed that it may be more convenient to view a single wave or a wave train or to obtain a more accurate reading and that was why different settings were used. The students, to enable easier and more accurate readings, adjusted the horizontal and vertical shift controls. When this had been completed and the students had had some exposure to the CRO and signal generator necessary to investigate signal degradation in network cabling.

The Experiment with Unshielded Twisted Pair (UTP) Cabling

The use of the CRO to investigate waveforms travelling along computer network category 5 UTP cabling was used. This consisted of using 400 meters of cable would on a drum. There were 4 sets of twisted pairs per cable. A total of 4 stations were provided, each with a CRO and signal generator. Each set of students had a signal generator and a dual beam CRO. One beam of the CRO was used to observe the input signal to the cabling and the other beam was used to detect the output signal after it had travelled through the cabling. Each input or output set of twisted pairs had a 56 ohm resistor across them too help to reduced impedance matching problems. Two sets of twisted pairs were used one to carry the signal to the other end of the cable where it was joined to another twisted pair to carry the signal back down the cable drum so the signals travelled a total of 800 meters. Normally the recommended length used is a maximum of about 100 meters. It was found necessary to use such a large length of cabling because the signal generators gave a maximum signal of 1 MHz. This meant that to observe the signal attenuation and distortion it needed a much greater length than 100 meters. Two workstations used each reel of cable that decreased the number of components used for this exercise. The use of reels rather than long lengths of cable meant that there was no need to have cable draped around the room, which could have presented a safety hazard if they were, near to the floor or crossed walkways in the workshop. The use of two stations for one reel of cabling also allowed the students to observe the effects of cross-talk. One signal generator was set to a square wave output and another to a sine wave output at 10x its frequency. The resulting square wave output of the first signal could be clearly seen to have a sine wave of 10x its frequency superimposed. This was also attempted at a range of frequencies. The effects of pulse spreading and phase shifting of pulses were also observed and students were encouraged to try a range of different frequencies and to note the results.

Students needed a lot of initial help to find the traces on the CRO screen during the workshop. There were also some problems with connections many of these could have been avoided using soldered joints. The students were given a wiring diagram

and instructions to set up the required circuits and this also caused further problems even though the termination resistors were pre-fixed in the circuit

Questions from the Students

Some students asked questions such as: Will mobile phones cause interference in the cabling? They were then encouraged to turn on their mobile telephones and find out the answer. This did in fact lead to a marked change in the signal output observed on the CRO. This also led on to a discussion about coaxial cabling and shielding.

Other students asked why we used the terminating resistors? They were encouraged to get answers by adding or removing such effects from the equipment use and to note the results. They disconnected the resistors and observing the effects of the reflected signals. This led on to a discussion of the method of finding where a break has occurring in a cable by noting the traversal time of the signal to the break and its reflection back to the signal source. Why do we use twisted pair wiring? Again lengths of the twisted pair cabling was untwisted and the distorting effects on the signal observed

Yet another question was does the unrolling of the cable from the reel effect the signal transmission? These students were helped to unroll the cable and spread it around the room for a short time taking care to avoid walkways. The signal showed no major changes when about 100 meters were spread around the laboratory.

The Survey

A total of 21 students handed in the survey which in the form of a questionnaire. The students were asked to put down what they thought and not what they might think staff would wish to hear. No names were to be included on returned sheets and they were to be left in a part of the laboratory not under the direct observation of staff.

The survey included questions on the level of their previous education in physics. One of the survey questions asked if they could use the CRO to note observe the signal and most of the students who had studied physics up to University Entrance level that is TEE in Western Australia and A-level in the UK said that they had been able to do this. In fact most students had been able to achieve this but a comparison of the difficulties that students reported were less with those with a higher physics background, where prior experience with the oscilloscope would have been more common.

The questionnaire also asked if their understanding of the associated material in the lectures had improved. Again most stated that it had improved. Another stated that they now had more clarity when considering clock cycles and waveform shapes. When asked what they thought were the most beneficial aspects of the CRO exercise to them. One answered that they were lost and stated: *"Frankly I don't know what the workshop is all about"* and that there were *"cables running about everywhere"*. Whilst another thought that it gave them an *"understanding how signals distort in cabling"*, or even that the experience of the use of the CRO was

the most useful part. Whilst others thought that their increased understanding of the waveform shapes and the frequency calculations were the more useful parts of the exercise.

The students were also asked whether they thought that the CRO should be included in future workshops. The result was almost unanimously that it should be included. A student who had worked for a telecommunications company for nearly 14 years much of it spent using the CRO and associated equipment answered, not unsurprisingly, that the exercise had not improved his understanding of how signals are distorted in cabling or of the use of the CRO. However, he thought that the exercises were useful for students. He suggested that CROs should be used to investigate actual signals along the UTP cabling in the laboratory, as this would be an interesting exercise. It would also be more in keeping with the real world nature of the NIM unit. This student also suggested tracing the signals through the network cards in a PC. Although such conditions would have led to more complication, it is a tempting idea. Another student suggested that more time was required, and a single workshop was neither long enough to adequately understand the concepts presented nor to master the CRO operation.

Another student noted that they would have liked more explanation for the use of the terminating resistors. One explanation given was that they absorbed energy from the incoming wave to avoid too much reflection of the signal. A wave analogy with water waves could be attempted in future, with wave refraction caused by an obstacle, eg an impedance mismatch, whilst non-reflection could be regarded as a situation with no obstacle eg just the water e.g. no impedance mismatch. The output voltage of the reel of cable was tested by the first author for the full range of the signal generator input voltages and frequencies. This was to avoid the danger of a high voltage being caused due to the coiled cable in the reel.

Bandwidth calculations have been used to assist throughput estimation⁵. This gives results in kilobytes/second and megabits/second and megabytes/second using the fact that a square wave signal can be considered either in terms of bits/second or Hz. The initial conversion of time period to frequency conversions using SI magnitudes and scientific notation were also practiced and then the conversions to bandwidth undertaken by the students.

Conclusions

Not surprisingly the two hour workshop was somewhat rushed. A better scenario may have been to introduce the CRO and signal generator during one laboratory period and then to build upon this foundation in the subsequent session. Many questions and ideas for future consideration resulted from this relatively short exercise.

Both CROs and square wave generators capable of working at higher frequencies were required to more achieve greater realism when compared to an actual network. Furthermore, a range of cabling including untwisted pairs and coaxial would have allowed comparisons between the different types of transmission media to have

take place. However, at least a start has been made and further work is planned for the future.

Cross-subject cooperation between staff concerned with physics and computing science teaching has enabled use of equipment and ideas to span both subjects allowing for the development of a workshop that would have not been possible with the equipment normally used on the NIM unit. The cost of the material used was minimal. Even the reels of UTP cabling could be reused as it was not cut into pieces only the ends were used to attach to connection blocks and terminal posts.

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3.2.3.4 Measurement and Observation inside a PC

This paper (Swan, Veal, & Maj, 2002) was published in the journal the World Transactions on Engineering and Technology Education UICEE, Vol 1 No.1, in Melbourne, Victoria, Australia. This journal is published by the United Nations International Conference on Engineering Education. The UNESCO International Centre for Engineering Education (UICEE) is based in the Faculty of Engineering at Monash University, Melbourne, Australia. The mission of the UICEE is to facilitate the transfer of information, expertise and research on engineering education.

The paper includes a description of the development of the CIM unit at ECU in response to employers' expectations of computer science graduates, and the need for students to develop skills in this area. Previous studies by the authors had demonstrated that some of the CIM students typically lacked sufficient understanding in physics and mathematics to fully support their learning in this unit. Some students lacked appreciation of representations of the waveforms and of signals described in the literature and unit material. Students drawing signals sloping backwards confirmed such suspicions as this indicated that part of the signal was undergoing a time reversal. Further enquires by staff found that this was not due to poor artistic skills but indicative of a misunderstanding of the representation used. The authors' trialled a range of practical workshop activities designed to improve their physics and maths skills within a CIM context. These activities ranged from simple readings of disk power plug and ISA bus DC voltages, to measuring the time period of ISA bus clock pulses and using this result to calculate frequency and bandwidth. Observations and measurements of the monitor synchronisation pulses also led to calculations of frequency and bandwidth. This approach is in line with the general philosophy of the CIM unit where both practical and theoretical exercises to help promote mutual reinforcement. Students are required to use a Cathode Ray Oscilloscope (CRO) to make these observations and measurements. Although almost all students had never used a CRO, they were able to obtain meaningful results after some brief orientation tasks. This work is an

example of cross subject cooperation between physics and computing science staff at ECU.

Additional new knowledge includes the results of students measuring a PC's local bus voltages and frequencies, as well as calculating the bandwidth of the data carrying capacity of the bus. The students also measured the synchronisation pulses for the vertical and horizontal sweep frequencies on the PC's VGA output. These readings were undertaken by students on a CS unit, many of the students came from a non-technical educational background. Student opinions with regard to the usefulness of these exercises were found via an anonymous survey given in the workshop after these exercises had been completed. There was an overwhelming positive response to their experience with the CRO and its use in the CIM laboratory. Most students thought that the CRO improved their understanding of how CRT computer monitors work.

Measurement and Observation inside a PC

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Abstract

At Edith Cowan University, a Computer Installation and Maintenance unit (CIM) was developed in response to employers' expectations of computer science graduates, and students' need to develop skills in this area. Previous studies have shown that these students typically lack sufficient physics and maths to properly support their learning in CIM. We began trailing various practical workshop activities designed to improve their physics and maths skills within a CIM context. These activities range from simple measurements of power plug DC voltages, to observing and measuring the period of clock pulses on an ISA bus, and then calculating the frequency and bandwidth. Observations and measurements of the monitor synchronisation pulses also led to calculations. This approach is in line with the general philosophy of the CIM unit where both practical and theoretical exercises to help promote mutual reinforcement. Students are required to use a Cathode Ray Oscilloscope (CRO) to make these observations and measurements. Although almost all students had never used a CRO, they were able to obtain meaningful results after some brief orientation tasks

Introduction

The last decade has seen a rapidly increasing demand for trained computer professionals with the widespread adoption of PC's by business and community organizations. However some of the skills required by employers are not provided by university computing degrees [9]. In particular, many employers demand practical skills in installing software and hardware as well as fault finding and maintenance of PC's.

A single semester Computer Installation and Maintenance unit (CIM) was developed at ECU to meet this demand [7]. It is regularly oversubscribed and enjoys high student approval ratings. The unit has no prerequisites (apart from normal university entry) and adopts a practical top down and problem orientated approach where the PC is considered as a collection of inter-related modules. Each module is looked at in detail appropriate to a first year unit and first line maintenance objectives. "First line maintenance" may be taken to mean on-site, in-situ problem identification and correction – the faulty module is identified and replaced. CIM consists of one two-hour lecture and one two-hour "hands on" workshop each week.

The workshops require students to take the cover off a PC to install and test a range of components (eg a CD-ROM drive). In particular they provide a supportive

environment where students can gain practical skills, experience, knowledge and confidence.

The results of surveys undertaken by staff on the CIM unit indicate that CIM students perceive the workshops as a very important part of this unit. The most recent such anonymous survey discovered that 51 students found the workshops very useful, 45 found them to be useful, 4 were neutral, whilst 1 noted that they were not useful and none found the workshops useless. Moreover most students wanted more practical and also thought that the practicals helped them to understand the theory aspects of the unit.

Physics Concepts

Physics concepts underpin a range of topics covered in CIM lectures and workshops including occupational health and safety. Following concerns that many CIM students were not demonstrating a rudimentary knowledge of school physics, a questionnaire was administered to ascertain their background in physics and test their understanding of simple electric circuits. A slim majority of students indicated that they had no physics above lower secondary school science. Although the questionnaire tested concepts and skills normally taught at this level, most students (including some with upper secondary school physics) recorded a poor result [13]. Unfortunately, this was in keeping with research that suggests that students often have difficulties with these basic concepts and some misconceptions are widespread [1,2,4,6,11].

In keeping with this, it was noticed by staff on the CIM unit that some students did not appear to have an appreciation of representations of the waveforms and of signals described in the literature and unit material. For example, students drawing signals sloping backwards confirmed such suspicions as this indicated that part of the signal was undergoing a time reversal. When questioned further on this matter it transpired that it was not due to poor artistic skills on the part of the students but rather a misunderstanding of the representation being used. Methods were sought to give students an understanding of the meaning of waveform representation. Hence there was a need to address the physics needs of CIM students within the CIM unit. The development of teaching strategies and materials is an ongoing collaborative project between physics and computer science staff at ECU.

Power Supply and ISA Bus Measurements

The ISA bus in common with many computer buses carries a combination of data, control, and power supply lines [3]. The oscilloscope was used by students to investigate the waveform of the DC supplies provided, hopefully a straight flat line, and to note the different voltages +5V, +12V, 0V, -5V and -12V. The students could also observe that these are the same as those provided by the PCs internal power supply plugs for the floppy and hard disk drive electrical power requirements

Many students had problems in converting between time periods and frequencies or imagining how such information might be used. Calculations involving frequency

and time periods were used in bandwidth calculations undertaken by students to indicate performance bottlenecks due to computer hardware limitations.

The following example illustrates the type of calculations that students are required to undertake. It should be noted that the concept of bandwidth used here is bits or bytes per second and not Hertz or Mega Hertz from Telecommunications theory. Bandwidth can be regarded as given by the following formula: $\text{Bandwidth} = \text{Clock} \times \text{Data Path Width} \times \text{Efficiency}$. *"The early Intel 80386 required a memory cycle time of 4 clocks cycles (Efficiency = 1/4) however, for the Intel 80x86 series, including the Pentium, the memory cycle time consists of only 2 clocks (Efficiency = 1/2) for external DRAM"* [12]. A 100MHz Pentium, with a data path of 8 bytes has a therefore bandwidth of 400Mbytes/s [8].

It was decided to allow students to observe the waveforms of the ISA bus clock line using the oscilloscope. The clock line was chosen because it would trigger the oscilloscope with an almost constant frequency to give a visible constant trace on the screen. The oscilloscopes could measure frequencies up to 20MHz and the ISA Bus clock bus frequency is 8.33 MHz [5]. Hence this frequency was within the capabilities of the 20MHz oscilloscopes used for measuring the frequency although not for accurately determining waveform shape. A rule of thumb measure indicates that at least 10x the frequency limit for sine waves is required for accurate square wave observation. The lack of suitable square wave generators of appropriate frequency further limited our testing of the ability of our CROs to accurately display 8MHz square waves in this respect.

Old decommissioned machines were utilised to avoid damage to our more modern PCs. This ensured that even if the oscilloscope probes shorted circuited any power carrying pins then it would not matter even if these machines were destroyed. The only spare PCs fulfilling these criteria were not of the same type. However, nearly all PCs possess an ISA bus and this provided common platform from which to obtain readings.

The use of the oscilloscope in this workshop was as a learning tool and not as part of their future likely employment in the CIM field as this unit covers only first line maintenance modular replacement is used. The use of such CROs to detect component malfunctioning is therefore unnecessary. This workshop provided the opportunity for students on a computing science unit to observe for themselves that what their text books and unit staff had informed them was correct by noting readings and making measurements. Such experiences are common in other science subjects.

With respect to the ISA bus Messmer notes that *"The bus frequency is generated by dividing the CPU clock, thus the ISA bus largely runs synchronous to the CPU"* [10]. As the ISA bus regularly resets its frequency students experienced problems in obtaining a stable trace. However, with a little perseverance and minor adjustments of the oscilloscope fine time base controls the resulting waveforms could be viewed with not too much difficulty.

It was important that staff are available to obtain a trace in case of difficulty. When students first start to become familiar with the CRO it is possible for them to be unable to find the trace and having a staff member on hand to show them how to locate it can assist students to gain confidence.

Student Workshop Activities with the CRO

Activities using a CRO (Cathode Ray Oscilloscope) were incorporated into two successive CIM workshops. About half an hour of each two-hour workshop was allocated for each CRO session and students normally worked in groups of three. In each CRO session, students were given a detailed work sheet to guide them through the various activities. The demonstrator was on-hand to help students through these activities.

During the first workshop students undertook activities to familiarise themselves with the basic functions of a CRO. These were to measure both DC and AC voltages, and to measure the period and see the shape of various periodic signals. In the first part students adjusted both the voltage and time scales in measuring the voltage of a household battery (1.5V DC).

In the second part, a frequency generator was used to produce various periodic signals for students to see and measure both voltages and time periods. In particular, students gained practice in calculating frequencies from the measured time periods. For many students this was a difficult task as it involved the use of prefixes and scientific notation. This problem has been identified and is currently being addressed. Students were also able to pick up and measure the period of noise in the wire from the 50Hz AC mains electricity in the room.

In a second workshop, students connected a fine voltage probe to the CRO and measured signals inside a computer where they measured some DC voltages. First they identified the colour of wires coming out of the power supply, and then measured the DC voltage of each corresponding power plug. Attention was then turned to the ISA Bus and its DC voltages were then measured.

Students were asked to observe the ISA bus clock signal and measure the period, calculate the frequency and finally calculate the ISA bus bandwidth. The period of the ISA bus clock signal should be $0.12\ \mu\text{s}$ giving a frequency of 8.33 MHz. Measurements for the period between $0.1\ \mu\text{s}$ and $0.2\ \mu\text{s}$ were common although many students did measure the anticipated value of $0.12\ \mu\text{s}$. Students then calculated the bandwidth for the 16 Bit ISA Bus (using an efficiency of 0.25). During the remainder of this workshop students looked at both ISA as well as the PCI bus architecture.

Evaluation of Workshop Activities

At the conclusion of the CRO activities, nearly all students completed an anonymous questionnaire on their experiences. They were asked to agree (or strongly agree) or disagree (or strongly disagree) with a number of statements, and were then invited to make comments on any benefits and difficulties encountered with the activities. Forty students completed the questionnaire and they were

overwhelmingly positive about their experiences with the CRO in the CIM workshops. Over three quarters of noted that time spent using the CRO was worthwhile; that the CRO activities should be incorporated in future CIM workshops and that their understanding of period and frequency had improved. Furthermore 90% of students agreed or strongly agreed that they were able to use a CRO to measure voltages and periods inside a computer. This was in agreement with our observations of these students at work.

The CRO is an instrument that students' do not have a hands-on encounter until tertiary level physics and only 13% of students had any physics at tertiary level. Indeed 42% of the students surveyed had no physics at school past compulsory general science at year 10. Designing a set of activities that would enable students from non-physics backgrounds to be able to use a fairly complicated instrument in a meaningful way in a relatively short amount of time was a major challenge.

Responses to the open ended questions that asked for the most beneficial and most difficult aspects of the activities covered a wide range of replies that probably reflected the diversity of educational backgrounds involved. However, seeing was the most common benefit followed by measuring with responses like *"to see the actual signals (instead of assuming them)"*, *"being able to measure frequencies and periods"* and *"being able to see the voltages of different pins"*. The most common difficulties experienced by the students were in reading or adjusting the CRO, the mathematics involved, or even in attempting to keep *"steady hands"* when taking measurements using the CRO probes.

The results of the survey were consistent with our observations during the workshops. Students were challenged by these activities in many ways, but with the assistance of their peers or the demonstrator, they were able to work their way through to the desired outcomes.

Consolidation and Extension

Buoyed with the success of the CRO activities these were consolidated into one workshop session and extended to include a new activity on monitors in the following semester. In this new set of activities, students probed the monitor outlet socket of a PC to view signals from the vertical and then the horizontal synchronisation pins in a VGA monitor socket. The pins were probed with partially opened up paper clips of the required thickness (using Sellotape as insulation) and attached to crocodile clips that fed the signal into the CRO.

The students measured the vertical and horizontal time periods, so they could calculate the vertical and horizontal synchronization frequencies and then the number of frames per second, and lines per frame (although the latter can be obtained directly from the time periods). The vertical synchronization frequency is the number of frames per second, and the number of lines per frame (which depends on the software display mode chosen) is given by dividing the horizontal synchronization frequency by the vertical synchronization frequency. Students who rapidly completed the tasks were given the option to change the screen display

resolution and observe the corresponding change in line and frame rates from a second measurement of the vertical and horizontal time periods.

At the conclusion of the workshop, nearly all students completed an anonymous questionnaire on their experiences, which included the relevant questions from the previous semester for comparison, plus two questions on the new monitor activity. The results for this semester were more positive than those previously obtained. In particular, students were stronger in their beliefs that time spent using the CRO was worthwhile and should be incorporated into future CIM workshops. After completing the monitor activity, over three quarters of the students agreed or strongly agreed that their understanding of how monitors produce pictures had improved.

Conclusions

Students require some knowledge of physics to be competent in installation and maintenance of computers. Cooperation between computer science staff involved in the CIM unit and physics staff has enabled students in CIM access to class sets of expensive equipment. Collaboration between these staff has allowed for the development of strategies to address students' physics needs in the context of CIM. The use of the CRO to measure voltages and time periods on an ISA bus is an example of how such collaboration can improve the experiences of students.

It should be noted that this collaboration has worked in both directions and physics students have also undertaken similar tasks in the CIM workshop to help improve their skills and appreciation of the practical importance of basic physics understanding to modern technological devices such as the PC. These tasks were modified to take into account the physics students' greater knowledge and experience of the CRO and probable lesser experience of the internal workings of a typical PC.

Although taking measurements and making observations is common for students in science units, this is not often the case in computer science units. However, it must be stressed that the CRO is used in the CIM unit primarily as a teaching aid and is not intended for diagnostic use. CIM students found the CRO activities worthwhile and were able to use the CRO to measure voltages and time periods.

For work on higher frequency buses such as the PCI bus and to effectively observe square waves on the ISA bus higher frequency CROs will be required to enable extension of this work to be extended to higher frequency buses and to provide reliable images of waveforms under investigation.

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3.2.4 B-Nodes

3.2.4.1 Is Computer Technology Taught Upside Down?

This paper (Maj & Veal, 2000a) was presented at the American Society for Engineering Education (ASEE), Computers in Education Division 2000 Annual Conference, held in St Louis, Missouri, USA. The ASEE is one of the peak engineering education bodies within the USA. Its annual conference is its leading venue for publication and presentation. This paper considers the 1991 ACM/IEEE-CS Joint Curriculum Task Force set benchmarks for award accreditation and provides the foundations of computer science curriculum, which identifies and recognizes the 'need for diversity and well-intentioned experimentation in computing curricula'. Computer Science is a relatively new discipline and given the rapid advances in technology is subject to on going debate, development and fragmentation. It is typically the requirement of many disciplines, such as multimedia, software engineering, e-commerce etc to incorporate computer technology as part of their curriculum. However, a detailed market analysis within Australia clearly indicated that both students and employers perceive the standard computer technology curriculum as increasingly irrelevant. Also included are results from an international study.

New knowledge presented includes the B-Node model presented as part of the move towards increasing levels abstraction in terms of computer hardware education. The B-Node model is extended in terms of bandwidth sources and sinks. There is also a consideration of the problems of only using simulation on the computer and networking technology units such as CIM and NIM. B-Node concepts are extended with suboptimal conditions enabling greater details of technical complexity to be considered via this approach.

The B-Node model is evaluated as a possible pedagogical framework for teaching engineering education in particular and its scope of application increased by considering its application to microprocessors, DRAMs as well as buses and chip sets.

Is Computer Technology Taught Upside Down?

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Abstract

There has been a continuing fragmentation of traditional computer science into other disciplines such as Multimedia, e-commerce, software engineering etc. In this context the standard computer technology curriculum designed for computer science students is in danger of becoming perceived as increasingly irrelevant – both by students and employers. The authors review expectations of both students and employers, as determined by market analysis, and present the results of implementing one possible solution to providing an introductory computer technology curriculum suitable not only for students from other disciplines but also as a basis for Computer Science majors.

Keywords: Computer Technology, Constructivism

Introduction

According to the 1991 ACM/IEEE-CS report, *"The outcome expected for students should drive the curriculum planning"*. Within Western Australia an exploratory market audit was conducted of a wide range of companies. From this survey a set of guidelines were developed for the type of skills expected of computer science graduates entering the field of computer and network support. Using the criteria developed a random selection of ten, final year Edith Cowan University (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"*. [11]

Interviews conducted with five ECU graduates employed in computer and network support 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"*. [20]

The initial ECU student questionnaire, first used in 1993, was also conducted in 1999 at two universities within the UK. Both universities have well established degree programs that are BCS accredited. The degree programs offer students the opportunity to examine a PC in the first year however they never take a PC apart.

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. The survey indicated that any practical knowledge students have of hardware is largely a result of experience outside the course. Furthermore, there is considerable potential demand from students of other disciplines for instruction in computer technology. According to a study of Multi-media students by Maj, *"It is significant that every student interviewed expressed the view that it would be extremely beneficial to have a much better knowledge of computer and network technology"* [10]. A demand that traditional courses in computer technology may not be meeting.

Computer Technology curriculum

The problems associated with teaching computer technology are not new. Mainstream computer science education is well supported by journal articles on various aspects of re-programmable hardware for educational purposes [7] and assembly language [6]. Simulation has proved to be a very useful tool [8], [18], [3]. Reid [16] used laboratory workstations to allow undergraduate students to *"build a complete, functioning computer - in simulation"*. Pilgrim [15] took an alternative approach in which a very small computer was designed in class and bread-boarded in the laboratory by students using small and medium scale TTL integrated circuits. Thereby, according to Pilgrim, providing students with the *"knowledge and experience in the design, testing and integration of hardware and software for a small computer system"*. According to Parker and Drexel [13] simulation is a preferred approach but note that students often do not see the 'big picture'. The difficulty of providing a suitable pedagogical framework is further illustrated by Coe and Williams [5] who address this problem by means of simulation. Barnett [1] suggests that standard computer architecture is too complex for introductory courses. However, the PC is now a low cost consumer item due to design and manufacturing changes. The result is PCs with a standard architecture and modular construction. However, traditionally computer technology education is typically based on digital techniques. Operation on PCs at this level simply does not exist any more. Valuable though simulation and breadboarding may be a typical PC support environment demands other knowledge and skills that include: upgrading PCs, safety, ability to recognize different system architectures etc. This problem is exacerbated not only by the constant and rapid changes in technology but also the requirement to teach computer technology to students from a wide range of discipline such as multimedia. The authors therefore attempted to find an alternative approach to teaching introductory computer technology.

Constructivism

Prior to examining how to improve student learning we attempted to attain a deeper understanding of how students learn and construct knowledge. Constructivism is the dominant theory of learning today. According to Ben-Ari, *"it can provide a new and powerful set of concepts to guide our debates on CSE (Computer Science Education)"* [2]. According to this theory students have their own cognitive structures each of which is the foundation of the learning process. A PC is

understood very differently by Computer Science and Multimedia students. Failure to recognize this results in fragile and incomplete learning in which new knowledge is merely a collection of facts to be memorized [19]. We attempted therefore to find a common conceptual framework held by students, from different disciplines, as the basis for a cognitive structure.

The PC – A Constructivist Nodal Model

We suggest that it is a common experience to perceive the PC as a modular device (CDROM, Zip Drive, Modem etc) used to store, view and process either local or networked data. The traditional method of teaching computer technology (digital techniques, assembly language etc) is not a good constructivist approach. According to Scragg [17] *"most (perhaps all) first courses in computer hardware are created 'upside down' - both pedagogically and pragmatically"*. This has the consequence that *"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"*. Accordingly Scragg recommends a top down approach starting with material already familiar to students and then working towards less familiar models. Clements suggests that a PC may be considered as a loosely coupled Multiple Instruction, Multiple Data (MIMD) device [4]. A PC is therefore a complex collection of heterogeneous devices interconnected by a range of bus structures. However, from a user perspective, a PC is a low cost, storage device capable of processing data. In this context we therefore define a PC as a MIMD architecture of sub-units or nodes. Each node (microprocessor, hard disc drive etc) can be treated as a data source/sink capable of, to various degrees, data storage, processing and transmission. This simple model may provide a suitable conceptual map and hence the framework for an introduction to computer technology. This model is conceptually simple; controls detail by abstraction and may allow students to easily make viable constructs of knowledge based on their own experience. However, to be of significant value this model must also be a tool that can actually be used by students. We therefore examined PC performance to further develop this model.

PC Performance - Bandwidth Nodes

Choosing a PC is now a common activity for many. Benchmarks can be used to evaluate PC performance that, in conjunction with factors such as price, is an aid to selection. Benchmark programs relevant to a typical single user, multi-tasking environment running a de facto standard suite of 32 bit applications include: SYSmark and Ziff-Davis PC Benchmark. Consumer magazines use Benchmark suites to evaluate PC's and publish their results [14]. As a relative guide Benchmarks are an aid to selection, however, all of these results must be interpreted and many questions still remain for users. Questions include:

- What difference in performance can a user expect if the bench mark value result is higher by 1 or 2 units or by a factor of 10 or more? For example, what difference in performance would a user expect between an IBM PC (Business Disk WinMark 98 value of 939) and a Gateway PC (Business Disk Win Mark 98 value of 1,380)?

- What difference in performance can a user expect from a Pentium 100 (iCOMP 90) and a Pentium 200 (iCOMP 142)? Are the scales linear, logarithmic, hyperbolic?
- As a user, how is the difference in performance manifested and perceived?
- How can different types of devices be compared, e.g. how can the performance of a hard disc drive be compared to a microprocessor?

We conclude that the plethora of benchmarks, though useful, do not provide the basis of a coherent conceptual model of a PC. Any measurement standard, to be of practical value to PC users, must be relevant to human dimensions or perceptions and use units based on the decimal scaling system. To a first approximation the performance of PC nodes can be evaluated by bandwidth with units in Bytes/s. Though useful it may not be the best initial, user oriented unit - a typical user runs 32 bit windows based applications. The user is therefore interacting, via a Graphical User Interface (GUI), with text and graphical images. For general acceptance a Benchmark must be easy to understand and should therefore be based on user perception of performance and as such be simple and use reasonably sized units. We suggest that a useful unit of measurement is the display of a single, full screen, full color image. For this paper we define a full screen image as 640x480 with 4 bytes per pixel, which represents 1.17Mbytes of data. The performance of a PC and associated nodes can still be evaluated using the measurement of bandwidth but with the units of standard images/s or frames/s. This unit of measurement may be more meaningful to a typical user because it relates directly to their perception of performance. To a first approximation, smooth animation requires a minimum of 5 frames/s (5.85Mbytes/s). Obviously sub multiples of this unit are possible such as quarter screen images and reduced color palette such as 1 byte per pixel. We have therefore a common unit of measurement, relevant to common human perception, with decimal based units, that can be applied to different nodes and identify performance bottlenecks. Each node (microprocessor, hard disc drive etc) can now be treated as a quantifiable data source/sink (Frames or Mbytes) with an associated transfer characteristic (Frames/s or Mbytes/s). This approach allows the performance of every node and data path to be assessed by a simple, common measurement - bandwidth. Where $\text{Bandwidth} = \text{Clock Speed} \times \text{Data Path Width}$ with the common units of Frames/s (Mbytes/s).

The PC as a Bandwidth node Model

The heterogeneous nature of the nodes of a PC is clearly illustrated by the range of measurement units used varying from MHz to seek times in milliseconds. Evaluation of these different nodes is therefore difficult. However, it is possible to compare the performance of different nodes using the common measurement of bandwidth in standard Frames/s or Mbytes/s. The Pentium processor has an external data path of 8bytes with maximum rated clock speeds in excess of 400MHz giving a bandwidth of more than 2735 Frames/s (3200Mbytes/s). Dual In Line Memory Modules (DIMMs) rated at 60ns (16MHz) with a data path width of 8 bytes have a bandwidth of 109 Frames/s (128Mbytes/s). The data transfer rate for a hard disc drive can be calculated from the sector capacity and rotational speed (data transfer rate = sector capacity x sectors per track x rps). Typical figures are in

the range of 4.3 Frames/s (5 Mbytes/s). Modern performance is typically measured in Kbits/s which can be converted to Mbytes/s or Frames/s. CDROM performance is quoted in speeds e.g. x32 speed where single speed is 150kbytes/s. CDROM speeds can easily be converted to Mbytes/s or Frames/s. According to Mueller [12], the maximum transfer rate of a bus in MBytes/s can be calculated from the clock speed and data width. This can then be converted to Frames/s. A PC can be therefore be understood as a hierarchical collection of nodes, interconnected by different buses, operating at different bandwidths. However, other factors not considered include the effects of compression, operating system overheads etc.

Nodes as a Constructivist Framework

As a result of the initial investigations at ECU a new curriculum was designed, implemented and fully evaluated at ECU [9]. Unlike the standard computer technology curriculum students are not taught digital techniques, assembly language programming etc. Rather the curriculum is based on a constructivist approach recommended by this paper. This curriculum has always been oversubscribed, has a very low student attrition rate, and attracts students from other faculties in ECU and students from other universities in the state. When one new unit from this curriculum was first introduced, from an enrolment of 118, only 66 were computer science students. Workshop exercises include: install master/slave hard disc drive; upgrade PCI video card, load an operating system. Other exercises on a subsequent unit include the installation and testing of: Digital Video Disc (DVD), flat bed scanner, PC video camera and a video conference link. An educational expert conducted a detailed analysis of student learning. The results were that this curriculum: *"is perceived as very valuable by students from different disciplines; supports learning in other units; and increases students' understanding of computers and computing"* [9]

This new curriculum, though perceived as valuable by students when first introduced, arguably lacked a coherent conceptual framework. This year we used bandwidth nodes as such a framework for the first time and evaluated the results. Using this conceptual framework the PC is considered as a series of nodes whose performance is measured by bandwidth (Frames/s). Using the standard compulsory ECU course evaluation questionnaire the unit was highly rated by students. Furthermore, a more detailed study was conducted to investigate student experience of the nodal concept. From an enrolment of eighty students, forty were given questionnaires. Thirty-six students thought the nodal concept should be taught. Thirty-five students thought that this concept helped them understand computer technology. Thirty-five students thought that using a common unit (Frames/s) helped in evaluating PC devices. Significantly half the respondents thought more time should be spent on this type of calculation. Advantages of this model include:

- Students perceive the PC as a unified collection of devices based on constructivist principles
- Node performance, measured in bandwidth (Frames/s) is a user based, easily understood measurement
- The units (Frames/s) use a decimal scaling system

- Students are able to critically analyze technical literature using this integrating concept.
- The model is suitable for students from a wide range of disciplines including Computer Science majors
- Nodes are independent of architectural detail

Digital Techniques

The authors do not suggest that the bandwidth node model should replace the teaching of this traditional computer technology curriculum (digital logic). Rather, it may serve as a useful introduction that provides both interesting and useful knowledge and skills.

Conclusions

This paper proposes nodes, whose performance is rated by bandwidth (frames/s), as the basis of an introduction to computer technology curriculum. Work to date indicates that modeling the PC as such a collection of nodes provides a good constructivist framework allowing technical detail to be introduced in a controlled, top-down manner that is readily understandable to students from all disciplines. The nodal model provides abstraction and hence is independent of architectural detail and can therefore accommodate rapid changes in technology.

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3.2.4.2 Architecture Abstraction as an Aid to Computer Technology Education

This paper (Maj & Veal, 2000a) was presented at the American Society for Engineering Education (ASEE), Computers in Education Division 2000 Annual Conference, held in St Louis, Missouri, USA. The ASEE is one of the leading engineering education bodies within the USA. The ASEE annual conference is its leading venue for publication and presentation. This paper considers the 1991 ACM/IEEE-CS Joint Curriculum Task Force set benchmarks for award accreditation and provide the foundations of computer science curriculum which identifies recognizes the 'need for diversity and well-intentioned experimentation in computing curricula'. Computer Science is a relatively new discipline and given the rapid advances in technology is subject to on going debate, development and fragmentation. It is typically the requirement of many disciplines, such as multimedia, software engineering, e-commerce etc to incorporate computer technology as part of their curriculum. However, a detailed market analysis within Australia clearly indicated that both students and employers perceive the standard computer technology curriculum as increasingly irrelevant.

New knowledge presented includes the B-Node model is first named and is also evaluated as a possible pedagogical framework for teaching engineering education in particular and its scope of application increased by considering its application to microprocessors, DRAMs as well as buses and chip sets and sub-optimal operation.

Architecture Abstraction as an Aid to Computer Technology Education

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Abstract

Reports such as the 1991 ACM/IEEE-CS Joint Curriculum Task Force set benchmarks for award accreditation and provide the foundations of computer science curriculum worldwide. The report identifies recognizes the 'need for diversity and well-intentioned experimentation in computing curricula'. Computer Science is a relatively new discipline and given the rapid advances in technology is subject to on going debate, development and fragmentation. It is typically the requirement of many disciplines, such as Multi-media, Software Engineering, and E-commerce etc to incorporate computer technology as part of their curriculum. However, a detailed market analysis within Australia clearly indicated that both students and employers perceive the standard computer technology curriculum as increasingly irrelevant.

Work to date clearly indicates that this standard approach provides technical detail and complexity that is inappropriate for introductory courses on computer and network technology. As part of an international study the same investigation is currently being conducted with several European universities. The results to date parallel those obtained from the WA study. Accordingly a new curriculum was designed to address this problem. This new curriculum is based on a modeling a PC as an interconnection of nodes. Evaluation of the curriculum indicates that this abstraction can be used as a new educational framework allowing technical detail to be introduced and controlled thereby ensuring that it is meaningful and therefore readily understandable to students not only from computer science but also other disciplines. Work to date indicates that this new model is not only technically valid but also supports increasing levels of technical complexity and hence articulates to the standard computer technology curriculum. Furthermore the abstractions used in this model are independent of technical detail and can therefore accommodate rapid changes in technology.

Introduction

Reports such as the 1991 ACM/IEEE-CS *Computing Curricula*¹ provide the foundations of computer science curriculum world wide and set benchmarks for accreditation by professional bodies. Within Western Australia an exploratory market audit was conducted of a wide range of industrial and commercial companies. This was complemented by a further detailed analysis of the IT department of a state wide rail company. From this survey a set of guidelines were

developed for the type of skills expected of computer science graduates entering the field of computer and network support. Using the criteria developed 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

The computer architecture and communication engineering units were: Computer Technology, Microprocessors, Data Communication & Computer Networks. These units follow the standard approach taken by most universities. The Computer Technology unit introduces students to computer systems and hardware i.e. number codes, assembly language (Motorola 6800), machine architecture etc. The Microprocessor unit is a detailed examination of microprocessor technology and an in-depth treatment of assembly language (Intel). The Data Communication & Computer Networks unit provides an understanding of the physical and logical elements of data communications with a detailed discussion of the ISO OSI model. Furthermore, interviews conducted with five ECU graduates employed in computer and network support 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. This problem is exacerbated not only by the constant and rapid changes in technology but also the requirement to teach technology to students from a wide range of discipline such as multimedia, e-commerce etc.³. 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." ⁴

Other countries similarly have professional accreditation. In the United Kingdom (UK) the British Computer (BCS) accredits university courses and has an internationally recognized examination scheme in two parts with Part II at the level of a UK honors degree in computing. The initial ECU student questionnaire, first used in 1993, was also conducted in 1999 at two universities in the UK. A similar study is currently being undertaken in Sweden. The first university has well established degree programs and is fully BCS accredited. The second university recently redesigned their IT awards, some of which are now BCS accredited. The degree programs at the first university offer students the opportunity to examine a PC in the first year as part of a module in Computer Organization. However they never take a PC apart. 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. The survey indicated that any practical knowledge students have of hardware is largely a result of experience outside the course. At the second university the results demonstrate that these students had a broad, hobbyist's understanding of the PC but no knowledge of health and safety law. Significantly, the students interviewed identified that their skills and knowledge of PCs and networks came from self-study or employment, not from courses at university. Again student responses indicated that such knowledge would be useful. Furthermore, according to a study of Multi-media students by Maj, *"It is significant that every student interviewed expressed the view that it would be extremely beneficial to have a much better knowledge of computer and network technology"*³. A demand that traditional courses in computer technology may not be meeting. We therefore examined developments in computer and network technology curriculum.

Computer and Network Technology Curriculum

The problems associated with teaching computer technology are not new. Units in microcomputer systems are fundamentally important to both computer science and engineering students. These address issues that include: computer organization, memory systems, assembly language, digital logic, interrupt handling, I/O and interfaces. Mainstream computer science education is well supported by journal articles on various aspects of re-programmable hardware for educational purposes⁶ and assembly language⁷. Simulation has proved to be a very useful tool^{8,9,10}. Reid used laboratory workstations to allow undergraduate students to *"build a complete, functioning computer - in simulation"*¹¹. Pilgrim¹² took an alternative approach in which a very small computer was designed in class and bread-boarded in the laboratory by students using small and medium scale TTL integrated circuits. Thereby, according to Pilgrim, providing students with the "knowledge and experience in the design, testing and integration of hardware and software for a small computer system"¹². According to Parker and Drexel simulation is a preferred approach in order to provide students with the 'big picture'¹³. The difficulty of providing a suitable pedagogical framework is further illustrated by Coe and Williams Coe et al address this problem by means of simulation¹⁴. Barnett¹⁵ suggests that standard computer architecture is too complex for introductory courses and recommends a simplified computer for educational purposes.

However, it is possible to consider the PC and network technology from a different perspective. The PC is now a (relatively) low cost consumer item. This has been possible due to design and manufacturing changes that include: Assembly Level Manufacturing (ALM), Application Specific Integrated Circuits (ASICs) and Surface Mounted Technology (SMT). The result is PCs with a standard architecture and modular construction – so simple that high school students take them apart. However, traditionally computer technology education is typically based on digital techniques, small-scale integration IC's, Karnaugh maps, assembly language programming etc. Operation on PCs at this level simply does not exist any more within the field of computer and network support. Valuable though simulation and

breadboarding may be a typical PC support environment demands other knowledge and skills that include: upgrading PCs, fault identification and correction procedures, safety, ability to recognize different system architectures etc. Simulation provides no experience of practical problems such as inserting a new input/output card into a PC and the associated skills that are needed. Furthermore, a new conceptual model is needed that provides abstraction in order to control detail is required as the foundation of curriculum for the diverse audience now wishing to study computer technology.

Constructivism

Prior to examining how to improve student learning we attempted to attain a deeper understanding of how students learn and construct knowledge. Constructivism is the dominant theory of learning today, the basis of which is that students must actively construct knowledge rather than passively absorb it via lectures. According to Ben-Ari considerable research has been undertaken in this field but commented:

"However, I could not find articles on constructivism in computer science education compared to the vast literature in mathematics and physics education' and that 'it can provide a new and powerful set of concepts to guide our debates on CSE (Computer Science Education)"¹⁶.

According to this theory students have their own cognitive structures each of which is the foundation of the learning process. By example, a PC is understood very differently by Computer Science, Multimedia and Business IT students. Failure to do so results in fragile and incomplete learning in which new knowledge is merely a collection of facts to be memorized¹⁷. The importance of the students own mental model is illustrated by Scott Brandt who wrote, *"The user's ability to apply a previously held mental model to the target (knowledge goal) will enhance the incorporation and construction of new knowledge"*¹⁸. We suggest that it is a common experience to perceive the PC as a modular device (CDROM, Zip Drive, Modem etc) used to store, view and process either local or networked data. The traditional method of teaching computer technology (digital techniques, assembly language etc) is not a good constructivist approach. According to Scragg: *"... most (perhaps all) first courses in computer hardware are created 'upside down' - both pedagogically and pragmatically"*. This has the consequence that: *"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"*¹⁹. Accordingly Scragg recommends a top down approach starting with material already familiar to students and then working towards less familiar material. We attempted therefore to find a common conceptual framework held by students, from different disciplines (especially multi-media), as the basis for a cognitive structure.

The PC – a Constructivist model

Models are used as a means of communication and controlling detail. By example, a transistor can be modeled by a simple diagram with parameters directly relevant to an engineer. The details of semi-conductor theory are not relevant in this context i.e. detail is encapsulated and hence controlled. Similarly a digital technique such as

sequential logic is a higher level modeling technique that masks the details of individual transistors. Models should have the following characteristics:

- Diagrammatic
- Self documenting
- Easy to use
- Control detail
- Hierarchical top down decomposition.

Clements suggests that a PC may be considered as a loosely coupled Multiple Instruction, Multiple Data (MIMD) device. According to Clements:

"Although most people do not regard it as a multiprocessor, any arrangement of a microprocessor and a floppy disc controller is really a loosely coupled MIMD. The floppy disc controller is really an autonomous processor with its own microprocessor, internal RAM and ROM."

and also that:

*"Because the FDC has all these resources on one chip and communicates with its host processor as if it were a simple I/O port, it is considered by many to be a simple I/O port. If it were not for the fact that the FDC is available as a single chip, engineers would be designing "true" multiprocessor systems to handle disc I/O"*¹⁸.

A PC is a complex collection of heterogeneous devices interconnected by a range of bus structures. However it can be modeled as a MIMD architecture of sub-units for nodes. Each node (microprocessor, hard disc drive etc) can be treated as a data source/sink capable of, to various degrees, data storage, processing and transmission. This simple model may provide the basis of a suitable conceptual map and hence the framework for an introduction to computer technology. This model is conceptually simple; controls detail by abstraction and may allow students to easily make viable constructs of knowledge based on their own experience. However, to be of significant value this model must also be a tool that can actually be used by students. Furthermore the model must be not only be technically valid but also provide a basis for more advanced studies. We therefore examined PC performance to further develop this model.

PC Performance - Bandwidth Nodes

Benchmark programs considered directly relevant to a typical single user, multi-tasking environment running a de facto standard suite of 32 bit applications include: AIM Suite III, SYSmark and Ziff-Davis PC Benchmark. Consumer magazines use Benchmark suites to evaluate PC's and publish their results²¹. Intel mark their microprocessors with a part number and the maximum rated clock speed. Furthermore they publish a special series of Benchmarks called the Intel Comparative Microprocessor Performance Index (iCOMP) that can be used as a relative gauge of microprocessor performance. For many AMD microprocessors the model designation does not correspond with the associated clock speed. For example, the AMD K5 PR133 has a clock speed of only 100MHz. The alternative P

Rating (PR) system was jointly developed by Cyrix, IBM, SGS Thompson, and AMD. This Benchmark is based on the Winstone, a de facto standard, windows based Benchmark suite. As an aid to more meaningful measurements specialist interest groups also evaluate equipment using specific applications²². As a relative guide Benchmarks are an aid to selection, however, all of these results must be interpreted and many questions still remain for users. Questions include:

- What difference in performance can a user expect if the bench mark value result is higher by 1 or 2 units or by a factor of 10 or more? For example, what difference in performance would a user expect between an IBM Aptiva EQ3 (Business Disk WinMark 98 value of 939) and a Gateway G6 300 (Business Disk Win Mark 98 value of 1,380)?
- How does the iCOMP rating compare to the PR rating?
- What difference in performance can a user expect from a Pentium 100 (iCOMP 90) and a Pentium 200 (iCOMP 142)? Are the scales linear, logarithmic, hyperbolic?
- As a user, how is the difference in performance manifested and perceived?
- How can different types of devices be compared, e.g. how can the performance of a hard disc drive be compared to a microprocessor?

We conclude that the plethora of benchmarks, though useful, do not provide the basis of a coherent conceptual model of a PC. Any measurement standard, to be of practical value to PC users, must be relevant to human dimensions or perceptions and use units based on the decimal scaling system.

To a first approximation the performance of PC nodes can be evaluated by bandwidth with units in Bytes/s. Though useful it may not be the best initial, user oriented unit - a typical user runs 32 bit windows based applications. The user is therefore interacting, via a Graphical User Interface (GUI), with text and graphical images. For general acceptance a Benchmark must be easy to understand and should therefore be based on user perception of performance and as such be simple and use reasonably sized units.

We suggest that a useful unit of measurement is the display of a single, full screen, full color image. For this paper we define a full screen image as 640 x480 with 4 bytes per pixel, which represents 1.17Mbytes of data. This appears to be the standard image for the new generation of video display adapters. The performance of a PC and associated nodes can still be evaluated using the measurement of bandwidth but with the units of standard images/s or frames/s. This unit of measurement may be more meaningful to a typical user because it relates directly to their perception of performance. To a first approximation, smooth animation requires a minimum of 5 frames/s (5.85Mbytes/s). Obviously sub multiples of this unit are possible such as quarter screen images and reduced color palette such as 1 byte per pixel. We first established a general experimental method to determine data transfer rates between nodes within a PC to evaluate the use of frames/s as a measurement of performance. A C program was used to transfer data between two nodes, a Hard Disc Drive (HDD) and Synchronous Dynamic RAM (SDRAM),

flagging the start and stop of this operation on the parallel port. An oscilloscope (100 micro second resolution), connected to this port measured the data transfer rate in Mbytes/s. The results obtained related directly to the manufactures technical specification of the HDD. We were able to detect the influence of HDD caching and also track and cylinder latency thus verifying the experimental method. A single, uncompressed 640x480, 4bytes/pixel-video image was generated and transferred from the HDD to both SDRAM and a third node, the video adapter card. The data transfer rate from HDD to SDRAM was 1.48Mbytes/s, which can be expressed as 1.21 frames/s. From the HDD to video adapter card the data rate was 1.37Mbytes/s i.e. 1.1 frames/s. The data transfer rate for the video card is 18.6Mbytes/s i.e. 15.1 frames/s. We have therefore a common unit of measurement, relevant to common human perception, with decimal based units, that can be applied to different nodes and identify performance bottlenecks. In this case the HDD is the limiting factor and unable to provide a bandwidth suitable for smooth motion in an animation sequence. The concept of using images to evaluate PC performance can be made directly relevant to users from different disciplines, in particular multi-media.

Each node (microprocessor, hard disc drive etc) can now be treated as a quantifiable data source/sink (Frames or Mbytes) with an associated transfer characteristic (Frames/s or Mbytes/s). This approach allows the performance of every node and data path to be assessed by a simple, common measurement – bandwidth. Where $\text{Bandwidth} = \text{Clock Speed} \times \text{Data Path Width}$ with the common units of Frames/s (Mbytes/s).

The PC as a Bandwidth Node Model

The heterogeneous nature of the nodes of a PC is clearly illustrated by the range of measurement units used varying from MHz to seek times in milliseconds. Evaluation of these different nodes is therefore difficult. However, it is possible to compare the performance of different nodes using the common measurement of bandwidth in standard Frames/s or Mbytes/s.

Microprocessor

All microprocessors, regardless of any internal architectural details, transfers data via the processor data bus. The Pentium processor has an external data path of 8bytes with maximum rated clock speeds in excess of 400Mhz giving a bandwidth of more than 2735 Frames/s (3200Mbytes/s).

Primary Memory – DRAM

Regardless of DRAM organizational structure, performance is measured in nanoseconds, which can easily be converted to MHz. The performance of SDRAM is now often quoted in MHz, e.g. 83MHz (12ns) or 100MHz (10ns). For example, Dual Inline Memory Modules (DIMMs) rated at 60ns (16MHz) with a data path width of 8 bytes have bandwidths of 109 Frames/s (128Mbytes/s).

Secondary Memory – Hard Disc Drive

The true maximum, sustained data transfer rate in Mbytes/s can be calculated from the sector capacity and rotational speed (data transfer rate = sector capacity x

sectors per track x rps). Typical figures are in the range of 4.3 Frames/s (5 Mbytes/s) with the number of sectors averaged thereby taking into account Zoned Bit Recording. The data transfer rate of interfaces is often quoted in latency, which can easily be converted to Mbytes/s or Frames/s.

Peripherals

Modem performance is typically measured in kbits/s which can be converted to Mbytes/s or Frames/s. CDROM performance is quoted in speeds e.g. x32 speed. A single speed CDROM provides a defined transfer rate of 150kbytes/s. When CDROM devices are used to transfer digital data it is possible to speed up the data transfer rates, all of which are multiples of the original single speed drives. CDROM speeds can easily be converted to Mbytes/s or Frames/s.

Bus Structures and Chip Sets

According to Mueller²³, the maximum transfer rate of a bus in MBytes/s can be calculated from the clock speed and data width. This can then be converted to Frames/s. It is possible to construct a diagrammatic representation of the bus structure hierarchy showing also the chip-sets used to interface between the different hierarchical levels.

A PC can be therefore be understood as a hierarchical collection of nodes, interconnected by different buses, operating at different bandwidths. Work to date indicates the bandwidth node model may be used for all the latest Multi-media devices (Video camera, Digital Video Disk (DVD), flat bed scanner etc). We then examined if this bandwidth node model was valid for increasing levels of technical complexity.

Sub-Optimal Operation – Technical complexity

Nodes typically operate sub-optimally due to their operational limitations and also the interaction between other slower nodes. For example, a microprocessor may need two or more clock cycles to execute an instruction. Similarly a data bus may need multiple clock cycles to transfer a single data word. The simple bandwidth equation can be modified to take this into account i.e. $\text{Bandwidth} = \text{Clock} \times \text{Data Path Width} \times \text{Efficiency}$. The early Intel 8088/86 required a memory cycle time of 4 clocks cycles (Efficiency = $\frac{1}{4}$) however, for the Intel 80x86 series, including the Pentium, the memory cycle time consists of only 2 clocks (Efficiency = $\frac{1}{2}$) for external DRAM [22]. A 100MHz Pentium, with a data path of 8 bytes has a therefore bandwidth of 341 Frames/s (400Mbytes/s).

Dual In Line Memory Modules (DIMMs) rated at 60ns (16MHz) with a data path width of 8 bytes have a bandwidth of 109 Frames/s (128Mbytes/s). When DRAM devices cannot complete a read or write request within the correct number of clock cycles the memory controller indicates to the microprocessor that another instruction cycle must be implemented, i.e. a wait state.²⁴ Each wait state increases the memory cycle time by one clock, hence an extra wait state for the 80x86 series would reduce the efficiency to $\frac{1}{3}$. For a 100MHz Pentium the bandwidth would be reduced from 341Frames/s (400Mbytes/s) to 227Frames/s (266Mbytes/s). It can be clearly seen that five wait states are needed to match the microprocessor and

DRAM (60ns) bandwidths. The Peripheral Component Interconnect (PCI) bus is also a 32 bit bus but operates at a fixed frequency of 33MHz. The PCI bus uses a multiplexing scheme in which the lines are alternately used as address and data lines. This reduces the number of lines but results in an increased number of clock cycles needed for a single data transfer. The maximum data transfer rate for the write operation (2 clock cycles) is 56Frames/s (66Mbytes/s) i.e. $(33\text{MHz} \times 4 \text{ bytes} \times 1/2)$, however the PCI bus is capable of burst transfer modes of arbitrary length in which case E can be taken as unity.

The bandwidth node model is capable of top down decomposition. A PC can be considered as a single node or a collection of nodes (microprocessor, electronic memory, hard disc drive etc). Each of these nodes can be modeled as a collection of nodes. By example a hard disc drive can be described as two nodes, the Electro-mechanical drive mechanism (motors, platters etc) that communicates to the hard disc controller (responsible for data separation, error correction, buffering etc) that in turn interfaces to the motherboard bus.

We conclude that the proposed bandwidth node model may be extended to accommodate the sub-optimal performance of PC sub-units. Furthermore this model may be used to provide greater technical depth. However no account is taken of compression or the effect of operating system overheads. Further work is currently being undertaken to analyze the effect of these variables.

Architectural Independence

There are many rapid changes in computer technology – the technical standards of today are likely to be obsolete tomorrow. It is possible, using this technique, to model all microprocessors (8086 to Pentium), all types of hard disc drive (ST 506, ESDI, IDE etc) all buses (ISA, EISA, MCA, LB and PCI). Preliminary investigations indicate that it is possible to model all multi-media devices using this bandwidth node technique.

Nodes as a Constructivist Framework

As a result of the initial investigations at ECU a new curriculum was designed, implemented and fully evaluated at ECU 25. Unlike the standard computer technology curriculum students are not taught digital techniques, assembly language programming etc. Rather the curriculum is based on a constructivist approach recommended by this paper. This curriculum has always been oversubscribed, has a very low student attrition rate, and attracts students from other faculties within ECU and students from other universities in the state. When one new unit from this curriculum was first introduced, from an enrolment of 118, only 66 were computer science students the others were from a wide range of disciplines, especially multi-media. Workshop exercises include: install master/slave hard disc drive; upgrade PCI video card, load an operating system. Other more advanced exercises in a subsequent unit include: the installation and testing of: Digital Video Disc (DVD), flat bed scanner, PC video camera, Infra-red communications link, Zip Disc, a video conference communications link via a local area network. Such workshops represent many of the common tasks required of students when entering the workforce.

An educational expert conducted a detailed analysis of student learning. Five students, chosen at random, were interviewed. Interviews were semi-structured consisting of a number of closed and open ended questions and respondents were encouraged to comment on any positive or negative aspect of the course and its effect on their learning. The results that the curriculum: *"is perceived as very valuable by students from different disciplines; supports learning in other units; increases students' understanding of computers and computing; generates a demand for further curriculum in this field"*²⁵.

This new curriculum, though perceived as valuable by students when first introduced, arguably lacked a coherent conceptual framework. Last year we used bandwidth nodes as such a framework for the first time and evaluated the results. Using this conceptual framework the PC is considered as a series of nodes that can store, process and transfer data. The operational characteristic of each node is considered in detail and its bandwidth calculated using the common units of Bytes/s and Frames/s. Using the standard ECU course evaluation questionnaire the unit was highly rated by students. Student understanding was evaluated by means of two assignments in which they were required to obtain the technical specifications for a PC and construct a nodal model with associated bandwidths in both Mbytes/s and Frames/s. Furthermore, a more detailed study was conducted. Thirty-seven students from forty responded that this method of teaching computer technology was beneficial.

Prior to the introduction of this model student previous student similar to this resulted in almost exclusively a list of hardware details copied directly from technical literature with little or no critical analysis. Most students most were able to predict the likely performance of a PC and identify nodes (devices) that would significantly handicap performance. Significantly, using this nodal model all additional progressive technical detail and complexity is additive to knowledge and understanding rather than being perceived by the student as simply a collection of factual data. Advantages to using this model include:

- Students perceive the PC as a unified collection of devices
- Node performance, measured in bandwidth (Frames/s) is a user based, easily understood measurement
- The units (Mbytes/s, Frames/s) use a decimal scaling system
- Students are able to evaluate different nodes of a PC by means of a common unit of measurement
- Students can easily determine the anticipated performance of a PC given its technical specification
- Students are able to critically analyze technical literature using this integrating concept.
- The model is suitable for students from a wide range of disciplines including Computer Science majors
- Nodes control detail and are valid for increasing levels of technical complexity.
- Nodes are independent of architectural detail
- Nodes are a diagrammatic and easy to use

- Nodes are self documenting
- Nodes can be used to provide hierarchical top down decomposition.

Digital Techniques

According to the report of the 1991 ACM/IEEE-CS Joint Curriculum Task Force report computer science curriculum includes: digital logic and systems, machine level representation of data, assembly level machine organization, memory system organization and architecture, interfacing and communications, and alternative architectures¹. The authors do not suggest that the bandwidth node model should replace the teaching of this traditional computer technology curriculum. Rather, it may serve as a useful introduction that provides both interesting and useful skills. This point is reinforced by Ramsden, *"Material should preferably be ordered in such a way that it proceeds from common-sense and everyday experiences to abstractions and then back again to the application of theoretical knowledge in practice"*²⁶.

Conclusions

This paper proposes nodes, whose performance is rated by bandwidth (frames/s), as the basis of an introduction to computer technology curriculum. Work to date indicates that modeling the PC as such a collection of nodes provides a good constructivist framework allowing technical detail to be introduced in a controlled, top-down manner that is readily understandable to students from all disciplines. This nodal model is also valid for increasing levels of technical complexity and hence may be suitable for more advanced studies. The nodal model provides abstraction and hence is independent of architectural detail and can therefore accommodate rapid changes in technology.

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3.2.4.3 A New Abstraction Model for Engineering Students

This paper (Maj, Veal, & Boyanich, 2001) was presented at the UNESCO International Centre for Engineering Education 4th UICEE Annual Engineering Education Conference, held in Bangkok, Thailand. The UNESCO International Centre for Engineering Education (UICEE) is based in the Faculty of Engineering at Monash University, Melbourne, Victoria, Australia. The mission of the UICEE is to facilitate the transfer of information, expertise and research on engineering education. It facilitates international conferences worldwide where peer reviewed papers are presented and published.

This paper considers conceptual models of the PC computer performance. The limitations on the use of benchmarks for promoting student understanding of CNT performance issues are considered. The application of recursive B-Node models as a means of aiding engineering student understanding of developments in CNT is presented, as are the use of B-Node diagrams that can permit the use of hierarchical decomposition. The approximation of Moore and Mealy state machines to B-Nodes is also considered. Examples are also given of digital systems approximation to B-Nodes. Also included is the potential application of B-Nodes to assist comparison between generations of digital computers from 1940s into the future. Results of an anonymous student evaluation of the B-Node model are presented which found that 50% of students thought that more time should be spent on calculations, and 90% thought that the B-Node concepts should be taught. Traditionally, introductory computer technology education is typically based upon digital techniques, small-scale integration IC's, Karnaugh maps etc. Results from an international investigation clearly demonstrated that for many students this approach is increasingly perceived as irrelevant. Work to date indicates that this modelling technique provides a good constructivist framework allowing technical detail to be introduced in a manner likely to accord with their previous experiences. Additional complexity is presented in a controlled, top-down manner that is readily understandable to students from all disciplines. This model is independent of architectural detail and could therefore accommodate rapid changes in technology. The full digital technology approach may be required by some students such as

those in computer science and engineering undergraduate courses who intend to undertake research and development in the computer hardware field. From a constructivist viewpoint an overall conceptual model could help to promote their learning.

Additional new knowledge includes a further development of the use of bandwidth concepts and student understanding of PC hardware development from a constructivist perspective. This was the first paper to use of B-Node diagrams and also the first paper noting the B-Node approximation to Moore and Mealy state machines. This is the first suggestion of the potential of E-Nodes to compare development of digital devices from an historical perspective.

A New Abstraction Model for Engineering Students

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Abstract:

Traditionally introductory computer technology education is typically based upon digital techniques, small-scale integration IC's, Karnaugh maps etc. Results from an international investigation clearly demonstrated that for many students this approach is increasingly perceived as irrelevant. A new higher level abstract modelling technique that could suit for both computer and network technology is proposed. Work to date indicates that this modelling technique provides a good constructivist framework allowing technical detail to be introduced in a controlled, top-down manner that is readily understandable to students from all disciplines. This model is independent of architectural detail and could therefore accommodate rapid changes in technology. The full digital technology approach may be required by some students such as those computer science and engineering undergraduates who intend to undertake research and development in the computer hardware field. Although from a constructivist viewpoint an overall conceptual model could still help to promote their learning.

Introduction

For many years the PC has been a widespread relatively low cost consumer item. Technically this has been made possible by design and manufacturing changes that include, Assembly Level Manufacturing (ALM), Application Specific Integrated Circuits (ASICs) and Surface Mounted Technology (SMT). The result is a PC with standard architecture and modular construction. The increasing use of PCs and associated equipment has led to an increasingly high demand for people with technical skills in computer and network support and other fields such as multimedia [6]. CIM and NIM were based upon the findings of a study by Maj, Robbins, Shaw and Duley [7] which found that 3rd year computing science students were unable to perform routine operation on a PC such as installing a hard disk drive to acceptable standard both of safety to themselves or without a high level of possibility of damage to the machine. Such skills were not provided in the curriculum at ECU or most other university computer science courses, but were judged to be very valuable by students and prospective employers. CIM and NIM were initially based upon fulfilling this mismatch between potential employers' requirements in computer and network support and the skills and knowledge possessed by computing science students. Maj, Fetherstone, Charlesworth and Robbins note that: *"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"* [5]. However, all of these students had successfully passed all of their units. Identical studies carried out at European universities has discovered a similar situation.

CIM and NIM are first level single semester units with two hours per week of 'hands on' workshops accompanying a two hour lecture. Maj notes that:

"A 4th year engineering student described the unit as 'very helpful' explaining that all the rest of his course was theoretical with nothing practical dealing with the 'components with which I have to work'. He said that 'I never see the component in the whole four years of my course' so to actually work with the components 'was helpful to my understanding' [5].

The diverse backgrounds of students attracted to the CIM and NIM unit meant that many had no previous education or training in technology. A method was required to enable these students to gain an understanding of PC technology in a single semester. Traditional methods of teaching computer hardware are often via digital electronics units whereby logic gates are combined into ever more complex arrangements. This can result in difficulty experienced by students when progressing from an appreciation of logic gates to an understanding of the operation of an actual PC. Barnett has even suggested that standard computer architecture is too complex for introductory courses [1]. The short 'half life of usefulness' for such knowledge is caused by the high rate of technological change in the computer hardware field. The concept of the 'usefulness of half life' refers the time required for knowledge to be only half as useful as it was at the start of that time period.

Conceptual models of the PC

Computing science academics often completely reverse the dictates put in place for software design and comprehension. They tend to apply 'bottom up' rather than 'top down' methods starting with an understanding of logic gates and then proceeding more complex arrangements using these gates. Scragg in the paper entitled *"Most computer organization courses are built upside down,"* [12], recommended a top down approach starting with material already familiar to students. This view is also taken up by Maj Veal and Charlesworth in the paper *"Is Computer Technology Taught Upside-down?"* [9]. The relatively long learning time associated with this 'bottom up' approach is due to the large quantities of disconnected lower level detail. When this problem is coupled with the short 'half life of usefulness' of knowledge gained via the 'bottom up' approach this often results in limited relevance and value to many students. Furthermore students with a non-technical background may be considerably disadvantaged until they have mastered digital techniques. Teaching computer hardware via logic gates not in line with modern practice where PC cards and microprocessors are interchanged and installed rather than individual logic gates.

Modelling is a common practice both in science and engineering. A new conceptual model is required that provides abstraction in order to control irrelevant technical detail. E.g. a transistor can be modelled by a simple diagram with parameters directly relevant to an engineer. The details of semi-conductor theory are not relevant in this context i.e. detail is encapsulated and hence controlled. Although in other contexts semi-conductor theory may be relevant. Similarly digital techniques such as sequential logic is a higher level modelling technique that masks the details of individual transistors but may be unsuitable as an initial basis for a conceptual

model of a PC. Sets of logic gates may have been the only readily obtainable hardware devices for students to gain 'hands on' experience with digital logic circuits 30 years ago. It was as close as students could get to 'hands on' experience with the insides of a computer. Then such provision would have been financially out of the question for many educational institutions. However today there is no longer this restriction and the necessity for many students to study PC hardware has lead to a need for new conceptual models.

Computer performance

Work on a new conceptual model for computer hardware was undertaken for CIM and NIM based upon computer performance as this can provide insights into hardware development and can enable students to assess prospective systems. Measures of performance could include benchmarks. A computer benchmark is a performance test and a variety of computer benchmarks have been in use for many years. Chen and Patterson note that, *"Good benchmarks assist users in purchasing machines by allowing fair, relevant comparisons"* [2].

However questions regarding the meaning of the significant figures given, comparison between the various benchmark readings, as well as any meaning which can be ascribed to particular readings are not be readily answered. A cursive glance at any personal computer magazine or newspaper computer advertisement section will result in a bewildering array of units and standards. User questions such as 'How much will a given graphics accelerator speed up my multimedia presentations?' or 'How fast will my new program load from the hard drive?' are not readily answered. Saavedra and Smith state that

"Standard benchmarking provides the run-times for given programs on given machines, but fails to provide insight as to why those results were obtained (either in terms of the machine or program characteristics) and fails to provide run-times for that program on some other machine, or some other programs on that machine" [11].

Bandwidth as a PC Performance Measurement

The problems of using benchmarks lead the authors to consider other computer performance indicators. Bottleneck predication and detection was regarded as suitable for the more technically knowledgeable user or technical staff. Buses can be cause bottlenecks on PCs and are critical to performance on modern bus based PCs. Finklstien and Weiss note that:

- *The bus bandwidth and transfer parameters place a limit on the system performance.*
- *The system bus is an interface that connects hardware components produced by different vendors and provide interoperability* [4].

Therefore bandwidth, or throughput, could be a suitable central theme for teaching PC hardware concepts. The initial use of a commonly perceived situation is recommended from a consideration of constructivist theory.

Constructivism

Constructivist educational theory is based on enabling students to build increasingly complex frameworks of understanding from their current frameworks. Vygotsky developed the concept of The Zone of Proximal Development, (ZPD) (Vygotsky, 1962) [16]. It is the phase at which a task can be mastered given appropriate support and keeping learning tasks within student's ZPD. This is vital from a constructivist viewpoint and Vygotsky also claimed that *"the larger the zone the better students will learn"*. Tharpe has noted that there *"... is no single ZPD for individuals because the zone varies with culture society and experience"* [13]. According to Ramsden: *"Material should be ordered in such a way that it proceeds from the common-sense and everyday experience to abstractions"* [10].

Such everyday experience for many PC users general speed of operation of the machines with which they interact and bandwidth is a major factor. Basing computer performance upon commonly appreciated measurements such as full screen full colour, full motion video would in accordance with constructivist theory.

A Bandwidth Model

Maj has developed a model based on throughput or bandwidth as discussed in *"Architectural Abstraction as an aid to Computer Technology Education"* [8]. Bandwidth is also a critical consideration in video, bus and many other system devices and thus providing a common measuring unit, also such measurements as bytes per second can be converted to Mega bytes per second or Gigabytes per second using S.I. scaling factors. In connection with the use of a full screen full colour Maj have noted that a full colour image as a useful unit of measurement he states defines a full screen image as 640 x 480 with 4 bytes per pixel representing 1.17 Mbytes of data. Maj, Veal & Charlesworth note that:

"... the performance of a PC and associated nodes can still be evaluated using the measurement of bandwidth but with the units of standard images/s or frames/s. This unit of measurement may be more meaningful to a typical user because it relates directly to their perception of performance. To a first approximation, smooth animation requires a minimum of 5 frames/s (5.85 Mbytes/s)".

They further state that:

"Each node (microprocessor, hard disc drive etc) can now be treated as a quantifiable data source/sink (Frames or Mbytes) with an associated transfer characteristic (Frames/s or Mbytes/s). This approach allows the performance of every node and data path to be assessed by a simple, common measurement – bandwidth. Where Bandwidth = Clock Speed x Data Path Width with the common units of Frames/s (Mbytes/s)". [9]

The units and concepts of bandwidth could be applied to, the IBM 360, early 1940s computers, future optical computers or a modern PC provided that they are digitally based machines. As an example of a bandwidth calculation The Pentium processor

has an external data path of 8bytes with maximum rated clock speeds in excess of 400MHz giving a bandwidth of more than 2735 Frames/s (3200Mbytes/s). Considering a PC as a series of nodes is reinforced by Clements who suggested that a Floppy Disc Drive may be considered as a loosely coupled Multiple Instruction, Multiple Data (MIMD) device [3]. A PC is therefore a complex collection of heterogeneous devices interconnected by a range of bus structures. However, from a user perspective, a PC is a low cost, storage device capable of processing data. In this context we therefore define a PC as a MIMD architecture of sub-units or Bandwidth Nodes (B-Nodes). Each node (microprocessor, hard disc drive etc) can be treated as a data source/sink capable of, to various degrees, data storage, processing and transmission. This simple model may provide a suitable conceptual map and hence the framework for an introduction to computer technology. It can be regarded as a sequence of B-Nodes. X denotes a particular B-node as in figure 1.



Figure 1

A path can be considered to be a link joining two B-Nodes a sequence of links and B-Nodes may be joined together with a line as shown in figure 2.

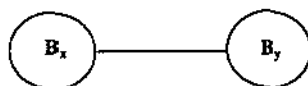


Figure 2

Both software and hardware measurements could then be checked against each other. Paths can also be contained within a B-Node enabling bandwidth modeling of higher or lower levels. B-Nodes could be placed wherever convenient in a system and may be considered to contain the whole or parts of one or more hardware devices as in figure 3.

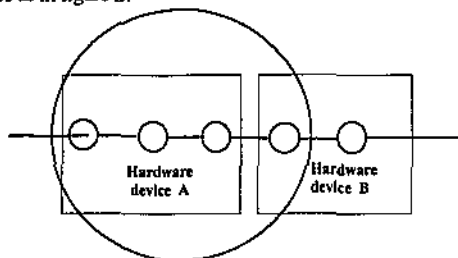


Figure 3

Such bandwidth models could also be used as an educational framework for courses concentrating on networks or on the internet. Other parts of a computer system such as the primary memory, are already regularly examined using bandwidth considerations. Bandwidth considerations also aid understanding of micro-coding requirements and are used for digital TV, digital radio. In Networking bandwidth has a well established history as papers such as "*The Bandwidth Famine*" by Wilkes, [17] can attest.

State Machines and Digital Systems

Since the initial work on B-Nodes work has been done to extend this model to include greater technical complexity. State machines are systems whose state changes according to input values. State evolution may be represented by a graph whose nodes represent state and edges represent state transitions. Output may be derived in two alternate ways leading to two different types of state machine: Moore Machine and Mealy Machine. Significantly both have input, output and a clocked state derived from logic. To a first approximation each machine may be modelled as a B-Node and the performance defined by the clock speed and the data path width. The 1-transistor, 1-capacitor cell is the fundamental unit of memory. This can be modelled as a B-Node. Such memory cells may be aggregated into a structured array with the associated pre-charge circuits, row and column decoders, sense amplifiers and input/output buffers i.e. DRAM memory cell array. A memory cell array may also be modelled as a B-Node. Regardless of the internal organization the performance of a memory cell array depends upon the clock speed and data path width. It is possible to model various digital circuits as B-Nodes and using standard logic boards evaluate their performance. Work to date suggests many devices in a PC may be modelled as B-Nodes using hierarchical decomposition. Work to date suggests that the B-Node model has wide applicability and may provide a useful pedagogical foundation for computer engineering. It is possible to model synchronous communications however problems exist for modelling arbitration protocols and asynchronous (event) transitions.

Student Evaluation

Whether such a model accords with the results of detailed experiments needs verification. A start has been made by measuring bandwidths of disk drive units via an oscilloscope. Further work is planned using assembly language based software bandwidth measurements. Students have used a simplified B-Node-model as part of their assignments where they were required to assess the suitability of PC systems to perform given functions. A detailed study was conducted to investigate student experience of the B-Node concept. From 80 students, 40 were given questionnaires, 36 thought the nodal concept should be taught, 35 thought that it helped them understand computer technology, 35 students thought that using a common unit (Frames/s) helped in evaluating PC devices. It is noteworthy that 50% of these students thought that more time should be spent on such calculations.

A test to investigate students basic mathematics and physics skills used in bandwidth calculations and discovered that at least 20% of students experienced difficulty in converting from frequency to time period, between SI magnitudes, and

also had problems with scientific notation. The test included questions to test these skills both individually and in combination. This investigation has been noted by Veal Maj and Swan [15] and was partly intended to complement assessments of competencies to ascertain levels of hands on practical skills in these units [14]. Short sessions of 5 to 10 minutes were included as part of the 2 hour workshops to give students extra examples in bandwidth calculations. This advanced from the simple to the more complex calculations over a period of weeks.

Conclusions

The authors do not suggest that the B-node model replace the teaching of a traditional computer technology curriculum (digital logic). Rather, it may serve as a useful introduction that provides useful knowledge and skills. Many students require an understanding of PC hardware for whom full digital technology approach may prove superfluous and the B-Node model could provide a simpler alternative. However an overview of the operation of disk drives and other devices is still required. A full digital technology approach may well be required by some students such as those computer science and engineering undergraduates intending to undertake research and development in the computer hardware field. From a constructivist viewpoint an overall conceptual model could still be useful to enhance learning. The investigation to determine student's skills in calculating bandwidths shows that further research is needed determine if the extra time spent on these topics in the workshops has resulted in a significant improvement. Bandwidth provides a conceptual structure for the units CIM and NIM using constructivist techniques. As students progress through their studies such conceptual frameworks could still be utilized. The problems inherent in using present benchmarks have been noted and bandwidth has been considered as a possible foundation for computer performance. More bandwidth measurements within the PC and other systems need to be carried out and the results checked for consistency by both software and hardware methods.

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3.2.4.4 Proposed New High Level Abstraction for Computer Technology

The paper (Maj, Veal, & Duley, 2001) was presented at the ACM Special Interest Group for Computing Science Education (SIGCSE) 2nd Technical Symposium in Computer Science Education, held at Charlotte, North Carolina, USA. The ACM is arguably the world's foremost body in the field of computing science and SIGCSE is most likely the world's foremost body in CS Education. This Annual Conference is their flagship worldwide forum for innovation in CS education.

This paper proposes a new generic model for modelling computer technology at higher levels of abstraction than those in current usage. Investigations to date indicate that this model is independent of the underlying details of a particular implementation technology and can therefore accommodate changes in the implementation technology. This new model is not only more directly relevant to the cheap, low cost modular architectures in use today but also work to date has strongly indicated it may be useful as the basis of a new pedagogical framework for teaching not only introductory and more advanced computer technology but also systems analysis and design. The use of constructivism in CNT education and its relevance to B-Node models is considered as is the use of derived units for CNT evaluation and comparison. The use of such derived units is applied to PC monitor performance requirements. Additional new knowledge includes the experimental results of further bandwidth investigation on HDDs to test B-Node concepts. B-Node concepts are broadened using recursive decomposition from commonly understood concepts within a constructivist framework. The self documentation nature of B-Nodes is also discussed. The relevance of the B-Node modeling in relation to the raising levels of abstraction in the British Computer Society (BCS) Hardware Curriculum is noted. The results of a series of experiments involving the use of a computer program written in the programming language C and used for internal bandwidth measurements in a PC are also discussed. These measurements were repeated using an oscilloscope. There is also a consideration of medical ultrasound imaging from a B-Node perspective.

A Proposed New High Level Abstraction for Computer Technology

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Abstract

Computer technology can be described using a range of models based on different levels of detail e.g. semiconductors, transistors, digital circuits. Such models are designed to progressively hid irrelevant detail and yet provide sufficient information to be useful for communication, design and documentation. However, developments in computer technology have resulted in a low cost, heterogeneous modular architecture that is difficult to model using current methods. This paper proposes a new generic method of modeling computer technology at a higher level of abstraction than those currently used. Investigations to date indicate that this model is independent of architectural detail and can therefore accommodate changes in technology. This new model is more directly relevant to the cheap, low-cost modular architectures in use today. Furthermore, all work to date has strongly indicated it may be useful as the basis of a new pedagogical framework for teaching not only introductory but also more advanced computer technology.

Keywords Computer technology education, modeling, constructivism.

Introduction

Digital techniques and modelling provide an abstraction that is independent of the underlying details of semiconductor switching. Such combinational or sequential circuits can be described without the complexity of their implementation in different switching technologies e.g. TTL, CMOS, BICMOS etc. Similarly details of semiconductor switching may be modelled using abstractions independent of the underlying details of quantum mechanics. Computer technology can therefore be described using a progressive range of models based on different levels of detail e.g. semiconductors, transistors, digital circuits.

Such models are designed to progressively hid, and hence control detail, and yet provide sufficient information to be useful for communication, design and documentation. This is in keeping with the ACM/IEEE Computing Curricula 1991 in which abstraction is a recurring concept fundamental to computer science (ACM, 1991a). Computing Curricula 1991 define nine subject areas that include Architecture as a pre-requisite chain of topics. However, computer design and manufacture has changed rapidly in the last decade. Assembly Level Manufacturing, Application Specific Integrated Circuits and Surface Mounted Technology have all lead to an ever-decreasing unit price and a resultant low cost PC with a standard architecture and modular construction. A state-wide survey by Maj found that computer technology is now managed as a modular system that

demands skills other than those provided by traditional computer science curriculum (Maj, Fetherston et al., 1998). From this survey a set of guidelines were developed for the type of skills expected of computer science graduates entering the field of computer and network support. Using the criteria developed a random selection of ten, final year Edith Cowan University (ECU) computer science undergraduates were interviewed from a graduating population of approximately one hundred.

The computer science degree at ECU is level one accredited, the highest, by the Australian Computer Society (ACS). The ACS curriculum is comparable to the ACM/IEEE 1991 Computing Curriculum. According to Maj none of the students interviewed had the skills expected by prospective employers (Maj, Fetherston et al., 1998). Interviews conducted with five ECU graduates found to be employed in computer and network support 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. The initial ECU student questionnaire, first used in 1993, was also conducted in 1999 at two universities within the UK. Both universities have well established degree programs that are British Computer Society (BCS) accredited. According to Maj (Maj, 2000) the results obtained were directly comparable to the original survey. Furthermore, there is considerable unmet potential demand from students of other disciplines for instruction in computer technology (Engel & Maj, 1999). Students from other disciplines wanted a better knowledge and understanding of computer technology but failed to see the relevance of the current curriculum. According to the 1991 ACM/IEEE-CS report, *"The outcome expected for students should drive the curriculum planning"* Significantly Clements comments, *"Consequently, academics must continually examine and update the curriculum, raising the level of abstraction"* (Clements, 2000c). A demand that traditional courses in computer technology may not be meeting.

Computing Curricula

Professional bodies are variously responsible for the accreditation of awards and defining curriculum content. The ACM/IEEE-CS Computing Curricula 1991 define nine subject areas that include Architecture. Different countries have their own professional bodies. During the 1970's and 1980's the British Computer Society (BCS) offered a two-part curriculum: Part I equivalent of a Higher National Diploma and Part II equivalent to an honours degree. This curriculum was available on an international basis with examination centres throughout the world. The Part I examination included an option, *"Fundamentals of Computer Technology"*. Part II built upon this with an option, *"Digital Computer Organization, Design and Engineering."* One of the topics in this unit *"Integrated Circuit Design and Fabrication"* required detailed knowledge of technologies that included: MOS devices: the inverter, NAND and NOR logic, scaling, stick diagram design rules, silicon wafer fabrication etc. A preliminary analysis of all the Part II examination papers in the topic *"Digital Computer Organization, Design and Engineering."* over the past twenty years, indicates this curriculum has progressively changed with respect to the technical detail expected of candidates. The new BCS Part II

curriculum is now called the Professional Graduate Diploma and the only hardware unit is *"Distributed and Parallel Systems"* which does not require candidates to have any knowledge of the technical detail previously demanded by the topic *"Integrated Circuit Design and Fabrication"*. The BCS Part I has been renamed Diploma and has a unit called *"Architecture"* with one section on Digital Logic (Combinational and sequential circuits). The BCS curriculum has adapted to the changes in the developments of computer technology.

Teaching Computer Technology

The problems associated with teaching computer technology are not new. Simulation has proved to be a very useful tool (Magagnosc, 1994), (Searles, 1993), (Bergmann, 1993), (Reid, Barington, & Kenney, 1992), and (Pilgrim, 1993), took an alternative approach in which a very small computer was designed in class and breadboarded in the laboratory by students using small and medium scale TTL integrated circuits. According to Parker and Drexel (Parker & Drexel, 1996) simulation is a preferred approach but note that students often do not see the 'big picture'. The difficulty of providing a suitable pedagogical framework is further illustrated by Coe and Williams (Coe et al., 1996) who address this problem by means of simulation. Barnett (Barnett III, 1995) suggests that standard computer architecture is too complex for introductory courses. The PC is now a low cost consumer item due to design and manufacturing changes. The PC has a standard, heterogeneous architecture and modular construction. However, traditionally computer technology education is typically based on digital techniques, Karnaugh maps etc. Operation on PCs at this level hardly exists any more. This problem is exacerbated not only by the constant and rapid changes in technology but also the requirement to teach computer technology to students from a wide range of discipline such as multimedia. The authors therefore attempted to find an alternative approach to teaching introductory computer technology.

Constructivism

Prior to examining how to improve student learning we attempted to attain a deeper understanding of how students learn and construct knowledge. Constructivism is the dominant theory of learning today. According to Ben-Ari commented, *"it can provide a new and powerful set of concepts to guide our debates on CSE (Computer Science Education)"* (Ben-Ari, 1998). According to this theory students have their own cognitive structures each of which is the foundation of the learning process. Computer Science and Multimedia students understand a PC very differently. We attempted therefore to find a common conceptual framework held by students, from different disciplines, as the basis for a cognitive structure that could be modelled.

Models and Modeling

Models are used as a means of communication and controlling detail. Diagrammatic models should have the qualities of being complete, clear and consistent. Consistency is ensured by the use of formal rules and clarity by the use of only a few abstract symbols. Levelling, in which complex systems can be progressively decomposed, provides completeness. According to Cooling (Cooling, 1991), there are two main types of diagram: high level and low level. High level

diagrams are task oriented and show the overall system structure with its major sub-units. Such diagrams describe the overall function of the design and interactions between both the sub-systems and the environment. The main emphasis is 'what does the system do' and the resultant design is therefore task oriented. According to Cooling, *"Good high-level diagrams are simple and clear, bringing out the essential major features of a system"*. By contrast, low-level diagrams are solution oriented and must be able to handle considerable detail. The main emphasis is "how does the system work". However, all models should have the following characteristics: diagrammatic, self-documenting, easy to use, control detail and allow hierarchical top down decomposition. Computer technology can be modelled using symbolic Boolean algebra (NOR, NAND gates). These gates may be implemented using solid-state electronic switches or even gas state electronics i.e. thermionic valves. At this lower level, the basic implementations of solid state switching may be described with models directly relevant to engineers at this level of operation. Logic gates may be connected to create combinatorial and sequential circuits and hence functional units such as Read Only Memory (ROM) etc. Such functional units can also be modelled but using high level diagrams. The underlying switching technology is not relevant at this higher level of abstraction.

At an even higher level of abstraction computer technology can be modelled as a collection of programmable registers. Dasgupta [9] suggested computer architecture has three hierarchical levels of abstraction. However, as suggested above, the PC is now a low cost consumer item with a standard, heterogeneous architecture and modular construction. A higher level of model is therefore needed that is directly relevant to this current technology. Other high level models, expressed as formalisms, exist with an associated mathematical framework and language. Hardware Description Languages offer precise modelling notation, however such notation may not be suitable for a first year course in computer technology.

The PC – A Constructivist Nodal Model

We suggest that it is a common experience to perceive the PC as a modular device (CDROM, Zip Drive, Modem etc) used to store, view and process either local or networked data. The traditional bottom up method of teaching computer technology is not a good constructivist approach. Accordingly Scragg (Scragg, 1991) recommends a top down approach starting with material already familiar to students and then working towards less familiar models. Clements suggests that, for example, a floppy disc drive may be considered as a loosely coupled Multiple Instruction, Multiple Data (MIMD) device (Clements, 1989). A PC is therefore a complex collection of heterogeneous devices interconnected by a range of bus structures. However, from a user perspective, a PC is a low cost, storage device capable of processing data. In this context we therefore define a PC as a MIMD architecture of sub-units or nodes (Maj, 2000). Each node (microprocessor, hard disc drive etc) can be treated as a data source/sink capable of, to various degrees, data storage, processing and transmission. This simple, high-level, task oriented model may provide a suitable conceptual map and hence the framework for an introduction to computer technology. Even though technical detail is lost, this model is conceptually simple; controls detail by abstraction and may allow students to easily make viable constructs of knowledge based on their own experience.

However, to be of significant value this model must also be a tool that can actually be used by students. We therefore examined PC performance to further develop this model.

PC Performance - Bandwidth Nodes

benchmarks can be used to evaluate PC performances that, in conjunction with factors such as price, are an aid to selection. In an attempt to obtain more meaningful evaluations consumer magazines use Benchmark suites to evaluate PC's and publish their results (Australian Personal Computer, 1998). As a relative guide Benchmarks are an aid to selection, however, all of these results must be interpreted and many questions still remain for users. Typically the user is not able to determine the type of scales used (linear, logarithmic etc) or the expected change in performance with higher benchmark values. Furthermore, as a user how is the difference in performance manifested and perceived. We conclude that the plethora of benchmarks, though useful, do not provide the basis of a coherent conceptual model of a PC.

Any measurement standard, to be of practical value to PC users, must be relevant to human dimensions or perceptions and use units based on the decimal scaling system. To a first approximation the performance of PC nodes can be evaluated by bandwidth with units in Bytes/s. Though useful it may not be the best initial, user oriented unit - a typical user runs 32 bit windows based applications. The user is therefore interacting, via a Graphical User Interface (GUI), with text and graphical images.

For general acceptance a Benchmark must be easy to understand and should therefore be based on user perception of performance and as such be simple and use reasonably sized units. We suggest that a useful unit of measurement is the display of a single, full screen, full colour image. For this paper we define a full screen image as 1024 x 1280 with 3 bytes per pixel, which represents 3.75Mbytes of data. The performance of a PC and associated nodes can still be evaluated using the measurement of bandwidth but with the units of standard images/s or frames/s. This unit of measurement may be more meaningful to a typical user because it relates directly to their perception of performance. To a first approximation, smooth animation requires approximately 30 frames/s (112.5Mbytes/s). Obviously sub multiples of this unit are possible such as quarter screen images and reduced colour palette such as 1 byte per pixel. We have therefore a common unit of measurement, relevant to common human perception, with decimal based units, that can be applied to different nodes and identify performance bottlenecks. Each node (microprocessor, hard disc drive etc) can now be treated as a quantifiable data source/sink (Frames or Mbytes) with an associated transfer characteristic (Frames/s or Mbytes/s). The nodes are now defined as B-nodes. This approach allows the performance of every node and data path to be assessed by a simple, common measurement - bandwidth. Where $\text{Bandwidth} = \text{Clock Speed} \times \text{Data Path Width}$ ($B = C \times D$) with the common units of Frames/s (Mbytes/s).

The PC as a Bandwidth Node Model

The heterogeneous nature of the nodes of a PC is clearly illustrated by the range of measurement units used varying from MHz to seek times in milliseconds. Evaluation of these different nodes is therefore difficult. However, it is possible to compare the performance of different nodes using the common measurement of bandwidth in standard Frames/s or Mbytes/s. We can therefore analyse the PC as a collection of B-Nodes with the units of Mbytes/s and Frames/s (Table 1). Given that Mbytes and Mbytes/s may be considered as fundamental units other derived units may be used. Similarly the characteristics of the data frame may be changed according to different applications more directly relevant to users. In medical applications radiology images are often stored digitally. A single ultrasound image represents approximately 0.26Mbytes of data (Dwyer, 1992), which at 30 frames per second is 7.8Mbytes/s.

Table 1: Bandwidth

Device	Clock Speed (MHz)	Data Width (Bytes)	Bandwidth (Mbytes/s) $B = C \times D$	Bandwidth (Frames/s)
Processor	400	8	3200	853
DRAM	16	8	128	34
Hard Disc	60rps	90Kbytes	5.2	1.4
CDROM			4.6	1.2
ISA bus	8	2	16	4.2

The performance of each device may be calculated using this metric. A PC can be therefore understood as a hierarchical collection of nodes, interconnected by different buses, operating at different bandwidths. We then examined if this bandwidth node model was valid for increasing levels of technical complexity.

Sub-optimal Operation

Nodes typically operate sub-optimally due to their operational limitations and also the interaction between other slower nodes. For example, a microprocessor may need two or more clock cycles to execute an instruction. Similarly a data bus may need multiple clock cycles to transfer a single data word. The simple bandwidth equation can be modified to take this into account i.e. $\text{Bandwidth} = \text{Clock} \times \text{Data Path Width} \times \text{Efficiency}$ ($B = C \times D \times E$). The early Intel 8088/86 required a memory cycle time of 4 clocks cycles (Efficiency = $\frac{1}{4}$) however, for the Intel 80x86 series, including the Pentium, the memory cycle time consists of only 2 clocks (Efficiency = $\frac{1}{2}$) for external DRAM (Mazidi & Mazidi, 1995). A 100MHz Pentium has a therefore bandwidth of 400Mbytes/s. Other devices can similarly be modelled. We conclude that the proposed simple bandwidth performance measurement may be extended to accommodate the sub-optimal performance of PC nodes. However, other factors not considered include the effects of compression, operating system overheads etc. The effect of these is currently being examined.

Recursive Decomposition

Further experimental work has demonstrated that B-nodes allow recursive decomposition. Hence a PC can be described as a B-node or a collection of devices

all modelled as B-nodes. Each device can also be modelled as a collection of B-nodes. By example a hard disc drive, itself a B-node, can be decomposed into B-Nodes that represent the electromechanical devices (motors, CHS architecture) and the hard disc controller (ENDEC, ECC, etc).

Experimental Results

We first established a general experimental method to determine data transfer rates between nodes within a PC to evaluate the use of frames/s as a measurement of performance. A C program was used to transfer data between two nodes, a Hard Disc Drive (HDD) and Synchronous Dynamic RAM (SDRAM), flagging the start and stop of this operation on the parallel port. An oscilloscope (100 micro second resolution), connected to this port measured the data transfer rate in Mbytes/s. The results obtained related directly to the manufactures technical specification of the HDD. We were able to detect the influence of HDD caching and also track and cylinder latency thus verifying the experimental method. A single, uncompressed 640x480, 4bytes/pixel-video image was generated and transferred from the HDD to both SDRAM and a third node, the video adapter card. The data transfer rate from HDD to SDRAM was 1.48Mbytes/s, which can be expressed as 1.21 frames/s. From the HDD to video adapter card the data rate was 1.37Mbytes/s i.e. 1.1 frames/s. The data transfer rate for the video card is 18.6Mbytes/s i.e. 15.1 frames/s. It was possible therefore to determine the relative performance of heterogeneous devices and determine bottlenecks in the system.

Nodes as a Constructivist Framework

As a result of the initial investigations at ECU a new curriculum was designed, implemented and fully evaluated at ECU (Maj, Fetherston et al., 1998). Unlike the standard computer technology curriculum students are not taught digital techniques, assembly language programming etc. Rather the curriculum is based on a constructivist approach recommended by this paper. This curriculum has always been oversubscribed, has a very low student attrition rate, and attracts students from other Faculties in ECU and students from other universities in the state. This new curriculum, though perceived as valuable by students when first introduced, arguably lacked a coherent conceptual framework. Last year we used B-nodes as such a framework for the first time and evaluated the results. Using this conceptual framework the PC is considered as a series of nodes whose performance is measured by bandwidth (Frames/s). Using the standard compulsory ECU course evaluation questionnaire the unit was highly rated by students. Furthermore, a more detailed study was conducted to investigate student experience of the nodal concept. From an enrolment of eighty students, forty were randomly selected and given questionnaires. Thirty-six students thought the nodal concept should be taught. Thirty-five students thought that this concept helped them understand computer technology. Thirty-five students thought that using a common unit (Frames/s) helped in evaluating PC devices. Advantages of this model include:

- Students perceive the PC as a unified collection of devices based on constructivist principles.
- Bandwidth in Mbytes/s can be considered as a fundamental unit from which other units may be derived.

- B-Node performance, measured in bandwidth (Frames/s) is a user based, easily understood measurement.
- B-Nodes are independent of architectural detail and hence may be of value for some time to come.
- B-Nodes are diagrammatic, self-documenting, easy to use and control detail.
- Using recursive decomposition B-Nodes can be used to model more complex computer technology devices.

Conclusions

This paper proposes nodes, whose performance is rated by bandwidth (frames/s), as the basis of an introduction to computer technology curriculum. Work to date indicates that modelling the PC as such a collection of nodes provides a good constructivist framework allowing technical detail to be introduced in a controlled, top-down manner that is readily understandable to students from all disciplines. The nodal model provides abstraction and hence is independent of architectural detail and can therefore accommodate rapid changes in technology. Furthermore, this technique supports more advanced studies in computer technology. However further work is needed to investigate how the effects of overheads such as the operating system can be incorporated into this model.

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3.2.4.5 Controlling Complexity in Information Technology: Systems and Solutions

This paper (Maj & Veal, 2001), was presented at the International Association of Science and Technology for Development (IASTED) conference on Computers and Advanced Technology in Education (CATE 2001). This conference, held at Banff, Canada, was a major conference venue in the field of computer education.

This paper discusses the topics of modelling digital infrastructure and the Structured Systems Analysis and Design Method (SSADM) and its utilisation in the selection of hardware. Also discussed is the lack of other suitable software engineering methods for such modelling. The application of B-Node concepts to E-commerce architecture is described. This paper also considers the sub-optimal B-Node operation. Further consideration is given to B-Nodes and E-Business architecture. Bandwidth in transactions per second is considered, as well as concepts of relative frequency, which are applied to bandwidth equations, the results are presented as are the findings from student questionnaires on B-Nodes and E-commerce servers.

New knowledge presented via this paper evaluated the B-Node modeling technique as a possible standard technique in structured systems analysis and design for evaluating hardware performance. The application of B-Node concepts to E-commerce servers and the evaluation of bottlenecks using derived units such as transactions per second (tps) using B-Nodes. B-Node bandwidth formulae are applied to Customer Model Behaviour Graphs (CMBGs) to evaluate bandwidth demands of ecommerce servers under differing patterns of customer behaviour.

Controlling Complexity in Information Technology: Systems and Solutions

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Abstract

There exist a wide range of methods that can be used for the analysis and design of IT systems. Some methods are based on a rigorous mathematical foundation (e.g. VDM). Other, less formal methods provide a clearly defined structured framework with associated tools and techniques. Uniquely soft system methodologies attempt to capture the complexity of human interactions with IT systems. Regardless of which type of method is used the final product must be a fully functioning IT system that meets the requirements of the Service Level Agreement. However a survey of a wide range of methods and a detailed analysis of one structured method indicated the lack of a simple method for modeling hardware. This paper evaluates the new B-Node modeling technique as a possible standard technique in structured systems analysis and design for evaluating hardware performance. The use of B-nodes as a pedagogical framework has been successfully evaluated and the results are presented.

Keywords: Systems Analysis and Design, modeling, B-Nodes

Introduction

In order for any Information Technology system (e.g. E-Commerce, Digital Library) to provide a prompt and possibly worldwide service they must be based on a complex infrastructure of hardware and software. Furthermore this system must provide a Quality of Service to meet the Service Level Agreement. In order to control the complexity associated with designing an IT system standard analysis and design methods are used. There are a wide range of methods that variously employ different modeling tools and techniques. A method consists of phases or stages that in themselves may consist of sub-phases. There exist a wide range of methods that include ad hoc (Jones 1990), waterfall (Royce 1970), participative (Mumford and Wier 1979), soft systems (Checkland 1981), prototyping (Naumann and Jenkins 1982), incremental (Gibb 1988), spiral (Boehm 1984), reuse (Matsumoto and Ohno 1989), formal (Andrews and Ince 1991), rapid application development (Martin 1991), object oriented (Coad and Yourdon 1991) and software capability (Humphrey 1990). Some systems development methods only stress the technical aspects. It can be argued that this may lead to a less than ideal solution as these methods underestimate the importance and difficulties associated with the human element. Regardless of the underlying theme of each information system all methods must provide techniques for modeling data, processes and system functions. However this wide variety of modeling techniques and associated metrics may in itself problematic and arguably adds to the

complexity. Furthermore, there appears to be no simple technique that will model the digital infrastructure (hardware and software) to determine if it will perform to an acceptable standard required by the analysis and design specifications. The Structure Systems Analysis and Design Method (SSADM) was evaluated in-depth as a method for developing an information system.

Structured Systems Analysis and Design Method

SSADM is mandatory for UK central government software development projects. This method is sponsored by the Central Computer and Telecommunications Agency (CCTA) and the National Computing Centre (NCC) thereby further ensuring its importance within the software industry within the UK. SSADM is a framework employing a wide range of techniques (Data Flow Diagrams, Entity Models, Entity Life Histories, Normalization, Process Outlines and Physical Design Control). SSADM is divided into six stages (Analysis, Specification of Requirements, Selection of System Option, Logical Data Design, Logical Process Design and Physical Design). The Physical Design translates the logical data design into the database specification and the logical process designs into code specifications. SSADM is recognized to be a highly structured method with numerous cross checks to ensure quality control.

The final stage of SSADM (Physical Design stage) includes a step called, 'Create Performance Predications and Tune Design (Step 630)'. The objectives of this step are to produce a tuned physical data and process design that meets the Performance Objectives previously agreed with users in a previous stage. SSADM provides tools that allow the estimation of storage requirements. From the Composite Logical Data Design and Logical Design Volumes, detailed information about the data volumes may be extracted. It is possible to obtain detailed information about: data space for each data group, volumes of each data group, volumes of relationships, variance of volumes over time etc. According to Ashworth, *"The basic approach to timing is to calculate the disk access time and CPU utilization time for each transaction. The actual elapsed time taken by a transaction (or response time for an on-line transaction) will probably be several times larger than that calculated."* And furthermore, *"The prediction of overall system performance is a difficult area and there are several simulation programs and experts system programs available which attempt to predict and improve system performance either generally or for specific hardware and software."* (Ashworth and Goodland 1990)

Other than this there are no simple tools or techniques that can be used for the selection of hardware. Furthermore, SSADM employ a range of different, heterogeneous performance metrics that include: MPS, CPU time, disk access time, number of instructions per database call etc. Such benchmark metrics are in themselves problematic.

Benchmarks - Background

There are wide ranges of different metrics that are used to describe the performance of a computer system. Benchmarks, in conjunction with factors such as price, are an aid to selection. Benchmark programs considered directly relevant to a typical single user, multi-tasking environment running a de facto standard suite of 32 bit

applications include : AIM Suite III, SYSmark and Ziff-Davis PC Benchmark. Consumer magazines use Benchmark suites to evaluate PC's and publish their results (PCs 1998) (Table 1).

Table 1: PC Benchmark Suite

Benchmark	Gateway G6 300	IBM Aptiva EQ3
Business Winstone 98	20.63	18.33
CD-ROM WinMark 98 : Overall	1,556.67	1,350
CPUmark 32	772	550.33
Business Disk WinMark 98	1,380	939
High-End Disk WinMark 98	3,783.33	2,736.67
Business Graphics WinMark 98	93.13	105.67
High-End Graphics WinMark 98	146	130

As a relative guide Benchmarks are an aid to selection, however, all of these results must be interpreted and many questions still remain for users. Questions include:

- What difference in performance can a user expect if the benchmark value result is higher by 1 or 2 units or by a factor of 10 or more? For example, what difference in performance would a user expect between an IBM Aptiva EQ3 (Business Disk WinMark 98 value of 939) and a Gateway G6 300 (Business Disk Win Mark 98 value of 1,380)?
- Are the scales linear, logarithmic, hyperbolic?
- What units are used? Does each Benchmark define their own (unspecified) units?
- As a user, how is the difference in performance manifested and perceived?

How can different types of devices be compared, e.g. how can the performance of a hard disc drive be compared to a microprocessor? Lilja defines the characteristics of a good performance metric and concludes, *"A wide variety of performance metrics has been proposed and used in the computer field. Unfortunately, many of these metrics are not good in the sense defined above, or they are often used and interpreted incorrectly"* (Lilja 2000). Measurements are used to make, exchange, sell and control objects. According to Barney, *"A measurement is the process of empirical objective assignment of numbers to properties of objects or events in the real world in a way such as to describe them"* (Barney 1985). History has many examples of measures in the search for useful standards. Early Egyptians defined one finger-width as a zebu and established an associated simple, reproducible and denary scale of standard measurements. It is significant that human dimensions were used as the basis of one of the first standards. The System International (SI) system meets the ancient requirements of simplicity and ease of use due to reasonably sized units. Measurements, therefore, require:

- Definition of units (relevant to human dimensions or perceptions)
- Establishment of standards
- Use of SI units (i.e. decimal scaling system)
- Derivable units

Given these required characteristics of performance metrics we examined some of the principles of modeling as the basis of the design of a new technique for modeling hardware.

Models and Modeling

Models are used not only as a means of communication and controlling detail but may also forming the basis of a conceptual understanding of a system. According to Cooling there are two main types of diagram: high level and low level. High-level diagrams are task oriented and show the overall system structure with its major sub-units. Such diagrams describe the overall function of the design and interactions between both the sub-systems and the environment. The main emphasis is 'what does the system do' and the resultant design is therefore task oriented.

According to Cooling, *"Good high-level diagrams are simple and clear, bringing out the essential major features of a system"* (Cooling 1991). By contrast, low-level diagrams are solution oriented and must be able to handle considerable detail. The main emphasis is 'how does the system work'. However, all models should have the following characteristics: diagrammatic, self-documenting, easy to use, control detail and allow hierarchical top down decomposition. In effect models provide abstraction to control complexity and change. There have been, and may continue to be, many technical developments that impact on computer and network technology education. Clements makes the point that, *"For example, the generation of students studying electronics in the 1950's leaned about the behavior of electrons in magnetic fields. The next generation studied transistor circuits, and the one after that studied integrated circuits. The traditional logic course changes rapidly."* (Clements 2000).

Digital techniques and modeling provide an abstraction that is independent of the underlying details of transistor theory. Such combinational or sequential circuits can be described without the complexity of their implementation in different switching technologies e.g. Transistor-Transistor Logic (TTL), Complementary Metal Oxide Semiconductors (CMOS) etc. Similarly details of semiconductor switching may be modeled using abstractions independent of the underlying details of quantum mechanics. Computer and network technology can therefore be described using a progressive range of models based on different levels of detail e.g. semiconductors, transistors, digital circuits, registers, device controllers, clients, servers etc. Each model is valid in the context in which it is used. All such models are designed to progressively hid and hence control detail and yet still provide sufficient information to be useful for communication, design and documentation. This is in keeping with the ACM/IEEE Computing Curricula 1991 in which abstraction is a recurring concept fundamental to computer science (Tucker, Barnes et al. 1991).

A PC can be described as a collection of sub-modules (microprocessor, electronic memory, hard disc drive etc) arranged in a memory hierarchy (Hwang and Briggs 1987). The performance of a PC depends therefore on the performance of individual sub-modules. However, the sub-modules employ different technologies

(electronic, electromechanical etc) and there exists therefore a wide range of performance metrics that include: MHz, nanoseconds, rpm, seek time, latency etc. The direct comparison and evaluation of these heterogeneous modules is therefore problematic. Furthermore, there appears to be no simple model that can be used to describe these sub-modules. A new higher-level abstract model of computer and network technology and associated metric is needed not only as a commercial tool but also as a new pedagogical tool.

Bandwidth Nodes

A PC and its associated sub-modules (microprocessor, electronic memory, hard disc drive etc) may be modeled using B-Nodes (Maj, Veal et al. 2000). Each B-Node can be treated as a data source/sink capable of, to various degrees, data storage, processing and transmission. The performance of each B-Node may be calculated, to a first approximation, by $\text{Bandwidth} = \text{Clock Speed} \times \text{Data Path Width}$ ($B = C \times D$) with units in either MBytes/s or Frames/s. A frame is defined as 1024×1024 pixels with a color depth of 3 bytes per pixel i.e. 3MBytes. This simple, high-level, task oriented model may provide a suitable conceptual map and hence the framework for an introduction to computer and network technology. Even though some technical detail is lost, this model is conceptually simple, controls detail by abstraction and may allow students to easily make viable constructs of knowledge based on their own experience. This is in keeping with constructivist principles as a top down approach starting with material already familiar to students and then working towards less familiar models. The units Frames/s may be more meaningful to a typical user because it relates directly to their perception of performance. To a first approximation, smooth animation requires approximately 30 Frames/s (90MBytes/s). The performance of each B-Node may be calculated using this metric. The use of B-Nodes using the performance metrics of Mbytes/s and Frames/s has been confirmed experimentally (Maj, Veal et al. 2000). We have therefore a common unit of measurement, relevant to common human perception, with decimal based units, that can be applied to different nodes and identify performance bottlenecks.

The heterogeneous nature of the modules of a PC is clearly illustrated by the range of measurement units used varying from MHz to seek times in milliseconds. Evaluation of these heterogeneous modules, each using different units of measurement, is therefore difficult. However if the modules are modeled as B-Nodes common units of measurement may be used - either Mbytes/s or Frames/s. The use of simple, fundamental units allows other units such as frame transfer time to be easily calculated. This allows the performance of heterogeneous units to be directly compared (Table 2) using the same units. The B-Node model has been successfully applied to a wide range of PC architectures allowing a direct comparison not only between different B-Nodes within a given PC but also comparisons between different PC's.

Using B-Nodes it was possible to analyze PC's with different Intel microprocessors (8088/6, 286, 386, 486 etc.) and various associated bus structures (Micro Channel Architecture, Extended Industry Standard Architecture, Video Electronic Standards (VESA) Local Bus).

Table 2: Bandwidth

Device	Clock Speed (MHz)	Data Width (Bytes)	Bandwidth (MBytes/s)	Bandwidth (Frames/s)
Processor	400	8	3200	1066
DRAM	16 (60ns)	8	128	42
Hard Disc	60rps	90Kb	5.4	1.8
CDROM	(30 speed)		4.6	1.5
ISA Bus	8	2	16	5.3
Ethernet	100	1/8	12.5	4.1

Sub-optimal Operation

B-Nodes typically operate sub-optimally due to their operational limitations and also the interaction between other slower nodes. For example, a microprocessor may need two or more clock cycles to execute an instruction. Similarly a data bus may need multiple clock cycles to transfer a single data word. The simple bandwidth equation can be modified to take this into account i.e. $\text{Bandwidth} = \text{Clock} \times \text{Data Path Width} \times \text{Efficiency}$ ($B = C \times D \times E$). The early Intel 8088/86 required a memory cycle time of 4 clocks cycles (Efficiency = $\frac{1}{4}$) however, for the Intel 80x86 series, including the Pentium, the memory cycle time consists of only 2 clocks (Efficiency = $\frac{1}{2}$) for external DRAM. Efficiencies can be calculated for each device and the performance calculated accordingly (Table 3).

Table 3: Bandwidth with Efficiency

Device	Efficiency	Bandwidth (MBytes/s) $B = C \times D \times E$	Bandwidth (Frames/s)
Processor	0.5	1600	533
DRAM	0.5	64	21
Hard Disc	0.5	2.7	0.9
CROM	0.5	2.3	0.8
ISA Bus	0.25	4	1.3
Ethernet	0.9	11.25	3.8

Further experimental work has demonstrated that B-nodes allow recursive decomposition. Hence a PC can be described as a B-node or a collection of devices (processor, DRAM, hard disc drive etc) all modeled as B-nodes. Each device can also be modeled as a collection of B-nodes. By example a hard disc drive, itself a B-node, can be decomposed into B-nodes that represent the electromechanical devices (motors, CHS architecture) and the hard disc controller (ENDEC, ECC, etc). However, other factors not considered include the effects of compression, operating system overheads etc. The effect of these is currently being examined.

B-Nodes and e-Business Architecture

Using a structured systems analysis and design method, such as SSADM, it is possible to design a database for an e-business system. For such a system the Customer Model can be used to describe the user behavior patterns in which the

number of clients, type of resources requested, pattern of usage etc are all used to determine the workload characteristics. Workload characteristics, in conjunction with the resource infrastructure model will determine site performance and whether or not the Service Level Agreements can be met. Customer Behavior Modeling methods have been successfully used to determine aggregate metrics for E-Commerce web sites (Menasce, Almeida et al. 1999). Using these various models it is possible to obtain a wide variety of different performance metrics that include: Hits/s, Page Views/Day, Unique Visitors etc.

Furthermore, the SSADM method employs a range of different, heterogeneous performance metrics that include: MPS, CPU time, disk access time, number of instructions per database call etc. Given this wide range of different units performance evaluation is problematic. By example how can the units of Hit/s be used to select the bus structure of a PC? However, if a web server is modeled as a B-Node then the performance metric is bandwidth with units of Mbytes/s.

The sub-modules of a server (microprocessor, hard disc, electronic memory etc) and also be modeled as B-Nodes, again using the same performance metric. The use of fundamental units (Mbytes/s) allow other units to be derived and used e.g. transactions per second (tps). Assuming the messages in a client/server interaction are 10kbytes each, the performance of each B-Node can be evaluated using the units of transactions/s (Table 4)

Table 4: Bandwidth

Device	Bandwidth (MBytes/s)	Bandwidth (tps)	Load (tps)	Utilization
Processor	1600	160k	250	<1%
DRAM	64	6.4k	250	4%
Hard Disc	2.7	270	250	93%
CDROM	2.3	230	250	>100%
ISA Bus	4	400	250	63%
Ethernet	11.25	1.1k	250	23%

If the demand on this server is 250 Transactions/s it is a simple matter to determine both performance bottlenecks and also the expected performance of the equipment upgrades. From table 4 it is possible to determine that for this web server, the hard disc drive, CDROM and ISA bus are inadequate. The metric of transactions/s can easily be converted to the fundamental unit of Mbytes/s, which can then be used to determine the required performance specification of alternative bus structures, CDROM devices and hard discs. A PCI (32 bit) bus structure is capable of 44Mbytes/s. A 40-speed CDROM device has a bandwidth of approximately 6Mbytes/s. Similarly replacing the single hard disc drive by one with a higher performance specification (rpm and higher track capacity) results in a new server capable of meeting the required workload (Table 5). Capacity planning is the process of predicting future workloads and determining the most cost-effective way of postponing system overload and saturation. Assuming that the web traffic is anticipated to rise to 550 transactions/s – the current single server solution will be

inadequate. To accommodate much higher web traffic a typical e-business configuration may consist of a front-end Web server, a Secure Web server, a Payments server, an Application server and a Database server.

Table 5: Upgraded Server

Device	Bandwidth (MBytes/s)	Bandwidth (Tps)	Load (Tps)	Utilization
Processor	1600	160k	250	<1%
DRAM	64	6.4k	250	4%
Hard Disc	12.5	1.25k	250	20%
CROM	6	0.6k	250	42%
PCI Bus	66	6.6k	250	4%
Ethernet	11.25	1.1k	250	23%

Assuming each server is a separate device connected by a 100Mbps Ethernet link it is possible to model this configuration using B-Nodes. Each server represents a B-Node. The communication link may be represented as a directed arc (arrow) annotated by its bandwidth performance (units MBytes/s or Transactions/s). Using Customer Behaviour Model Graphs (CBMG's) it is possible to evaluate the relative frequency that each dedicated server is used. Assuming probability based on relative frequency our performance equation is now $\text{Bandwidth} = \text{Clock Speed} \times \text{Data Path Width} \times \text{Efficiency} \times \text{Frequency}$ ($B = C \times D \times E \times F$). For each server the results can be tabulated (table 6).

Table 6: E-Commerce Servers

	Network Bandwidth (Tps)	F	Actual server load (Mbytes/s)	Actual server load (Tps)
Web server	1.1k	0.5	5.625	0.55k
Secure server	1.1k	0.05	0.5625	0.055k
Payment server	1.1k	0.05	0.5625	0.055k
Database server	1.1k	0.2	2.25	0.22k
Application server	1.1k	0.1	1.125	0.11k

The load data obtained from table 6 can then be used to evaluate the performance of the individual components in each server. In the case of the Web server the actual load is 5.625Mbyte/s (0.55kTransactions/s) from which the utilization of each module can be evaluated (table 7).

Table 7: Evaluation of E-Commerce Web server

Web Server	Bandwidth (Tps)	Load (Tps)	Utilization
Processor	160k	550	<1%
DRAM	6.4k	550	9%
Hard Disc	1.25k	550	44%
CROM	0.6k	550	92%
PCI Bus	6.6k	550	8%
Ethernet	1.1k	550	50%

B-Nodes as a Pedagogical Framework

Clements comments, *"While the knowledge base academics must teach is continually expanding, only a fraction of that knowledge can be taught during a student's time at a university. Consequently, academics must continually examine and update the curriculum, raising the level of abstraction"* (Clements 2000).

A new curriculum based on B-Nodes was designed, implemented and fully evaluated at ECU (Maj and Veal 2000). Unlike the standard computer technology curriculum students are not taught digital techniques, assembly language programming etc. This new curriculum has always been oversubscribed, has a very low student attrition rate, and attracts students from other Faculties in the university and students from other universities in the state. Using the standard compulsory ECU course evaluation questionnaire the unit was highly rated by students. Furthermore an educational expert conducted an in-depth analysis with very positive results (Maj, Fetherston et al. 1998).

In addition to this a more detailed study was conducted to investigate student experience of the B-Node concept. From an enrolment of eighty students, forty were randomly selected and given questionnaires. Thirty-six students thought the B-Node concept should be taught. Thirty-five students thought that this concept helped them understand computer technology. Thirty-five students thought that using a common unit (Frames/s) helped in evaluating PC devices. As a result of the evaluation, one student wrote:

"The lack of meaningful and comparable technical specifications makes the task of calculating the performance of a PC and its individual components a difficult one. The computer industry appears to be a law unto oneself, with incomplete or non-existent technical specifications. The use of standards, terms and abbreviations that are not comparable across different systems or manufacturers. This all leads to frustration and confusion from consumers and users of these computer systems and components"

And for a given technical specification the student wrote:

"Sounds impressive, yet by undertaking the exercise of converting to the components common units the relative performance of the PC and its individual components can be measured and conclusions drawn. You will finally be able to see exactly what you are purchasing, its strengths, weaknesses and overall value"

Advantages of the B-Node model include:

- Students perceive the PC as a unified collection of devices based on constructivist principles.
- Bandwidth in Mbytes/s can be considered as a fundamental unit from which other units may be derived.
- B-Nodes are independent of architectural detail and hence may be of value for some time to come.
- B-Nodes are diagrammatic, self-documenting, easy to use and control detail.
- Using recursive decomposition B-Nodes can be used to model more complex computer technology devices.

Conclusions

A survey of a wide range of methods and a detailed analysis of one structured method (SSADM) indicated the lack of a simple method for modeling hardware. A possible modeling method is B-Nodes. B-Nodes are a simple, easy to use, diagrammatic and self-documenting modeling technique. They are scalable and can be used for PC modules (microprocessor, hard disc etc) and a network of e-commerce servers. The use of recursive decomposition allows detail to be controlled. A server may be modeled as a B-Node or collection of B-Nodes (microprocessor, hard disc etc). Each of these B-Nodes may further be modeled as a collection of other B-Nodes. B-Nodes use a fundamental performance metric (Mbytes/s) from which other, more meaningful metrics may be derived. As B-Nodes use abstraction they are independent of underlying technologies and are applicable not only for old and current technologies but may well be of value for some time to come. From the results to date the use of B-Nodes as a tool in systems analysis and design methods is to be recommended. B-Nodes have been used and the pedagogical basis of a new technology curriculum and successfully evaluated.

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3.2.4.6 Modelling Website Infrastructure Using B-Node Theory

This paper (Kohli, Veal, & Maj, 2003) was presented at the 9th Australia and New Zealand Systems (NNZSYS) Conference, held in Melbourne Victoria. This conference is a leading international conference held in the Australasian region and brings together theoreticians and practitioners in the systems field.

This paper considers both the importance of the modeling of web systems and the application of B-Node theory to this problem domain. Models and modelling are considered along with the importance of modelling web infrastructure down to the hardware level from a consideration of the workload on the system. A range of methods used to evaluate website performance are considered. Experiments undertaken by the authors to evaluate simple internetwork performance in a laboratory situation are described.

Additional new knowledge includes results of experiments using the B-Node model to test bandwidth using FTP between hosts, the application of B-Node theory to bottleneck location, with results and confirmation of the minimum bandwidth node being the bottleneck. Latency was subsumed into the resulting bandwidth via the calculations used in the B-Node analysis.

Modelling Website Infrastructure using B-Node Theory

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Introduction:

A large volume of business is conducted via the Internet (Schneider & Perry, 2000). However, this has resulted in increased transaction delay times as systems and computer networks become overloaded (Devlin, Gray, J. B, & .G, 1999). Surveys and studies indicate that slow downloading time is the most often cited reason that an online customer leaves a site and searches for another vendor's site (Bakos, 1998). According to Shklar: *"Sites have been concentrating on the right content". Now, more of them specially e-commerce sites realize that performance is crucial in attracting and retaining online customers.*" (Shklar, 1998). The performance of an Internet site is dependant not only upon the behavior of end users using that site but also the performance of the technologies employed. Currently there are a number of different models for defining e-business web sites performance, such as the 'business', 'functional', 'customer', and 'resource' models (Menasce, Virgilio, & Almeida, 2000). The Customer Behavior Modeling Graph (Inverardi & Wolf, 1995) (Union, 1996) and Client /Server Interaction Diagrams (CSIDs) (Stohr & Kim, 1998) are techniques that can be used to capture the navigation patterns of customers during site visits and hence obtain quantitative information on workloads. However, although these models attempt to predict user behavior, they do not provide information about the actual load on the systems running on such sites. In the final analysis user load must be translated to hardware requirements thereby allowing performance bottlenecks to be identified. However, such problems associated with infrastructure design are non-trivial. According to Fenik *"Being able to manage hit storms on commerce sites requires more than just buying more plumbing."* (Fenik, 1998). In order to predict the workload characteristics of e-commerce sites, effective modelling needs to be undertaken to determine key bottlenecks within the system. It is therefore necessary to investigate different types of models which could be used to model the infrastructure of e-commerce web sites.

Model Requirements:

Models are used not only as a means of communication and controlling detail but may also form the basis of a conceptual understanding of a system. According to Cooling there are two main types of diagram: high level and low level (Booch, James Rumbaugh, & Jacobson, 1999; Cooling, 1991). High-level diagrams are task oriented and display overall system structure and major sub-units. Such diagrams describe the overall function of both the design and interactions between both the sub-systems and the environment. The main focus is upon finding answers to the question what does the system do? According to Cooling, *"Good high-level diagrams are simple and clear, bringing out the essential major features of a*

system" (Cooling, 1991). By contrast, low-level diagrams are solution oriented and must be able to handle considerable detail. The main emphasis is 'how does the system work'. However, all models should have the following characteristics: diagrammatic, self-documenting, easy to use, control detail and allow hierarchical top down decomposition. For example, the Data Flow Diagram (DFD) (Hawryszkiewicz, 2001) model enables a complex system to be partitioned (or structured) into independent units of an amenable size so that the entire system can be more easily understood. It is possible, therefore, to examine a system in overview and with increasing levels of detail, whilst maintaining links and interfaces between the different levels. DFD's are not only simple, but also graphical; hence they serve not only as documentation but also as a communication tool (Pressman, 1992). DFD's are therefore a top-down diagrammatic representation of information flow within a system, and are a means of defining the boundaries and scope of the system being represented, checking the completeness of the analysis and providing the basis for program specifications. This technique is relatively simple to use, yet powerful enough to control complexity during the analysis and design of both small and large systems. It is recognized that communication with end users is especially important as this helps to validate a model for correctness. There are various high level models that are used to evaluate web site performance.

Web Performance

There are various well established methods for evaluating Internet site performance (Menasce, Almendia, & L.Dowly, 1994). The Customer Behaviour Modeling Graph (CBMG) can be used to measure aggregate metrics for web sites (Menasce & Almendia, 1999). Using this modeling technique it is possible to obtain a wide variety of different performance metrics that include: hits/s, unique visitors etc. However, when using this technique it is not possible to relate these metrics to hardware specifications. The Client /Server Interaction Diagrams (CSIDs) (Stohr & Kim, 1998) can be used to capture the navigation patterns of customers during site visits and hence obtain quantitative information on workloads. However, it does not provide any insight into how the workload will affect the underlying infrastructure. Furthermore, the World Wide Web (WWW) has some unique characteristics that distinguish it from traditional systems (Almedia, Bestavros, Crovella, & Oliveira, 1996; Almeida, Virgilio Almeida, & Yates, 1997; Arlitt & Williamson, 1996; Mogul, 1995). Firstly, the number of WWW clients is in the range of tens of millions and rising. Secondly, the randomness associated with the way users visit pages makes the problem of workload forecasting and capacity planning difficult. (Menasce, Almendia, & Dowdy, 1994).

Benchmarks are the standard metrics used in defining the scalability and performance of a given piece of hardware or software. For example the Adaptive Computing System (Sanjaya, Chirag, & John, 2000) is a collection of benchmarks that focus upon specific characteristics from the start of a computation until its completion. Benchmarks evaluate the ability of a configurable computing infrastructure to perform a variety of different functions. SPECWEB and TPC-C (Smith, 2000) are notable benchmarks in the e-business environment. These benchmarks come close to representing the complex environment of an e-business

workload. Benchmark programs are used for evaluating computer systems. Different end user applications have very different execution characteristics; hence there exists a wide range of benchmark programs. The four main categories are: science and engineering (examples include; Whetstones, Dhrystones, Livermore loops, NAS kernels, LINPACK, PERFECT club, SPEC CPU), Transaction Processing (for example; TPC-A, TCP-B, TPC-C), server and networks (examples include; SPS/LASSIS, SPEC web) and general use (examples include; AIM Suite III, SYSmark, Ziff-Davis PC Benchmark). However none of these benchmarks are directly relevant to E-commerce web transactions. The Transaction Processing Council introduced the TPC-W that simulates the workload activities of a retail store Web sites (Smith, 2000). In the TPC-W standard the products are books and the user is emulated via a remote Browse that simulates the same HTTP traffic as would be seen by a real customer using the browser. E-business sites have transient saturation so it is hard to use these benchmarks to get the correct idea about the actual load generated on the web servers. Benchmarks currently in use fail to measure the web performance characteristics, whilst others may be incorrectly interpreted (Humphrey, 1990; Lilja, 2000). According to Skadron, *"Research cannot pursue futuristic investigation when they are limited to systems for which no benchmark programs are available. The current short coming in computer systems evaluation could ultimately even obstruct the innovation that is driving the information technology revolution"* (Kevin Skadron et al., 2003). Furthermore the basic problem still remains. Using benchmarks it is not possible directly relate the technical specification to the metrics used in the service level agreements. The difficulties of developing effective models for large networks are becoming greater as noted by Clark, *"As networks grow to connect millions of nodes, and as these nodes all communicate in unpredictable patterns, the resulting behaviour becomes very difficult to model or predicts"* (Clarke & Pasquale, 1996). The question was then asked, what methods do IT web site managers use to design and manage the performance of an Internet web site?

Commercial Practices

A questionnaire was distributed to several small to medium size companies in Western Australia. The results indicated that infrastructure requirements were typically based upon past experience and also purchasing the highest performance equipment within budget constraints (Maj & Kohli, 2002). Alternatively companies outsourced this problem to vendors. These approaches are arguably entirely unsatisfactory as they relegate IT systems analysis to conventional 'wisdom' and mythology (Maj & Kohli, 2002). None of the companies analysed employed any techniques for modelling infrastructure performance. The scope of the above survey is currently being extended both within Australia and internationally. From the data gathered to date it can further be concluded that most companies were not aware of an effective model that could be applied to effectively model e-commerce website workloads. Hence there is current need for such a new model in this area.

Modelling infrastructure Using B-Nodes

Computer and network equipment is complex. Furthermore they use a wide range of heterogeneous technologies with different performance metrics. By example hard disc drive performance is often quoted in rpm; electronic memory

performance is quoted in nanoseconds; microprocessor performance is quite in MHz etc. This results in two problems. Firstly the performance of a web site (server with switches, hubs etc) depends upon the speed of the slowest device. It is not possible, using these metrics, to easily determine the relative performance of each device. Is 10ns electronic memory faster or slower than a 1GHz microprocessor? Secondly it is difficult to relate the technical performance metrics to user requirements defined in the Service Level Agreement. Can a hard disc drive operating at 5,000 rpm deliver 100 web pages per minute? The B-Node model was proposed to address these problems (Maj & David Veal, 2000). The B-Node model:

- Can be used to model a wide range of computer and network technology equipment
- Is diagrammatic, self documenting and easy to use
- Uses recursive decomposition, hence can be used to model both small systems (e.g. a server) or a larger system (e.g. an Intranet)
- Uses a common performance metric (Mbytes/s). Hence the performance of heterogeneous technologies can easily be compared
- Uses a common fundamental unit (Mbytes/s) allowing other units to be derived. Hence it is possible to define the performance of a wide range of different technologies using, for example, a common, derived metric such as web pages per second.

The B-Node model has been used to model an E-commerce server and hence identify hardware bottlenecks. It has also been used to evaluate the performance of different E-commerce servers (Web server, payment server etc) (Maj, Veal, & Boyanich, 2001). However, the use of bandwidth as a sole indicator of performance may be problematic. According to McComas notes there are problems due to bandwidth and latency (McComas, 2001b), as does Buzen and Shum, (Buzen & Shum, 1996b). This point is also made with respect to network technology by Oppenheimer

"It is possible to improve throughput such that more data per second is transmitted, but not increase goodput, because the extra data transmitted is overhead or retransmissions ...more data is transmitted per time, but the user sees worse performance. ...most end users are concerned about throughput rate for applications. Marketing materials from some networking vendors refer to application-layer throughput as 'goodput'. Calling it goodput sheds light on the fact that it is a measurement of good and relevant application-layer data transmitted per unit time" (Oppenheimer, 2001).

In effect, it is possible to have higher bandwidth but it is not being used effectively to transfer data. Hennessy also notes the:

"... pitfall of using bandwidth as the only measure of network performance. ... this may be true for some applications such as video, where there is little interaction between the sender and the receiver, but for many applications such as NFS, are of a request-response nature, and so for every large message there must be one or

more small messages ... latency is as important as bandwidth" (Hennessy & Patterson, 1996a).

In spite of this the B-Node model has many potential advantages and it may be possible to address the latency issue.

Using B-Nodes to Measure Network Technology Performance:

A wide range of different files were transferred between two PCs using a simple cross over cable using FTP. This represented the base line performance. Then a range of different networking technologies were introduced and the performance measured. In order to address the problem of latency the authors have subsumed the effects of latency under a definition of bandwidth. Namely bandwidth = the size of the file in Mbytes / total time to send that file:

$$B = L_1 / T_T$$

Where $T_T = t_1 + t_L$

B = (bits passed)/(time taken to pass those bits)

L_1 = Length of the files in Mbytes.

t_1 = Time required to transfer the file

t_L = Latency measured in (msec)

Table 1 shows a summary of various devices with respect to bandwidth using File Transfer Protocol (FTP):

Technology	Bandwidth (Mbytes/s)
PC crossover cable PC	11.5
PC switch PC	11.5
PC router PC	7.5

Table 1 B-Node performance figures (Mbytes per second)

The crossover cable between two PCs can be modelled as a B-Node with a performance of 11.5Mbytes/sec. A switch can be modelled as a B-Node with a performance also of 11.5Mbytes/sec. In effect a switch works at 'wire speed' and has no measurable affect on performance. A router modelled as a B-Node gives a performance of 7.5 Mbytes/sec. The use of common fundamental units allows two different technologies (layer 2 switches and layer 3 routers) to be compared. Furthermore, common derived units can be used. Assuming the messages in a web transaction are 10 Kbytes each and the load is 1000 per second. It can then be concluded from Table 2 by introducing a Router will create a bottleneck in the system as the utilisation is more than 100%. Additionally it is possible to identify, using meaningful metrics the relative performance of each technology which can then help network designer to better design web sites infrastructure.

Technology	Bandwidth (Mbytes/s)	Transaction size (Kbytes)	Load	Utilization
PC crossover cable PC	11.5	10	1000	86%
PC switch PC	11.5	10	1000	86%
PC router PC	7.5	10	1000	133%

Table 2 B-Node performance figures (Transactions per second)

The authors are further developing the experiment by taking into account different protocol like HTTP and HTTPS and the use of Access control list (ACL).

Conclusion:

The performance of Network application affects the productivity in many areas: e-commerce, a model base approach provides a good foundation for developing solutions to these problems. The B-Node model is simple, diagrammatic and self-documenting modelling technique, it use common fundamental units which can help the network designer to identify the key bottlenecks within the system. The B-Node model is undergoing development and testing in an attempt to model infrastructure from the bottom up to enable top down conceptual understanding of workload characteristics.

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3.2.5 B-Nodes and CBAs (Capstone Paper)

3.2.5.1 Computer Technology Curriculum – A New Paradigm for a New Century

This paper (Maj & Veal, 2000b) was published in the Journal of Research and Practice in Information Technology (JRPIT), in the November 2000 issue. The Australian Computer Society (ACS) is the leading professional body for computing within Australia and the JRPIT, formerly, Australian Computer Journal, is its flagship publication. The JRPIT has a rejection rate of greater than 80%.

This is the capstone paper that brings together CBAs and B-Nodes as well as later work on B-Node formulae. This paper includes a consideration of standards, measures and errors, and levels of abstraction required with respect to B-Node theory. Computer technology is a complex and constantly changing field. These characteristics place considerable on-going demands on teaching and curriculum development. Given the prevalence of PCs, this problem is further exacerbated by an increasing number of students from different disciplines attending both introductory and advanced courses on computer and network technology. Lecturers need a new pedagogical framework of a PC based on a new higher-level abstract model. Such a model must be suitable for a wide-range of students, to assist in the development of understanding, to support different levels of technical detail, and to be valid for both current and future generations of digital technologies. This paper proposes Bandwidth-Nodes (B-Nodes) as such an abstract model and the basis of computer and network technology curriculum. Work to date had indicated that modeling the PC as a collection of B-Nodes, whose performance is rated by bandwidth measured in frames/s, provides a viable constructivist framework that is readily understandable by students from all disciplines. Results to date indicate this framework is also valid at increasing levels of technical complexity.

New knowledge includes bringing together in greater depth the need for theoretical concepts such as B-Nodes to assist in future-proofing student learning, which is of special importance on hands-on units due to the rapid obsolescence of much of the acquired knowledge due to the rapid rate of technological change. These considerations form the motivation underpinning the proposed new

framework presented for combining high level abstraction of B-nodes with the need for hands-on skills and knowledge. The use of bandwidth via B-Node modelling is discussed as a possible basis for a computer benchmark.

Computer Technology Curriculum –A New Paradigm for a New Century

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Abstract

Computer technology is a complex and constantly changing field. These characteristics place considerable on-going demands on teaching and curriculum development. Given the prevalence of PCs this problem is further exacerbated by an increasing number of students from different disciplines attending both introductory and advanced courses on computer and network technology. Lecturers need a new pedagogical framework of a PC based on a new higher-level abstract model. This model must be suitable for a wide-range of students, assist in the development of understanding, support different levels of technical detail and be valid for both current and future generations of digital technologies. This paper proposes Bandwidth-Nodes (B-Nodes) as such an abstract model and the basis of computer and network technology curriculum. Work to date indicates that modeling the PC as a collection of B-Nodes, whose performance is rated by bandwidth measured in frames/s, provides a viable constructivist framework that is readily understandable by students from all disciplines. Results to date indicate this framework is also valid at increasing levels of technical complexity. Furthermore, it is essential to provide students with procedural knowledge that is relevant to both student and employer expectations. Competency based testing is proposed as a mechanism to provide assurance of appropriate levels of such practical skills and results of its implementation are presented.

Keywords

Curriculum, Bandwidth, Constructivism, Modeling

Background

The computer science curriculum at Edith Cowan University (ECU) is Level 1 accredited by the Australian Computer Society (ACS). However, a study by Maj, Robbins, Shaw and Duley, of final year computer science graduates at ECU found that students could not perform routine operations on a PC, to an acceptable standard of safety based on employer expectations:

"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 PC's to an acceptable commercial standard" (Maj et al., 1998b).

These skills, though not provided by the curriculum, were perceived as extremely valuable by both students and potential employers. Other investigations indicated a similar situation with computer science graduates from other universities within Western Australia. Other countries similarly have professional accreditation. In the United Kingdom the British Computer Society (BCS) accredits university courses. The BCS curriculum guidelines are broadly equivalent in both depth and scope to those of the Australian Computer Society. The initial ECU student questionnaire, first used in 1993, was also conducted in 1999 at two universities within the UK. A similar study is currently being undertaken in Sweden. One of the selected UK university has well-established degree programs and is fully BCS accredited. The degree programs at this university offer students the opportunity to examine a PC in the first year as part of a module in Computer Organization. However they never take a PC apart. Students are taught network modeling, design and management but they do not physically construct networks. A random selection of twelve final year computer science undergraduates selected from a graduating population of approximately one hundred was interviewed using the ECU questionnaire. The results were directly comparable to the original ECU results in that students lacked knowledge about PC technology and the basic skills needed to operate on computer and network equipment in a safe manner. This is despite the fact that nearly every student thought such knowledge and skills would be beneficial. The survey clearly demonstrated that any practical knowledge students have of hardware was largely a result of experience outside the course. The second university analyzed recently redesigned their IT awards, some of which are now BCS accredited. At this second university four final year (BSc, Hons), students were randomly selected and interviewed using the ECU questionnaire. These results demonstrate that these students had a broad, hobbyists' understanding, of the PC but no knowledge of health and safety law or networks. Significantly, all students interviewed identified that their skills and knowledge of PCs and networks came from self-study or employment, not from courses at university. Again student responses indicated that such knowledge would be useful. Further, more detailed investigations are currently being undertaken. In the final analysis the predominate reason students attend university is to get skills, knowledge and a qualification to assist them in gaining employment or to improve their prospects of promotion (Review, 1996).

Curriculum Design

Based on the results of the initial 1993 ECU student survey two new units (Computer Installation & Maintenance (CIM) and Network Installation & Maintenance (NIM)) were designed and implemented at ECU. Both CIM and NIM are introductory units, with no pre-requisites, that form the basis of a complete course of study in computer and network technology management. In order to meet the perceived expectations of employers and students these units were designed to incorporate a significant practical component in order to simulate, as closely as possible, a typical commercial environment. Accordingly a new, dedicated laboratory was designed and constructed at an initial cost of \$35,000. The extensive use of decommissioned equipment significantly helped reduce the cost. With this budget it was therefore possible to provide each of the 10 workplaces (two students per workplace) with 4 different types of PC of increasing complexity and cost. The logistics of maintaining this non-traditional Computer Science laboratory are non-

trivial. Veal and Maj, (2000) found that each two hour CIM and NIM workshop must be allocated up to two hours of technical support. Also, in contrast to other units in which only the first hour is supervised the entire CIM and NIM workshops must be fully supervised. Furthermore, in order to minimize loss of equipment it is necessary at the start of each workshop for students to complete and sign a checklist of equipment.

Students on the CIM unit are required to work in a laboratory environment that is potentially hazardous – both to students and equipment. In keeping with employer expectations, this mandates a rigorous approach to workshop practices and the inclusion of Health & Safety legislation as part of the curriculum. The first lecture and workshop on this unit are compulsory and address both health and safety in the workplace and the associated legal foundations. It is assumed that students have no knowledge of either the legal system or their obligations based on the Western Australian Occupational Safety and Health Act 1984 (Reprinted as at November 16, 1995). After a brief overview of the legal system, the tort of negligence is addressed with reference to negligent misstatement. However, particular emphasis is placed on negligent acts and the associated Duty of Care (foreseeability and proximity) and Standard of Care (gravity and practicality of precaution) of both employee and employer all in the context of a computer and network support environment. The examination had a compulsory question on health and safety. It was found by Maj that,

"The first workshop was concerned entirely with workshop practice and students were required to read both the university and workshop regulations - it was emphasized that misconduct would not be tolerated. Misconduct is taken to include failure to observe good workshop practice. Compulsory attendance at the first lecture and workshop were verified by a signed declaration. Failure to comply was an automatic disqualification from continuing the unit". (Maj et al., 1998b)

Significantly the workshop exercises provide a practical, inter-disciplinary, problem oriented approach. Rather than lowering academic standards Professor Lowe (Armitage, 1995) argues, *"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"*. 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. Instead, 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. Ramsden (1992) argues that, *"Material should preferably be ordered in such a way that it proceeds from common-sense and everyday experiences to abstractions and then back again to the application of theoretical knowledge in practice"*. A further reason for using these PCs is to provide a concrete experience for the enhancement of the procedural and declarative abstract knowledge to be learnt by the student. This is necessary because, according to Piaget (1952), it is quite possible that large numbers of the younger students may not be able to reason abstractly. The unit NIM is based on

the internationally recognized NOVELL curriculum. There are number of Network Operating System (NOS) providers (Novell, Microsoft, IBM, Digital etc.). When this curriculum was first introduced the dominant NOS for Local Area Networks (LAN's) was Novell NetWare (Economist, 1995). Our preliminary market analysis indicated that employers required graduates to have a working knowledge of networks, in particular Novell. Novell have internationally recognized professional development programs - the Novell Certified Network Engineer (CNE) and Master CNE. The NIM unit also introduces students to alternative platforms such as Windows NT. In addition to this, there are extensive practical workshops that include: network card installation, cable testing, NOS installation, network security, first line maintenance and trouble shooting (Lachowicz et al., 1996). At the completion of this unit students are able to obtain partial Novell Certified status. At normal commercial rates this would cost students approximately \$3,000.

Both units have been evaluated over several semesters using the standard ECU unit evaluations. The feedback has consistently been very positive. Furthermore, these units are always oversubscribed, have low attrition rates and regularly attract cross-institutional enrolments. The CIM unit has been fully evaluated by Dr T Fetherston, a senior academic in the field of education, to assess the educational content of this non-traditional, university unit. The results demonstrated that this unit was considered:

"valuable by students from different disciplines; supports learning in other units; increases students' understanding of computers and computing; is clearly distinguished from a TAFE unit; generates a demand for further curriculum in this field; is enhanced by the series of lectures and workshops given by an experienced computer support technician and is about right in terms of difficulty" (Mnj et al., 1998a).

Given the prevalence of PCs, many students without a Computer Science or Engineering background now study computer technology. When the CIM unit was first introduced at ECU in 1996, from an enrolment of 118, only 66 were computer science students. These students were from either the second and third year of their degree. The CIM unit is an elective unit and first year computer science students are not allowed to study elective units. There were students from a wide range of disciplines (security, psychology, biological and chemical sciences) at various stages in their studies. Significantly, some final year B.Eng. (Computer Systems Engineering) students enrolled on this unit. This broad intake of students from a wide variety of disciplines and at different stages of their studies has persisted. In this context there are two main pedagogical problems. Firstly, what is the best way to measure the procedural knowledge that is considered important for both students and employers? In effect the practical skills and knowledge taught during the workshops are not assessed. Secondly, even though a top down, hierarchical, modular analysis approach, as recommended by Scragg (1991), was taken for the unit CIM it lacked a coherent conceptual framework or model. What is needed is a new pedagogical framework of a PC that is: suitable for a wide-range of students, will assist in the development of understanding, valid for different levels of technical detail and will support more advanced studies.

Procedural Knowledge - Competency Based Assessment

The CIM curriculum has a significant practical component that requires students to work in a laboratory environment that is potentially hazardous – to both equipment and students. It was found by Maj et al., *"the students who claimed to have prior experience in this field damaged more equipment than the novices. Clearly 'self evaluation' of skills is inadequate"*. (Maj et al., 1998b).

Generic skills are characteristic of a whole class of skills that are increasingly recognized as an important component of undergraduate courses (Bartley, 1999). However this curriculum mandates the teaching and testing of specific skills. A market analysis mentioned by Maj et al., (1998b) clearly indicated that employers require a level of competency in commercially relevant skills e.g. to be able to safely install and test new equipment in a computer. The general lack of information given to students regarding employer expectations has been noted by Havard et al., (1998), *"On completion of their academic programme the graduate was given no way of knowing how their skills compared to the requirements of industry"*.

A new competency based metric is perhaps needed to measure these specific skills directly relevant to employer expectations. Competency Based Assessment (CBA) offers a possible method of testing specific practical skills. In an Australian context, Karmel (1995) suggests that the competency movement had been driven to improve education/training outcomes in relation to the work of work from entry to professional level. Whilst CBA is well established in Technical and Further Education (TAFE), there exists some debate as to their relevance in Higher Education. Goldsworthy mentions a critique of what might be inferred from CBA: *"Competency based standards in effect are an ad hoc measure of skills they measure performance after the event. The activity is performed and measured after the skills, experience and knowledge have been acquired"*. (Goldsworthy, 1993) However in a written examination, the assessment activity is also performed and measured after the acquisition of the skills, experience and knowledge. Furthermore, standard written examinations do not necessarily provide a prediction as to how well students might perform in the workplace. The relevance of CBA in the university sector is further questioned by Hamly and cited by Goldsworthy (1993) in that, *"most of the higher order intellectual skills which universities impart are not capable of measurement as competencies and that universities must therefore resist their implementation"*. Merely because higher order skills may not be tenable to direct measurement should this exclude measuring other very important and potentially commercially relevant skills?

Other general criticisms of CBAs are that creativity is not tested and they take too much time. Written examinations enable students to demonstrate knowledge depth but arguably at the cost of width. Multi-choice questions provide the means to test students across a large portion of the syllabus but may not allow students to show their in depth of knowledge. Written assignments can give students an opportunity, working collaboratively, to search literature and demonstrate creativity. CBAs may be used to test practical skills not tested via other forms of assessment but offer no

assurance of a deep understanding of the field. The authors conclude that no single assessment technique is sufficient. All forms of assessment have advantages and disadvantages and must be used as appropriate.

Within the CIM curriculum students are currently assessed by means of a standard written examination and two written assignments. However, it is possible for a student to successfully pass these units without ever attending any workshop. Accordingly the authors designed and tested CBA for the CIM unit. The CBA model used in the CIM unit was designed to meet the following criteria:

- Meaningful to students, staff and prospective employers.
- Part of the normal workshops.
- Easy to manage and does not cause excessive extra work to staff

The results according to Veal are:

"The students were assessed during a standard two-hour workshop. The work was conducted in a normal manner with the assessor independently evaluating students. At no point was the workshop interrupted, or extra time taken. Ten students were evaluated. Despite the fact that considerable emphasis is placed on ensuring that students are provided with the highest possible standard of good workshop practices to underpin Health & Safety the results clearly indicated that some students did not demonstrate a satisfactory competency in basic safety practices. It would not have been possible to determine this result without a CBA." (Veal et al., 1999)

It is possible to solve the first problem raised in section 2 of this paper i.e. to measure the procedural knowledge and skills that are taught during the workshops in a simple, meaningful and cost effective manner.

Learning Theory

There remains the second problem i.e. is it possible to provide students, from a wide range of backgrounds (Computer Science, IT, Multimedia, Business IT etc), with a new pedagogical framework that can be used as the basis of ongoing learning and curriculum delivery? Furthermore, any such conceptual model must not only be technically correct but also valid for different levels of complexity thereby supporting more advanced studies.

Prior to examining how to improve student learning we attempted to come to a deeper understanding of how students learn and construct knowledge. Constructivism is the dominant theory of learning today, the basis of which is that students must actively construct knowledge rather than passively absorb it via lectures. According to Ben-Ari considerable research has been done in this field but commented, *"However, I could not find articles on constructivism in computer science education compared to the vast literature in mathematics and physics education"* and that *"it can provide a new and powerful set of concepts to guide our debates on CSE (Computer Science Education)"* (Ben-Ari, 1998). In this theory students have their own cognitive structures each of which is the foundation of the learning process. By example, a PC is likely to be understood very differently by

Computer Science, Multimedia and Business IT students. For Business students the PC may represent a device for conducting business; however Multimedia students may perceive it as the medium by which web pages are designed and hosted. It should be recognized that all these different conceptual models are not necessarily wrong but merely represent alternative conceptual frameworks. Furthermore, Ben-Ari argues that a, "*teacher cannot ignore the student's existing knowledge; instead he or she must attempt to question the student in order to understand what models the student possess, and only then attempt to guide the student to the 'correct' theory*" (Ben-Ari, 1998). Failure to do so results in fragile and incomplete learning. The traditional method of teaching computer technology (digital techniques, assembly language etc) is not a good constructivist approach.

Furthermore, there have been and may continue to be many technical developments that impact on computer technology education. Clements (2000) makes the point that, "*for example, the generation of students studying electronics in the 1950's leaned about the behavior of electrons in magnetic fields. The next generation studied transistor circuits, and the one after that studied integrated circuits. The traditional logic course changes rapidly*". However, digital techniques and modeling provide an abstraction that is independent of the underlying details of transistor theory. Such combinational or sequential circuits can be described without the complexity of their implementation in different switching technologies e.g. Transistor-Transistor Logic (TTL), Complementary Metal Oxide Semiconductors (CMOS) etc. Similarly details of semiconductor switching may be modeled using abstractions independent of the underlying details of quantum mechanics. Computer technology can therefore be described using a progressive range of models based on different levels of detail e.g. semiconductors, transistors, digital circuits. Such models are designed to progressively hide and hence control detail and yet still provide sufficient information to be useful for communication, design and documentation. This is in keeping with the ACM/IEEE Computing Curricula 1991 in which abstraction is a recurring concept fundamental to computer science (Tucker et al., 1991). Computing Curricula 1991 define nine subject areas that include Architecture as a pre-requisite chain of topics.

However, computer design and manufacture has changed rapidly in the last decade. Assembly Level Manufacturing, Application Specific Integrated Circuits and Surface Mounted Technology have all lead to an ever-decreasing unit price and a resultant low cost PC with a standard architecture and modular construction. Such developments have resulted in changes in the way in which the computer infrastructure is now perceived and managed. Again according to Clements (2000), "*While the knowledge base academics must teach is continually expanding, only a fraction of that knowledge can be taught during a student's time at a university. Consequently, academics must continually examine and update the curriculum (computer architecture), raising the level of abstraction*". We attempted therefore to develop, if possible, a new higher-level abstract model of computer technology. This model must represent a common conceptual framework held by students from different disciplines, and hence form the basis of a cognitive structure. Any such structure must allow students to easily make viable constructs of knowledge base¹

on their own experience. We therefore examined various conceptual frameworks to support this approach.

Computer Technology – A New Benchmark

choosing a PC is now a common activity for many. Benchmarks can be used to evaluate PC performance that, in conjunction with factors such as price, are an aid to selection. We submit that users' ideas of a PC are typically based on performance and this could be the basis of a constructivist teaching approach. We therefore examined benchmarks in general in order to evaluate their potential use as a pedagogical tool.

Benchmarks - Background

Benchmark programs considered directly relevant to a typical single user, multi-tasking environment running a de facto standard suite of 32 bit applications include: AIM Suite III, SYSmark and Ziff-Davis PC Benchmark. Consumer magazines use Benchmark suites to evaluate PC's and publish their results (APC, 1998) (Table 1).

Table 1: PC Benchmark Suite

Benchmark	Gateway G6 300	IBM Aptiva EQ3
Business Winstone 98	20.63	18.33
CD-ROM WinMark 98 : Overall	1,556.67	1,350
CPUMark 32	772	550.33
Business Disk WinMark 98	1,380	939
High-End Disk WinMark 98	3,783.33	2,736.67
Business Graphics WinMark 98	93.13	105.67
High-End Graphics WinMark 98	146	130

Intel marks their microprocessors with a part number and the maximum rated clock speed. Furthermore they publish a special series of Benchmarks called the Intel Comparative Microprocessor performance Index (iCOMP) that can be used as a relative gauge of microprocessor performance. However more than half of the PCs (under \$1,000) now sold in the USA are likely to have Advanced Micro Devices (AMD) microprocessors (Economist, 1998). For many AMD microprocessors the model designation does not correspond with the associated clock speed. For example, the AMD K5 PR133 has a clock speed of only 100MHz. The alternative P Rating (PR) system was jointly developed by Cyrix, IBM, SGS Thompson, and AMD. This Benchmark is based on the Winstone, a de facto standard, windows based Benchmark suite. As an aid to more meaningful measurements specialist interest groups also evaluate equipment using specific applications (Results, 1999). As a relative guide Benchmarks are an aid to selection, however, all of these results must be interpreted and many questions still remain for users. Questions include:

- What difference in performance can a user expect if the benchmark value result is higher by 1 or 2 units or by a factor of 10 or more? For example, what difference in performance would a user expect between an IBM Aptiva EQ3 (Business Disk WinMark 98 value of 939) and a Gateway G6 300 (Business Disk Win Mark 98 value of 1,380)?

- How does the iCOMP rating compare to the PR rating?
- What difference in performance can a user expect from a Pentium 100 (iCOMP 90) and a Pentium 200 (iCOMP 142)? Are the scales linear, logarithmic, hyperbolic?
- What units are used? Does each Benchmark define their own (unspecified) units?
- As a user, how is the difference in performance manifested and perceived?
- How can different types of devices be compared, e.g. how ca. the performance of a hard disc drive be compared to a microprocessor?

We conclude that the plethora of benchmarks, though useful, do not provide the basis of a useful, coherent conceptual model of a PC that can be used as a pedagogical framework. We therefore re-examined the basic issues of measurements in an attempt to find such a model.

Standards, Measures and Errors

Measurements are used to make, exchange, sell and control objects. According to Barney, *"A measurement is the process of empirical objective assignment of numbers to properties of objects or events in the real world in a way such as to describe them"* (Barney, 1985). History has many examples of measures in the search for useful standards. Early Egyptians defined one finger-width as a zebu and established an associated simple, reproducible and denary scale of standard measurements. It is significant that human dimensions were used as the basis of one of the first standards. The Systems Internationale (SI) system meets the ancient requirements of simplicity and ease of use due to reasonably sized units. Measurements, therefore, require the definition of units, the establishment of standards, the formation of scales for the comparison of measured quantities and ease of use. It can therefore be argued that any measurement standard, to be of practical value to PC users, must therefore have the following characteristics:

- Relevant to human dimensions or perceptions
- Units based on the decimal scaling system
- Have quantifiable errors

We therefore examined bandwidth as a possible fundamental measurement of performance.

Bandwidth

All the sub-units of a PC (microprocessor, RAM, Hard Disc Drive etc) may be considered as 'black box' processors in Multiple Instruction Multiple Data (MIMD) architecture. According to Clements (1989), *"Because of the generality of the MIMD architecture, it can be said to encompass the relatively tightly coupled arrangements and the very loosely coupled geographically distributed LANs"*. In this context Clements continues:

"Although most people do not regard it as a multiprocessor, any arrangement of a microprocessor and a floppy disc controller is really a loosely coupled MIMD. The

floppy disc controller is really an autonomous processor with its own microprocessor, internal RAM and ROM."

and further that:

"Because the FDC (Floppy Disc Controller) has all these resources on one chip and communicates with its host processor as if it were a simple I/O port, it is considered by many to be a simple I/O port. If it were not for the fact that the FDC is available as a single chip, engineers would be designing "true" multiprocessor systems to handle disc I/O."

A PC is therefore a complex collection of heterogeneous devices interconnected by a range of bus structures. In this paper we define a PC as a MIMD architecture of sub-units or nodes. Each node (microprocessor, hard disc drive etc) can be treated as a data source/sink. This approach allows the performance of every node and data path to be assessed by a simple, common measurement – bandwidth. Where $\text{Bandwidth} = \text{Clock Speed} \times \text{Data Path Width}$ ($B = C \times D$) with the common units of Mbytes/s. We can therefore analyze the PC accordingly.

Microprocessor

There are various measurements of microprocessor performance such as: clock cycles per instruction (CPI), clock cycle time, Instruction count and iCOMP. By example the Pentium II MMX is clocked at 233MHz with an iCOMP Index 2.0 rating of 267. The AMD K5 PR133 is clocked as 100MHz. However, all microprocessors, regardless of any internal architectural details, transfer data via the processor data bus and hence their performance can be simply evaluated using the bandwidth formula ($B = C \times D$). By example, the Pentium processor has an external data path of 8 bytes with maximum rated clock speeds in excess of 400Mhz giving a bandwidth of more than 3200 Mbytes/s i.e. ($C \times D = 400\text{MHz} \times 8$ bytes).

Primary Memory – DRAM

Dynamic Random Access Memory (DRAM) is a volatile, electronic storage medium available in a variety of organizational structures such as Extended Data Out (EDO) and Synchronous Dynamic Random Access Memory (SDRAM). Regardless of DRAM organizational structure, performance is measured in nanoseconds, which can easily be converted to MHz. The performance of Synchronous DRAM is now often quoted in MHz, e.g. 83MHz (12ns) or 100MHz (10ns). The performance of RAM can easily be evaluated using the bandwidth formula ($B = C \times D$). For example, Dual In Line Memory Modules (DIMMs) rated at 60ns (16MHz) with a data path width of 8 bytes have a bandwidth of 128 Mbytes/s i.e. ($C \times D = 16\text{MHz} \times 8$ bytes).

Secondary Memory – Hard Disc Drive

Hard disc performance is quoted by a variety of measures that include: seek times (average, track to track, full stroke), rotational speed (rpm), internal data rate (Mbytes/s), track capacity and data transfer rates (buffer to host, in Mbytes/s). The bandwidth equation ($B = C \times D$) is still valid if rotational speed and track capacity

are used instead of clock frequency and data path width i.e. $B = \text{rps} \times \text{track capacity}$. Typical figures are in the range of 5 Mbytes/s with the number of sectors averaged thereby taking into account Zoned Bit Recording.

Peripherals

Modem performance is typically measured in Kbits/s which can be converted to Mbytes/s. CDROM performance is quoted in speeds e.g. x32 speed where x1 speed is defined as a data transfer rate of 150 kbytes/s. Bandwidth for a x32 speed CDROM is therefore approximately 4.6Mbytes/s.

Bus Structures and Chip Sets

A Pentium based PC has a hierarchy of bus structures each operating at a different specification. Buses include: the Industry Standard Architecture (ISA), Peripheral Components Interconnect (PCI) bus and the Advanced Graphics Port (AGP). Bus performance is variously given by address/data multiplexing, data-path width, clock frequency, etc. However, for each bus the bandwidth can be simply calculated using the formula $B = C \times D$. By example the ISA bus has a data path of 2 bytes and operates at a clock frequency of 8MHz which gives a bandwidth of 16 Mbytes/s.

The heterogeneous nature of the nodes of a PC is clearly illustrated by the range of measurement units used varying from MHz to seek times in milliseconds. In this context it is difficult to easily evaluate the relative performance of each device on a PC. However, it is possible to compare the relative performance of different nodes using the simple equation ($B = C \times D$) with the common unit of measurement of bandwidth in Mbytes/s i.e. B-Nodes (table 2).

We suggest the following advantages to modeling a PC as a collection of B-Nodes and using Bandwidth as a common measurement unit:

- 1 A byte is a commonly understood quantity.
- 2 The SI scaling system may be used e.g. Mbytes/s, Gbytes/s.
- 3 Performance in Mbytes/s can easily be derived if not specified.
- 4 Nodal model is independent of any underlying architectural details.
- 5 Dissimilar devices can be evaluated using this simple nodal model.
- 6 Performance 'bottlenecks' can be identified.

Table 2: Bandwidth

Device	Clock Speed (MHz)	Data Width (Bytes)	Bandwidth (Mbytes/s) $B = C \times D$
Microprocessor	400	8	3200
DRAM	16	8	128
Hard Disc	60rps	90 Kbytes	5.2
CDROM			4.6
ISA Bus	8	2	16

We then examined if this bandwidth node model would support increasing levels of technical complexity. B-Nodes typically operate sub-optimally due to their operational limitations and also the interaction between other slower B-Nodes. Work to date indicates that the simple bandwidth equation can be modified to take this into account i.e. $\text{Bandwidth} = \text{Clock} \times \text{Data Path Width} \times \text{Efficiency}$. This simple mnemonic ($B = C \times D \times E$) can be applied to every node within the PC. By example the ISA bus does not transfer data on every clock pulse. At least 3 clock pulses are needed giving an efficiency factor of 1/3. Hence for an ISA bus operating sub-optimally, $B = 8 \times 2 \times 0.33$ i.e. 5.3 Mbytes/s. It should be noted that derivation of the efficiency factor requires a reasonable understanding of the underlying technologies. Finally we analyzed a spectrum of PCs ranging from those based on the first generation processor (8088, 8 bit ISA, floppy disc drive etc) through to those based on the latest fifth generation processors (Pentium, PCI, AGP etc). It was possible to describe every PC examined using both the simple and more advanced bandwidth node models. It can be concluded that given the bandwidth node model is valid for all the different generations of digital PC technology to date, it may continue to be useful for succeeding generations.

A Proposed User-based Benchmark

Bandwidth measured in Mbytes/s, though useful is not a good initial scaffolding tool - a typical user runs 32 bit windows based applications. The user is therefore interacting, via a Graphical User Interface (GUI), with text and graphical images. For general acceptance a benchmark must be easy to understand and should therefore be based on user perception of performance and as such be simple and use reasonably sized units. We suggest that a useful unit of measurement is the display of a single, full screen, full color image. We define a full screen image to have a resolution of 1024 x 1280 (1.25Mpixels) with a color depth of 3 bytes per pixel, which represents a total of 3.75 Mbytes of data (1.25Mpixels x 3 bytes per pixel). Obviously sub multiples of this unit are possible such as quarter screen images and reduced color palette such as 1 byte per pixel. The performance of a PC and associated B-Nodes can still be evaluated using the measurement of bandwidth but with the units of standard full screen, full color images/s or frames/s. Furthermore, full motion video requires about 30 frames/s, which represents (112.5 Mbytes/s). We suggest the unit of measurement based on full motion video is more meaningful to a typical user because it relates directly to their perception of performance. Furthermore, the units of frames/s can be directly derived from the more fundamental unit of performance of Bytes/s. The relative performance of each B-Node can therefore be evaluated by its ability to produce full motion video (full screen, full color). By example the previously discussed microprocessor can operate at a performance 28 times that needed to produce full motion video (table 3).

Table 3: Full motion video

Device	Bandwidth (Mbytes/s) $B = C \times D$	Bandwidth (Frames/s) = Mbytes/Frame size	Full motion video (FMV) (Full screen, full color)
Microprocessor	3200	853	28 x FMV
DRAM	128	34	1.1 x FMV
Hard Disc	5.2	1.3	0.04 x FMV
CROM	4.6	1.2	0.04 x FMV
ISA Bus	16	4.2	0.14 x FMV

This method of measuring data transfer rates between within a PC using frames/s as a measurement of performance was confirmed experimentally. A C program was used to transfer frames between two B-Nodes, a HDD and SDRAM, flagging the start and stop of this operation on the parallel port. An oscilloscope (100 micro second resolution), connected to this port, was used to measure and derive the data transfer rate in Frames/s. The results obtained related directly to the manufactures technical specification of the HDD. It should be noted that video compression was not used. We are currently conducting further experiments to evaluate the effects of compression and the operating system overheads. We have therefore a common unit of measurement, relevant to common human perception with decimal based units, that can be applied to different B-Nodes and identify performance bottlenecks.

The concept of using images to evaluate PC performance can be made directly relevant to users from different disciplines. By example, in the medial profession there are number of radiological imaging techniques, such as Magnetic Resonance Imagery (MRI), Computerized Tomography (CT), Ultrasound etc, that all store images digitally (Dwyer, 1992). A typical MRI image is approximately 0.13 Mbytes of data. Furthermore, given that Mbytes/s are our fundamental unit it is a simple procedure to convert both text and sound data to this common unit. Each node (microprocessor, hard disc drive etc) can now be treated as a quantifiable data source/sink (Frames or Mbytes) with an associated transfer characteristic (Frames/s or Mbytes/s). This approach allows the performance of every node and data path to be assessed by a simple, common measurement – bandwidth. Where Bandwidth = Clock Speed x Data Path Width with the common units of Frames/s (Mbytes/s). Each node is defined as a B-node (Bandwidth-Node).

B-Nodes as a Constructivist Framework

In answer to the second problem posed by this paper we propose a new pedagogical framework that defines a PC as a collection of B-Nodes. The performance of all B-Nodes may be calculated using the same formula ($B = C \times D$) with the bandwidth units of Frames/s. This year, in addition to the competency-based workshops, we used B-Nodes as the pedagogical framework for the first time and evaluated the results. During the early lectures in the CIM unit we started with a simple hierarchical bandwidth node model, based on common student experience, of a person (microprocessor) at a desk with a note pad (RAM) and a filing cabinet (Hard

disc drive). With this simple example it is possible to describe each device as a node and calculate its bandwidth using a common, easily understood unit of measurement i.e. the number of pages of A4 text that can be transferred per unit time between the person, desk and filing cabinet. The analogy can then be made between the person (microprocessor), notepad (RAM) and filing cabinet (hard disc drive). Using this conceptual framework every device in the PC is considered as a series of nodes whose performance is measured by bandwidth with the units of Frames/s. The operational characteristic of each node is then considered in detail and its bandwidth calculated using the common units of Bytes/s and Frames/s. The units of Frames/s are a user based, easily understood measurement. The workshops require students to implement the conceptual knowledge presented in the lectures thereby integrating conceptual and procedural knowledge. No digital techniques or assembly language programming are taught. Using the standard compulsory ECU course evaluation questionnaire the unit was highly rated by students. Furthermore, a more detailed study was conducted to investigate student experience of the nodal concept. From an enrolment of eighty students in the unit CIM, forty were given questionnaires. According to Maj (Maj et al., 2000),

"Thirty-six students thought the nodal concept should be taught. Thirty-five students thought that this concept helped them understand computer technology. Thirty-five students thought that using a common unit (Frames/s) helped in evaluating PC devices. Significantly half the respondents thought more time should be spent on this type of calculation."

Student understanding was evaluated by means of two assignments in which they were required to obtain the technical specifications for a PC and construct a nodal model with associated bandwidths in both Mbytes/s and Frames/s. One student wrote:

"The lack of meaningful and comparable technical specifications makes the task of calculating the performance of a PC and its individual components a difficult one. The computer industry appears to be a law unto oneself, with incomplete or non-existent technical specifications. The use of standards, terms and abbreviations that are not comparable across different systems or manufacturers. This all leads to frustration and confusion from consumers and users of these computer systems and components"

And for a given technical specification the student wrote:

"Sounds impressive, yet by undertaking the exercise of converting to the components common units the relative performance of the PC and its individual components can be measured and conclusions drawn. You will finally be able to see exactly what you are purchasing, its strengths, weaknesses and overall value"

Prior to the introduction of this model previous student answers to this type of assignment resulted in almost exclusively a list of hardware details copied directly from technical literature with little or no critical analysis. However, using this

model most students were able to predict the likely performance of a PC and identify B-Nodes that would significantly handicap performance. However, 22 students, from an enrolment of 80, demonstrated some fundamental misconceptions and badly failed one or more of the assignments. The bandwidth node model depends on an understanding of frequency (MHz), scientific notation, units etc. As a separate experiment students were evaluated for their understanding of simple physics. The failure rate was comparable to the results from the assignments with a distinct bi-modal distribution. The failure to succeed in the assignments appears to correlate with a lack of understanding of simple physics. Further work is needed and this problem is currently being studied in detail. However, as an attempt to address this problem the concepts of units, frequency etc are introduced, furthermore at the conclusion of the workshops students are now given the opportunity to participate in an informal tutorial (Veal et al., 2000). Since the introduction of these tutorials the assignment failure rate has fallen to less than 5%. Significantly, using this nodal model all additional progressive technical detail and complexity is additive to knowledge and understanding rather than being perceived by the student as simply a collection of factual data.

Advantages to using this pedagogical model include:

- Students can perceive the PC as a unified collection of devices
- Node performance, measured in bandwidth (Frames/s) is a user based, easily understood measurement
- The units Mbytes/s and Frames/s use a decimal scaling system
- Students are able to evaluate different B-Nodes of a PC by means of a common unit of measurement
- Students can easily determine the anticipated performance of a PC given its technical specification
- Students are able to critically analyse technical literature using this integrating concept.
- The model is suitable for students from a wide range of disciplines (Computer Science, Multimedia, IT, Business IT)
- The model is valid for increasing levels of technical complexity.
- B-Nodes are independent of architectural detail

Based on our results to date we strongly recommend the bandwidth node model as the pedagogical framework for introductory curriculum in computer technology. The authors do not suggest that the bandwidth node model should replace the teaching of this traditional computer technology curriculum (digital logic etc). Rather, that it may represent a higher level of abstraction and hence serve as a useful introduction to students from a wide range of disciplines. By example digital logic (sequential and combinational) modeling represents a higher level of abstraction than the underlying details of transistor technology. Similarly transistor modeling represents a higher level of abstraction than the underlying details of semiconductor theory.

Conclusions

This paper proposes B-Nodes, whose performance is rated by bandwidth (frames/s), as the pedagogical basis of computer technology curriculum. Work to date indicates that modeling the PC as such a collection of B-Nodes provides a good constructivist framework allowing technical detail to be introduced in a controlled, top-down manner that is readily understandable to students from all disciplines. This nodal model represents a new, higher level of abstraction that is also valid for increasing levels of technical complexity and hence suitable for more advanced studies. Given this model provides abstraction it is therefore independent of architectural detail and can therefore accommodate rapid changes in technology. It is valid for all generations of digital PC technology to date and may therefore continue to be useful for some years to come. The author's recommend that the associated workshop exercises should be integrated to the lecture based conceptual knowledge thereby providing students with the opportunity to acquire commercially relevant skills. Such skills can be easily evaluated by competency-based assessment. Our on-going work includes investigating the effects of: data compression, operating systems etc and a more in-depth educational evaluation.

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3.3 A Summary of the Major Conclusions from the Published Papers

These published papers have covered the main research questions namely:

"Is it possible to have CNT curricula that are more directly relevant to both student and employer expectations without suffering from rapidly obsolescence?"

The published papers argue for the inclusion of hands-on skills within unit curricula and their effective assessment as a solution to the first part of this question.

The requirement to avoid rapid obsolescence necessitated a high level abstract model independent of particular technological implementation details. This led to the question:

"Is it possible to develop a new, high level abstraction model for use in CNT education?"

- The B-Node model was proposed as a solution to this question which was offered as a method to help future-proof student learning in the face of rapid technological advancement?
- The need for the B-Node model resulted from the rejection of current computer and networking benchmarks as a basis for such an abstract model due to their transient nature and inconsistencies between different benchmarks.
- The B-Node models are presented within the published papers in a range of typical contexts.
- The use of the B-Node model means that students needed to possess a basic level of understanding and skill in mathematics to be able to use such a model.

Meeting employer expectations necessitates a consideration of the role of the university in modern society as well as the suitability of hands-on skill requirements within a university context.

The use of workshops in which such hands-on skills are to be practised raises the problem of ensuring safety which is needed to fulfil both practical and legal requirements.

Furthermore, the inclusion of hands-on skills required their effective assessment. This resulted in the research question:

"Can an effective, efficient and meaningful assessment be undertaken to test students' hands-on skills and understandings?"

CBAs were offered as a solution to this question which led to a consideration of the competency debate with education. Moreover, CBAs were also utilised as an effective measure to test student safety practices and understanding in addition to lectures, written examination questions, MCQs and workshops.

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APPENDIX A

MATHS AND PHYSICS PROBLEMS WITH BANDWIDTH CALCULATIONS

An abstract model may require a certain level of mathematical understanding and skill to be applied effectively as well as a basic knowledge of the underlying physics. However, basing CNT developments upon high level abstract models can be problematic if students are unable to apply such models due to an insufficient understanding of the basic mathematics and physics required.

Clement has noted some problems that students experienced on introductory physics programs may be caused by their preconceptions (Clement, 1982). For example, important basic knowledge such as D.C current flow is often misunderstood (Arons, 1982, 1990; Cohen, Eylon, & Ganiel, 1983; Fredette & Clement, 1981; Osborne & Freyberg, 1985). Wilkinson has discussed approaches to teaching physics from real life experiences (Wilkinson, 1999).

Armstrong and Croft have noted problems experienced by undergraduates due to lack of mathematical skills and knowledge (Armstrong and Croft 1999). Whilst Boustead notes that new mathematical concepts should fit into previous knowledge (Boustead, 2000). Such comments resonate with the constructivist approach referred to previously.

Mathematics can be considered in respect to students' basic skills and knowledge requirements (Brown, 1999; Madgid, 1998). However, there is also a need for mathematical literacy developed via problem solving and investigation (Goldsmith & Mark, 1999). Mathematics may also be required to help to promote logical thinking (Drier, Dawson, & Garofalo, 1999).

The educational use of mathematics as a tool has been considered (Confrey, 1997; Hunt & Lawson, 1996; Kumar & Jalkio, 1998), whilst an industry perspective of its need has been investigated (McHenry, 1992). Mathematics can

be studied for its own sake and this need not preclude its use in understanding technology (Keitel, 1992; Kelemen, Tucker, Henderson, Bruce, & Astrachan, 2000; Small, 1999).



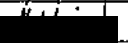
APPENDIX B

PUBLICATION MATRIX

The matrices presented in Appendix B indicate the relative inputs of the contributing authors to the multiple author publication considered. Minor indicates a substantial contribution within this category was not performed by this author, whereas major indicates that a substantial contribution was made by the author in this category. Equal denotes an equal contribution in that category by the contributing authors.

Assessing Hands-on Skills on CS1 Computer and Network Technology Units

Authors: D Veal, S. P. Maj, R. Duley. (2001) Presented at the ACM SIGCSE 32nd Technical Symposium on Computer Science Education, Charlotte, NC. USA.

	Contributions (Major/equal/minor)	Author 1 Veal	Author 2 Maj	Author 3 Duley
1.	Problem definition	Major	Minor	Minor
2.	Literature review	Major	Minor	Minor
3.	Hypothesis formulation	Major	Minor	Minor
4.	Experimental design	Major	Minor	Minor
5.	Establish experimental platform (e.g. design and implement hardware/software)	Major	Minor	Minor
6.	Data Collection	Major	Minor	Minor
7.	Data interpretation	Major	Minor	Minor
8.	Critical analysis	Equal	Equal	Minor
9.	Drafting of paper	Major	Minor	Minor
10.	Revisions of final paper	Major	Minor	Minor
11.	Submission of final paper	Major	Minor	Minor
12.	Presentation of paper (conference)	Minor	Major	Minor
	Signature 1			
	Date	21/11/03		
	Signature 2			
	Date	21/11/03		
	Signature 3			
	Date	21/11/03		

Should IS Management Courses Provide Hands-on Experience in Computer and Network Installation?

Authors: D. Veal, and S. P. Maj. Presented at the Americas Conference on Information Systems (AMCIS) 2001, held in Boston, MA, USA

	Contributions (Major/equal/minor)	Author 1 Veal	Author 2 Maj
1.	Problem definition	Equal	Equal
2.	Literature review	Major	Minor
3.	Hypothesis formulation	Equal	Equal
4.	Experimental design	Equal	Equal
5.	Establish experimental platform (e.g. design and implement hardware/software)	NA	NA
6.	Data Collection	Equal	Equal
7.	Data interpretation	Major	Minor
8.	Critical analysis	Equal	Equal
9.	Drafting of paper	Major	Minor
10.	Revisions of final paper	Major	Minor
11.	Submission of final paper	Major	Minor
12.	Presentation of paper (conference)	Minor	Major
	Signature 1 [REDACTED]		
	Date 21/11/2003		
	Signature 2 [REDACTED]		
	Date 21/11/03		

Multiple Choice Questions on a Computer Installation and Maintenance Unit

Authors: D. Veal, A. Engel, S. P. Maj. Presented at the 5th Baltic region seminar on engineering education. UICEE held in Gdynia, Poland from 17-19 September, 2001.

	Contributions (Major/equal/minor)	Author 1 Veal	Author 2 Engel	Author 3 Maj
1.	Problem definition	Major	Minor	Minor
2.	Literature review	Major	Minor	Minor
3.	Hypothesis formulation	Major	Minor	Minor
4.	Experimental design	Major	Minor	Minor
5.	Establish experimental platform (e.g. design and implement hardware/software)	Major	Minor	Minor
6.	Data Collection	Major	Minor	Minor
7.	Data interpretation	Equal	Equal	Minor
8.	Critical analysis	Equal	Equal	Minor
9.	Drafting of paper	Major	Minor	Minor
10.	Revisions of final paper	Equal	Equal	Minor
11.	Submission of final paper	Major	Minor	Minor
12.	Presentation of paper (conference)	Minor	Major	Minor
	Signature 1 [redacted]			
	Date 21/11/2003			
	Signature 2 [redacted]			
	Date 22/11/2003			
	Signature 3 [redacted]			
	Date 21/11/03			

Computer and Network Technology Education at Maximum Value and Minimum Cost

Authors: D. Veal, S. P. Maj. This paper was presented at the American Society for Engineering Education (ASEE), computers in education division 2000 annual conference, held in St Louis, Missouri, USA

	Contributions (Major/equal/minor)	Author 1 Veal	Author 2 Maj
1.	Problem definition	Equal	Equal
2.	Literature review	Minor	Major
3.	Hypothesis formulation	Equal	Equal
4.	Experimental design	Equal	Equal
5.	Establish experimental platform (e.g. design and implement hardware/software)	NA	NA
6.	Data Collection	Equal	Equal
7.	Data interpretation		
8.	Critical analysis	Equal	Equal
9.	Drafting of paper	Major	Minor
10.	Revisions of final paper	Major	Minor
11.	Submission of final paper	Major	Minor
12.	Presentation of paper (conference)	Major	Minor
	Signature 1 [Redacted]		
	Date 21/11/2003		
	Signature 2 [Redacted]		
	Date 21/11/03		

Is a Practical Computer Installation and Maintenance Unit Cost Effective?

Authors: S. Cikara, D. Veal, A. Watson, S. P. Maj. This paper was presented at the 5th Baltic region seminar on engineering education. UICEE, held at Gdynia, Poland, from 17-19 September, 2001.

	Contributions (Major/equal/minor)	Author 1 Cikara	Author 2 Veal	Author 3 Watson	Author 4 Maj
1.	Problem definition	Equal	Equal	Minor	Equal
2.	Literature review	Minor	Major	Minor	Minor
3.	Hypothesis formulation	Equal	Equal	Minor	Equal
4.	Experimental design	Minor	Major	Minor	Minor
5.	Establish experimental platform (e.g. design and implement hardware/software)	N/A	N/A	N/A	N/A
6.	Data Collection	Major	Major	Major	Minor
7.	Data interpretation	Minor	Major	Minor	Minor
8.	Critical analysis	Minor	Major	Minor	Minor
9.	Drafting of paper	Major	Major	Minor	Minor
10.	Revisions of final paper	Major	Major	Minor	Major
11.	Submission of final paper	Major	Minor	Minor	Minor
12.	Presentation of paper (conference)	Major	Minor	Minor	Minor
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	Date 21/11/2003				
	Signature 3 [redacted]				
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	Signature 4 [redacted]				

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Physics: Implications for Computer Technology

Authors: D. Veal, S. P. Maj, G. I. Swan, This paper was presented at the American Society for Engineering Education (ASEE), physics and engineering physics division, 2000 annual conference, held at St Louis, Missouri, USA.

	Contributions (Major/equal/minor)	Author 1 Veal	Author 2 Maj	Author 3 Swan
1.	Problem definition	Equal	Minor	Equal
2.	Literature review	Equal	Minor	Equal
3.	Hypothesis formulation	Major	Minor	Minor
4.	Experimental design	Major	Minor	Minor
5.	Establish experimental platform (e.g. design and implement hardware/software)	Equal	Minor	Equal
6.	Data Collection	Equal	Equal	Equal
7.	Data interpretation	Major	Minor	Minor
8.	Critical analysis	Equal	Equal	Equal
9.	Drafting of paper	Major	Minor	Minor
10.	Revisions of final paper	Equal	Minor	Equal
11.	Submission of final paper	Minor	Minor	Minor
12.	Presentation of paper (conference)	Major	Minor	Minor
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	Date 21/11/2003			
	Signature 2 [Redacted]			
	Date 21/11/03			
	Signature 3 [Redacted]			
	Date 21/11/03			

Mathematics Requirements on a Computer Technology Unit

Authors: D. Veal, S P Maj, G. I. Swan. This paper was presented at the mathematics division of the American Society for Engineering Education (ASEE), 2001 annual conference, held at Albuquerque, New Mexico, USA.

	Contributions (Major/equal/minor)	Author 1 Veal	Author 2 Maj	Author 3 Swan
1.	Problem definition	Major	Minor	Minor
2.	Literature review	Major	Minor	Minor
3.	Hypothesis formulation	Equal	Equal	Equal
4.	Experimental design	Equal	Equal	Equal
5.	Establish experimental platform (e.g. design and implement hardware/software)	Major	Minor	Minor
6.	Data Collection	Major	Minor	Minor
7.	Data interpretation	Major	Minor	Minor
8.	Critical analysis	Equal	Equal	Equal
9.	Drafting of paper	Major	Minor	Minor
10.	Revisions of final paper	Major	Minor	Minor
11.	Submission of final paper	Major	Minor	Minor
12.	Presentation of paper (conference)	Major	Minor	Major
	Signature 1 [redacted]			
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	Signature 2 [redacted]			
	Date 21/11/03			
	Signature 3 [redacted]			
	Date 21/11/03			

The Use of an Oscilloscope as an Educative Tool on a Network Installation & Maintenance Unit

Authors: D. Veal, S. P. Maj, G. I. Swan This paper was presented at the Experimentation and Laboratory Oriented Studies Division at the American Society for Engineering Education (ASEE), 2001 annual conference held in Albuquerque, New Mexico, USA.

	Contributions (Major/equal/minor)	Author 1 Veal	Author 2 Maj	Author 3 Swan
1.	Problem definition	Major	Equal	Equal
2.	Literature review	Equal	Minor	Equal
3.	Hypothesis formulation	Major	Minor	Minor
4.	Experimental design	Equal	Minor	Equal
5.	Establish experimental platform (e.g. design and implement hardware/software)	Major	Minor	Minor
6.	Data Collection	Major	Minor	Minor
7.	Data interpretation	Major	Minor	Minor
8.	Critical analysis	Major	Minor	Minor
9.	Drafting of paper	Major	Minor	Major
10.	Revisions of final paper	Major	Minor	Major
11.	Submission of final paper	Major	Minor	Minor
12.	Presentation of paper (conference)	Major	Minor	Minor
	Signature 1			
	Date 21/11/2003			
	Signature 2			
	Date 21/11/03			
	Signature 3			
	Date 21/11/03			

Measurement and Observation Inside a PC

Authors: G. I. Swan, D. Veal, S. P. Maj. (2002) Published in the Transactions on Engineering and Technology Education. Melbourne, Vic, Australia.

	Contributions (Major/equal/minor)	Author 1 Swan	Author 2 Veal	Author 3 Maj
1.	Problem definition	Equal	Equal	Equal
2.	Literature review	Equal	Equal	Minor
3.	Hypothesis formulation	Equal	Equal	Minor
4.	Experimental design	Equal	Equal	Minor
5.	Establish experimental platform (e.g. design and implement hardware/software)	Equal	Equal	Minor
6.	Data Collection	Equal	Equal	Minor
7.	Data interpretation	Equal	Equal	Minor
8.	Critical analysis	Equal	Equal	Equal
9.	Drafting of paper	Major	Major	Minor
10.	Revisions of final paper	Equal	Equal	Minor
11.	Submission of final paper	Minor	Major	Minor
12.	Presentation of paper (conference)	N/A	N/A	N/A
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	Signature 2 [Redacted]			
	Date 21/11/2003			
	Signature 3 [Redacted]			
	Date 21/11/03			

Is Computer Teckuology Taught Upside Down?

Authors: S. P. Maj, D Veal, P. Charlesworth. This paper was presented at the 5th annual conference on Innovation and Technology in Computer Science Education (ITCSE) held in Finland in 2000.

	Contributions (Major/equal/minor)	Author 1 Maj	Author 2 Veal	Author 3 Charlesworth
1.	Problem definition	Major	Minor	Minor
2.	Literature review	Major	Minor	Minor
3.	Hypothesis formulation	Major	Minor	Minor
4.	Experimental design	Major	Minor	Minor
5.	Establish experimental platform (e.g. design and implement hardware/software)	Major	Minor	Minor
6.	Data Collection	Equal	Minor	Equal
7.	Data interpretation			Minor
8.	Critical analysis	Equal	Equal	Minor
9.	Drafting of paper	Major	Minor	Minor
10.	Revisions of final paper	Equal	Equal	Minor
11.	Submission of final paper	Major	Minor	Minor
12.	Presentation of paper (conference)	Major	Minor	Minor
	Signature 1			
	Date			
	Signature 2			
	Date			
	Signature 3			
	Date			

Architectural Abstraction as an aid to Computer Technology Education

Authors: S. P. Maj, D. Veal. This paper was presented at the American Society for Engineering Education (ASEE), computers in education division. conference held at St Louis, Missouri, USA.

	Contributions (Major/equal/minor)	Author 1 Maj	Author 2 Veal
1.	Problem definition	Major	Minor
2.	Literature review	Major	Minor
3.	Hypothesis formulation	Major	Minor
4.	Experimental design	Major	Minor
5.	Establish experimental platform (e.g. design and implement hardware/software)	Major	Minor
6.	Data Collection	Major	Minor
7.	Data interpretation	Major	Minor
8.	Critical analysis	Equal	Equal
9.	Drafting of paper	Major	Minor
10	Revisions of final paper	Major	Minor
11	Submission of final paper	Major	Minor
12	Presentation of paper (conference)	Major	Minor
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	Date 21/11/03		
	Signature 2 [Redacted]		
	Date 21/11/2003		



A New Abstraction Model for Engineering Students

Authors: S. P. Maj, D. Veal, A. Boyanich. Presented at the UNESCO International Centre for Engineering Education 4th UICEE annual engineering education conference, in 2000 held in Bangkok, Thailand.

	Contributions (Major/equal/minor)	Author 1 Maj	Author 2 Veal	Author 3 Boyanich
1.	Problem definition	Major	Minor	Minor
2.	Literature review	Major	Minor	Minor
3.	Hypothesis formulation	Major	Minor	Minor
4.	Experimental design	Major	Minor	Minor
5.	Establish experimental platform (e.g. design and implement hardware/software)	Major	Minor	Minor
6.	Data Collection	Major	Minor	Minor
7.	Data interpretation	Major	Minor	Minor
8.	Critical analysis	Equal	Equal	Minor
9.	Drafting of paper	Major	Minor	Minor
10.	Revisions of final paper	Equal	Equal	Minor
11.	Submission of final paper	Major	Minor	Minor
12.	Presentation of paper (conference)	Major	Minor	Minor
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	Signature 2 [Redacted]			
	Date 21/11/2003			
	Signature 3 [Redacted]			
	Date 21/11/03			

Controlling Complexity in Information Technology: Systems and Solutions.

Authors: Maj, S. P. and D. Veal, Presented at the IASTED International Conference - Computers and Advanced Technology in Education (CATE 2001), held in Banff, Canada.

	Contributions (Major/equal/minor)	Author 1 Maj	Author 2 Veal
1.	Problem definition	Major	Minor
2.	Literature review	Major	Minor
3.	Hypothesis formulation	Major	Minor
4.	Experimental design	Major	Minor
5.	Establish experimental platform (e.g. design and implement hardware/software)	Major	Minor
6.	Data Collection	Major	Minor
7.	Data interpretation	Major	Minor
8.	Critical analysis	Equal	Equal
9.	Drafting of paper	Major	Minor
10.	Revisions of final paper	Equal	Equal
11.	Submission of final paper	Major	Minor
12.	Presentation of paper (conference)	Major	Minor
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	Date 21/11/03		
	Signature 2 		
	Date 21/11/2003		

Modelling Website Infrastructure Using B-Node Theory

Authors: G. Kohli, D. Veal and S. P. Maj. This paper was presented at the 9th Australia and New Zealand Systems (NNZSYS) Conference held in November in Melbourne Victoria.

	Contributions (Major/equal/minor)	Author 1 Kohli	Author 2 Veal	Author 3 Maj
1.	Problem definition	Major	Minor	Minor
2.	Literature review	Major	Major	Minor
3.	Hypothesis formulation	Major	Minor	Major
4.	Experimental design	Major	Major	Minor
5.	Establish experimental platform (e.g. design and implement hardware/software)	Major	Major	Minor
6.	Data Collection	Major	Major	Minor
7.	Data interpretation	Major	Major	Minor
8.	Critical analysis	Minor	Major	Minor
9.	Drafting of paper	Major	Minor	Minor
10.	Revisions of final paper	Major	Major	Minor
11.	Submission of final paper	Major	Minor	Minor
12.	Presentation of paper (conference)	Major	N/A	Minor
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	Date 21/11/2003			
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	Date 21/11/03			

Computer Technology Curriculum – A New Paradigm for a New Century

Authors: S. P. Maj, D. Veal. This paper was published in the Journal of Research and Practice in Information Technology in November 2000. (Formerly the Australian Computer Journal).

	Contributions (Major/equal/minor)	Author 1 Maj	Author 2 Veal
1.	Problem definition	Equal	Equal
2.	Literature review	Equal	Equal
3.	Hypothesis formulation	Equal	Equal
4.	Experimental design	Equal	Equal
5.	Establish experimental platform (e.g. design and implement hardware/software)	Equal	Equal
6.	Data Collection	Equal	Equal
7.	Data interpretation	Equal	Equal
8.	Critical analysis	Equal	Equal
9.	Drafting of paper	Equal	Equal
10.	Revisions of final paper	Equal	Equal
11.	Submission of final paper	Equal	Equal
12.	Presentation of paper (conference)	N/A	N/A
	Signature 1 [Redacted]		
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	Signature 2 [Redacted]		
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APPENDIX C

WORK IN PROGRESS

Work to date strongly supports that the B-Node model has pedagogical value. The equation $B = CDE$ has the advantage of giving a first order approximation to performance in MB/s from which more meaningful units, such as medical images per second may be derived. Furthermore technical complexity is aggregated into the E component. However, E has not as yet been experimentally defined. Initial work on PCs gave some results but failed to produce definitive answers. PC technology is highly complex with large amounts of built in intelligence that can serve to confuse attempts obtain meaning bandwidth measurements.

Towards the completion of this award networking devices such as switches and routers became available for research. The following paper "A Framework for a Network Performance Model based upon B-Nodes" was the result of a series of experiments undertaken to measure bandwidth using the routers and switches. These experiments included measuring the time taken to send files across an internetwork using FTP such that the data flows converge to cross a common part of the link. A formula is developed to predicate the transmission times and it was found that these times could be predicated to within an error of five percent. The effect of ACLs on bandwidth was also measured a value found for the decrease in bandwidth per ACL statement for the routers. The latency of the routers was investigated using extended PING.

The following paper describes some of the results obtained from this work and has been submitted for blind peer review to the 9th Annual Conference on Innovation and Technology in Computer Science Education (ITCSE) conference. This conference is to be held in Leeds, UK 28th – 30th June 2004 and is sponsored

by the ACM SIGCSE. This is a leading international venue for Computer Science Education.

A Framework for a Network Performance Model Based Upon B-Nodes

D. Veal	G. Kohli	S.P. Maj	J. Cooper
School of Computing and Information Science	School of Computing and Information Science	School of Computing and Information Science	School of Computing Science
Edith Cowan University	Edith Cowan University	Edith Cowan University	Curtin University of Technology
Perth WA Australia	Perth WA Australia	Perth WA Australia	Perth WA Australia

ABSTRACT

There are currently various methods by which network and internetworking education can be addressed. Examples include simulation modelling or analytically modeling both of which may be mathematically based (e.g. queuing theory) and highly complex. The authors have developed a new model, the B-Node, which is based upon simple formulae derived from an investigation of computer networks. This model provides a conceptual framework for performance analysis based upon bandwidth considerations from a constructivist perspective. The bandwidth centric B-Node model uses high level abstraction decoupled from the implementation details of the underlying technology which provides the possibility of future proofing student learning by decoupling this model from the underlying low level details of the particular technological implementation. This model has been successfully trialed in computer technology units. This paper represents an initial attempt to develop B-Node theory further in the field of networking education and presents a description of some of our work to date which includes details of experiments undertaken to measure bandwidth and formulae derived and applied to the investigation of converging data streams.

Introduction

There are many ways of teaching computer networking. Davies notes that: *"Network courses are often based on one or more of the following areas: The OSI model; Performance analysis; and Network simulation"* (Davies, Ransbottom, & Hamilton, 1998). The OSI model is a popular approach that is used extensively in the Cisco Networking Academy Program (CNAP) (Cisco, 2001) and other Cisco learning materials. With respect to simulation Davis describes the Optimized Network Engineering Tools (OPNET) system that that can model networks and sub-networks, individual nodes and stations and state transition models that defines a node (Davies et al., 1998). However, Davies gives no indication as to the accuracy of this simulation or of the limits of its application.

The development and testing of networking simulations may depend upon student's possessing knowledge and having suitable experience in computer programming languages that many networking students might not possess.

Performance analysis can use analytical based models that are often specialized in their area of application and may involve the use of complex mathematics which could be problematic for many computer networking students. Its advantages include the use of powerful mathematical tools. However, these models may not be based upon real systems. Queuing is a form of analytical modelling (Kleinrock, 1975). Networks or queues can also be analyzed (Menasce & Almeida, 2002). However, queuing analysis often assumes a Poisson distribution, which isn't the case with most networks (Lilja, 2000; Paxton & Floyd, 1995).

Performance analysis in computer networking can be based upon various models such as bandwidth in MB/s which is commonly used as a performance indicator. Also, students can perceive differences in performance with respect to bandwidth which can be used as a starting point for a constructivist based performance model.

Constructivism

The dominant theory of conceptual understanding in education is constructivism. This has been extensively tested in the field of science and mathematics education (Coburn, 1991; Confrey, 1991; Driver & Bell, 1985; Wheatley, 1991). Although Constructivism is a foundation of many modern teaching practices it has not been influential within computer education as noted by Ben-Ari: *"Constructivism is a theory of learning which claims that students construct knowledge rather than merely receive and store knowledge transmitted by the teacher. Constructivism has been extremely influential in science and mathematics education, but not in computer education"* (Ben-Ari, 1998). The knowledge the learner has already constructed will affect how new knowledge is interpreted. (Mestre, 2000), *"Put in the simplest way, to understand what someone has said or written means no less but also no more than to have built up a conceptual structure that, in a given context, appears to be 'compatible' with the structure the speaker had in mind. – and this compatibility, as a rule, manifests itself in no other way than that the receiver says and does nothing that contravenes the speaker's expectations"* (von Glasersfeld, 1989). The importance of conceptual understanding in the field of computer science education has been highlighted by the ACM who note that: *"Concepts are the raw material for understanding new information technology as it evolves"* (ACM, 2001). Hence there is a need to develop a performance based model in computer networking curricula that has its foundation based upon students' common conceptual understanding. The B-Node model provides such a foundation based upon the students' own perceptions of computer network performance.

B-Node Models

B-Node models are bandwidth centric high level abstractions which are independent of the underlying implementation details of a particular technology (Maj & Veal, 2001). The rapid rate of technological change within the field of Computer and Networking Technology (CNT) has given rise to the need to future proof student learning by not including details of the underlying technological implementation which may change rapidly as the technology progresses. (Maj &

Veal, 2000b; Maj, Veal, & Duley, 2001). Furthermore additional advantages of a bandwidth centric approach are that bandwidths can be readily measured in computer networks and bandwidths are often included in network equipment specifications. As B-Nodes are high level abstract models they allow the possibility of recursive decomposition into their lower level component parts.

Potential Problems of a Bandwidth Centric Approach

A bandwidth centric approach needs to address the problem of latency. Hennessy and Patterson, under a heading of "Fallacies and Pitfalls" mention the: "... *pitfall of using bandwidth as the only measure of network performance. ... this may be true for some applications such as video, where there is little interaction between the sender and the receiver, but for many applications such as NFS, are of a request-response nature, and so for every large message there must be one or more small messages ... latency is as important as bandwidth*" (Hennessy & Patterson, 1996b). In this paper latency is addressed by subsuming its effects under a heading of bandwidth by defining bandwidth as being equal to the size of the file transmitted from source to destination, divided by the time taken to send that file. Latency is simply included in the time to transfer the file. Both devices and networks may produce more bandwidth that results in a lower performance when compared to another system that produces better performance with less bandwidth (McComas, 2001a). Yet any measure of performance has its drawbacks and may not yield meaningful results in all circumstances.

Deterministic B-Node Models

The authors chose to concentrate upon an initial deterministic model rather than a stochastic model. Lai and Baker note that: "*Deterministic models are typically easier to work with mathematically than stochastic models, enabling us to find an analytical solution rather than a numerical one. Unfortunately, a deterministic model implies modeling with absolute certainty and many things cannot be known with enough certainty to make this practical*" (Lai & Baker, 2000). However, a deterministic model can allow the checking of the basic parameters upon which to base a more complex stochastically model. These initial parameters are to be based upon experimental results.

Table 1: Device Chain Abbreviations

Device chain	Abbreviations
PC to fibre link to PC	PFP
PC to PC	PP
PC to switch to PC	PSP
PC to Router to PC	PRP
PC to Switch to two Routers to Switch to PC	PS2RSP
PC to Switch to three Routers to Switch to PC	PS3RSP

The Experiments

The B-Node model has analytical components and yet is both relatively simple to use and quantitatively based. These investigations commenced with experiments using PING to determine a baseline for subsequent bandwidth measurements. The following shorthand was used for a given chain of networked devices

The PING Experiments

Extended PING is a program used to check connectivity at the first three layers of the OSI model. This was used under Windows XP to measure the latency between a source and destination. The version of PING used under Windows XP only gives a resolution of 1 ms and is of unknown accuracy. To address this problem we used a baseline of two PCs connected by a single crossover working at 12.5MB/s full duplex. The results are shown in Figure 1 which shows the size of the data transferred against the transfer times. This also provides a measure of the bandwidth as 5.48 MB/s. the actual bandwidth is twice this value, approximately 11 MB/s, due to Round Trip Time (RTT). Multiple values were taken to obtain a better approximation of bandwidth. The slope for respective devices gives bandwidths which are tabulated in table 2.

Table 2: Legend for PING Transfer Time Graph

Devices	Line plotted on graph	Bandwidth (MB/s) (Slope x 2)
PP	a	11.1
PSP	b	11.4
PSRSP	c	7.9
PS2RSP	d	7.5
PS3RSP	e	7.3

It can be seen from Figure 1 that when a switch replaces a crossover cable as the link between two PCs this introduces a latency of much less than 1 ms and the link operates at line speed (measured to be approximately 11 MB/s) as the slopes of lines 'a' and 'b' are approximately equal. The latency introduced by the addition of a switch is negligible at this level of difference as shown by the horizontal differences of points on the lines of 'a' and 'b'. The latency of adding extra routers and is given by the time between lines 'c' and 'd' and lines 'd' and 'e' which is approximately 1ms.

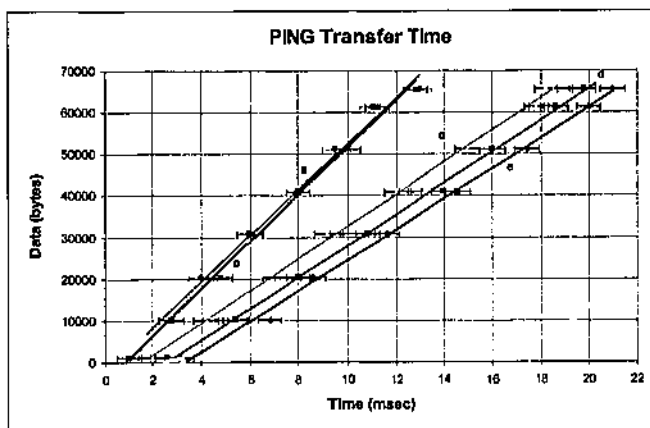


Figure 1: Data Verses PING Transfer Time

It can be clearly seen that the with the introduction of a router the bandwidth drops from 11.4 MB/s to approximately 7.5 MB/s as given by the difference in twice the slope of appropriate lines. It should be noted that fast switching was enabled by default on all routers and switches.

FTP Transfer Time Experiments

Further experiments were conducted by transmitting across a series of devices using File Transfer Protocol (FTP). To investigate larger file transfers PING can only send data up to 64KB. Figure 2 shows the bandwidths obtained using different configurations an example of which shown in Figure 3. This showed that the addition of a router in a series of (B-Nodes) decreased the bandwidth to 7.5 MB/s - in keeping with the previous PING experiment.

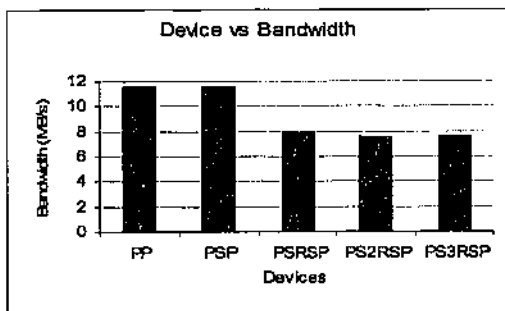


Figure 3: Device Verses Bandwidth for FTP Transfers

Negative Bandwidth Experiments

In order to model the reduction in bandwidth due to the addition processing on devices e.g. (a router) the authors measured the decrease in observed bandwidth when processing is taking place compared to the bandwidth when this processing is not taking place, and they defined this as 'negative bandwidth'.

To further investigate the effect of processing in the router, upon the bandwidth of traffic flowing through it, Access Control Lists (ACLs) were used to provide a measure of 'negative bandwidth'. ACLs can affect router performance as noted by Davis who notes that: *"Using access lists for route filtering is CPU intensive. Overuse of routing filtering can slow the flow of packets. Typically your router uses net flow or fast processors for fast switching. When you use route filtering, you use the slowest mode of process switching. The router usually has but one processor available for process switching"* (Davies, 2002). Significantly effects of ACLs are not quantified even though such a measure can be useful. To obtain such a measure experimentally extended ACLs of varying numbers of statements were applied to router Fast Ethernet interfaces and effects upon bandwidth noted. The results are shown in Figure 4. It can be concluded that, with the equipment used, the decrease in bandwidth is approximately 32kB/s per additional ACL statement as indicated by the slopes. (The dashed line is represents a file size of 150MB and the solid line indicates a file size of 15MB).

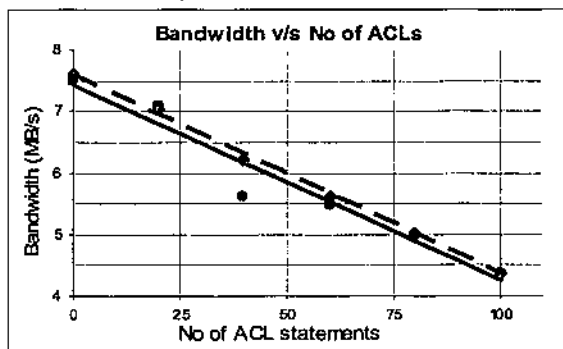


Figure 4: Bandwidth Verses Number of ACL Statements

B-Node Model Requirements

The B-Node model would need to handle both series and parallel configurations. These are represented as in figures 5 and 6. Given a chain of devices in series the resultant bandwidth is the minimum bandwidth of given set of individual bandwidths of each of these devices.

Where: $B(\text{Resultant}) = \text{Min}\{B_1, B_2, B_3, \dots\}$.

This minimum result was also noted by Jain and Dovrolis (Jain and Dovrolis, 2002).

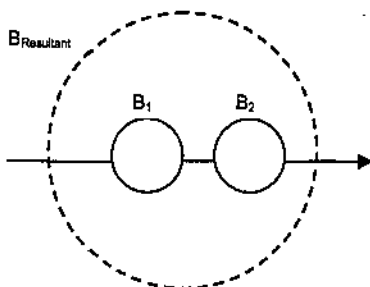


Figure 5: B-Nodes in Series

ACLs were applied to a series of routers and the major effect on the overall source to destination bandwidth was dominated by the router with the maximum number of ACLs statements. Furthermore, this principle can also be seen to apply in Figure 5 when routers were introduced into the chain the bandwidth dropped from 11.5 MB/s to 7.5 MB/s. As well as routers in series data can also flow through parallel routes through an internetwork as show in Figure 6. The division of such flows can depend upon the particular routing protocol implemented (Lammie & Pfund, 2002; McGregor, 2001). This requirement lead to a resultant bandwidth which is the sum of given set of parallel bandwidths:

$$B(\text{Resultant}) = \text{Sum} \{B_1, B_2, B_3, \dots\}$$

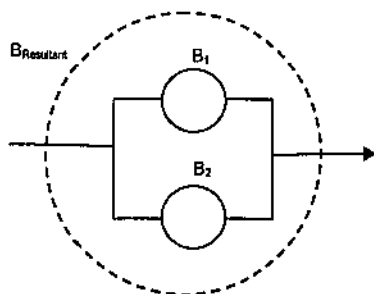


Figure 6: B-Nodes in Parallel

Modeling the Flow of Data

To allow for more complex configuration the modelling of networks and internetworks via bandwidth based B-Nodes requires a consideration of converging, diverging, counter-flow and crossing data-flows. These have the representations shown in Figure 7.

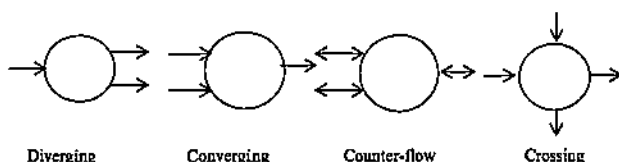


Figure 7: Data Flow Representations

Converging Data Flows

Files were concurrently sent across a network from a source PCs to a destination PCs that is from P_1 to P_4 , P_2 to P_5 and P_3 to P_6 as shown in figure 8.

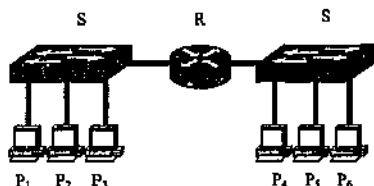


Figure 8: Experimental Configuration

Files of different length, such that $L_3 > L_2 > L_1$, were first sent individually between PSRSP configuration. A value of channel capacity C , which is the bandwidth from the source PC to a destination PC using FTP, was previously found to be 7.5 MB/s. Next the effect of the files sharing the capacity C of the link was investigated. The version of FTP used only gave transfer times therefore an experimental design technique used to reduce timing errors used was to send a series of files across the network, whereby each subsequent file sent was smaller than the previous file and also arrived ahead of it, as shown in Figure 9. As the initial bandwidths of the file transmission without any other data sharing the channel was $7.5\text{MB/s} = C$.

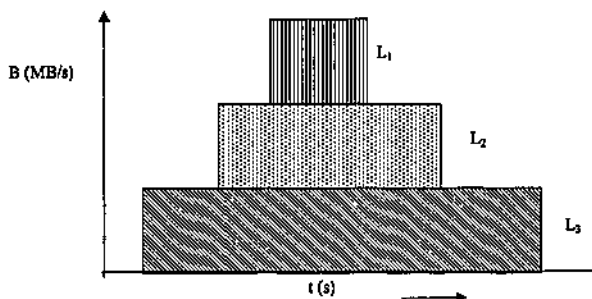


Figure 9: File transmission sequences

The Convergence Formula

A hypothesis was that the files would “squeeze” into the channel and so become elongated with respect to time. This can be seen by considering the diagrams in Figure 10 and Lie presents a similar argument for such elongation (Lai & Baker, 2000). This is in keeping with what was expected from equal priority packet switching.

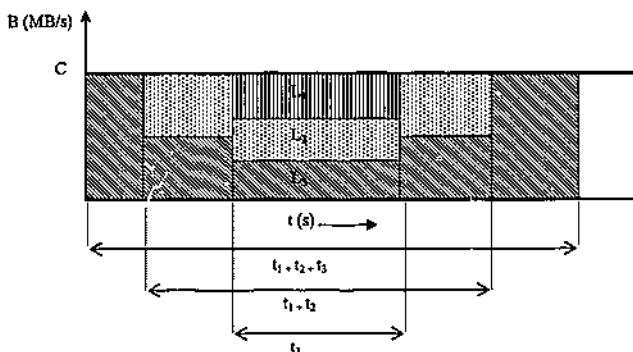


Figure 10: File bandwidths ‘squeezed’ into a channel

If three files of equal bandwidth attempt to share the channel at the same time then $C/3$. The following formula derivation assumes equal bandwidths on data flows, equal priority packet switching and also that the channel capacity $C \leq \text{sum of the individual bandwidths of the data flows}$. This gives the following series for the times to transfer the files and results in the formula shown for determining total transfer time. Assuming nested file transmission times as in figure 10 and that N represents the number of files to be transmitted.

$$\begin{aligned}
 \text{Time } t_1 &= L_1/(C/3) = 3L_1/C \\
 \text{Similarly } t_2 &= (\text{remaining data in } L_2)/\text{bandwidth} \\
 &= (L_2-L_1)/(C/2) = 2(L_2-L_1)/C \\
 t_3 &= (L_3-L_2)/C \\
 t_{\text{total}} &= t_1 + t_2 + t_3 \dots t_N \\
 &= N L_1 / C + (N-1)(L_2 - L_1)/C \dots + (L_n - L_{n-1})/C
 \end{aligned}$$

This series results in the following formula for the nth term:

$$t_n = \frac{(N - n + 1) (L_n - L_{n-1})}{C}$$

Where $L_0 = 0$ and $B_0 = 0$.

It can be seen by considering diagram 9 that the file L_1 will arrive with a time of t_1 and file L_2 will arrive with a time $t_1 + t_2$ and so on. These results were confirmed by experiment within an accuracy of 5% or better which confirms how the FTP files converged. These experiments were needed to form a foundation upon which to build more complex models to form networks and internetworks. Such internetworking models can then be made more complex as show in Figure 11.

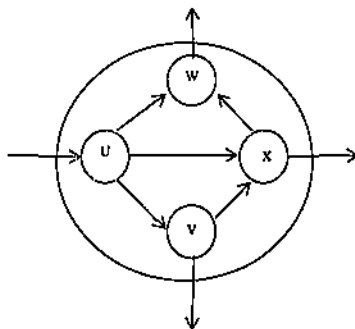


Figure 11: B-Nodes with Recursive Decomposition

The B-Node model needs to undergo further development and testing and testing and its breakdown points need to be determined.

Conclusions

Constructivism offers the possibility of meaningful conceptually based measures of performance. B-Node models are high level abstractions that are decoupled from the underlying technological detail. From the work to date, under the constraints of the equipment used, it may be concluded that the switches operated at line near to a

line speed. Furthermore, introducing routers into the path of the data flow reduced bandwidths. The authors have quantitatively evaluated the negative bandwidth introduced per extra extended ACL statement. Further investigations are being undertaken to determine the effects of counter-flows and cross-flows. The B-Node model needs further investigation and its breakdown points need to be determined. Further work is planned to repeat these experiments with a range of routers switches and PCs and to use a range of other protocols such as HTTP as the transfer program. Work to date suggests that this simple quantitative model may support student learning.

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APPENDIX D

CONVERGING FLOWS OF DATA WITH UNEQUAL BANDWIDTHS

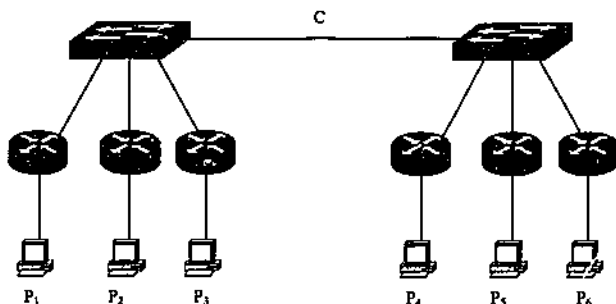
Introduction

Towards the end of this study Cisco Internetworking equipment became available for teaching purposes and this was subsequently utilised into research further developing the B-Node model. Part of this research was described in Appendix C where equal bandwidth converging flows of data were considered. This led to a requirement to model realistic situations such as converging flows of data across a common link were of unequal bandwidth. Formulae have been developed for such situations but have not yet been tested experimentally due to time constraints of the approaching thesis submission date. The necessary extensive literature search for similarly formulae has also not yet been undertaken.

Unequal bandwidth convergence formulae could also be applied to situations where the bandwidths appear to be equal within a few percent of each other. In such cases its use could achieve a better result than those obtained using the equal bandwidth formula. To derive a formula, let the channel capacity = C , which is the bandwidth from the source PC to a destination PC using FTP. (This was used as a common TCP file transfer program for the initial investigations other transfers are to be investigated in the future).

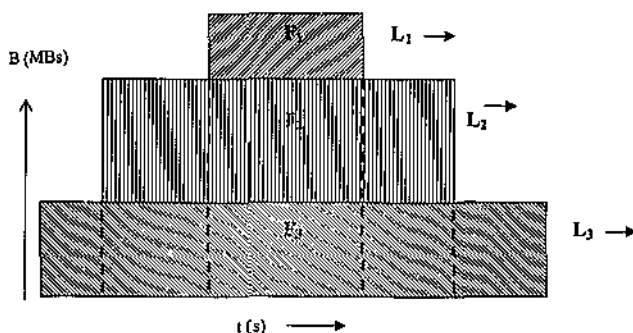
A converging flow (figure 9) with ACLs applied to router interfaces can be used to create data flows of unequal bandwidths. It should be noted that the reason to use switches is to avoid the need for routers with multiple Ethernet interfaces. The bottleneck should occur at the single link that will carry all the converged flows of data.

Figure 9 An Experimental Configuration for Investigating Converging Flows of Data



N files ($F_1, F_2, F_3, \dots, F_N$) are transmitted each of decreasing length ($L_N, \dots, L_3, L_2, L_1$) respectively. The files are sent such that F_1 , goes from P_1 to P_2 , F_2 goes from P_2 to P_3 and F_3 , goes from P_3 to P_6 . Furthermore, the files are of such lengths that F_2 starts after F_3 has started but finishes before F_3 and F_1 starts after F_2 has started, but completes its transmission across the channel before it and so on. This leads to the situation showing the nested file transmission times (figure 10). This is necessary because the FTP program under windows only gives transmission and such nested transmission ensures that the F_1 shares with F_2 and file F_3 for a known time and similarly file F_2 shares with only file F_3 also for a known time.

Figure 10 Unequal Bandwidth Nested File Transmission



In figure 10 the differing heights of the files indicates their unequal bandwidths. Appendix C gave the equal bandwidth convergence formula. With the convergence of flows of data of unequal bandwidths a suitable formula is required.

The Unequal Bandwidth Convergence Formula

When these files squeeze into a channel of capacity C MB/s, such that C is less than or equal to the bandwidths of the files F_1 , F_2 or F_3 this leads to the files sharing bandwidths as shown in figure 11.

Figure 11 Unequal Bandwidth Nested File Transmission via a Channel

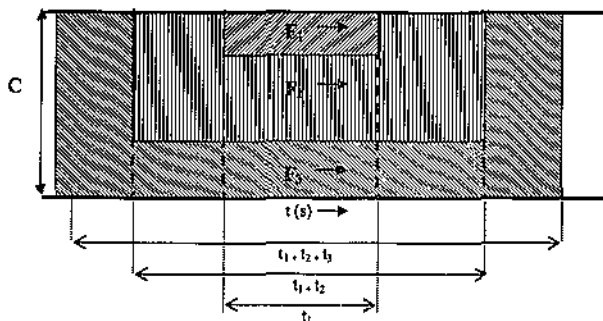





Table 11 indicates the symbols and patterns associated with figure 11.

Table 11 Transmitted Files: Lengths, Transmission Times and Patterns.

File	File length (MBs)	Time to transmit file (s)	Grid pattern
F_1	L_1	t_1	
F_2	L_2	$t_1 + t_2$	
F_3	L_3	$t_1 + t_2 + t_3$	
F_N	L_N	$t_1 + t_2 + t_3 \dots t_N$	

Let t_1 = time for file F_1 to share the channel capacity with $N-1$ other files where N number of files initially sharing the channel.

Let t_2 = time for file F_2 to share the channel capacity with F_3 after file F_1 has traversed the channel.

Hence the time to transmit a file is:

$$t_n = \frac{\text{Length remaining of the } n\text{th file that is to be sent when the channel is being shared by } N-n \text{ files}}{\text{Channel bandwidth available to the } n\text{th file}}$$

$$t_n = \frac{\text{Length of the } n\text{th file} - \text{Length of file the } n\text{th file already sent}}{\text{Channel bandwidth available to the } n\text{th file}}$$

However, the length of the file F_n already sent = t_{n-1} multiplied by its share of channel during that time period + t_{n-2} multiplied by its share of channel during that time period + ...

$$B_n \text{ has a share of the channel bandwidth} = B_n C / (B_N + B_{N-1} + \dots B_n)$$

$$= \frac{B_n C}{\sum_{j=n}^N B_j}$$

$$\text{Hence the length of file } F_n \text{ already sent} = \frac{t_{n-1} B_n C}{\sum_{j=n-1}^N B_j} + \frac{t_{n-2} B_n C}{\sum_{j=n-2}^N B_j} + \dots$$

$$= \sum_{k=1}^{n-1} \frac{B_n C t_k}{\sum_{j=k}^N B_j}$$

Recall that:

$$t_n = \frac{\text{Length remaining of the } n\text{th file that is to be sent}}{\text{when the channel is being shared by } n \text{ files}}$$

$$\text{Channel bandwidth available to the } n\text{th file}$$

Substituting:

$$t_n = \frac{L_n - \sum_{k=1}^{n-1} \frac{B_n C t_k}{\sum_{j=k}^N B_j}}{\frac{B_n C}{\sum_{j=n}^N B_j}}$$

Rearranging:

$$t_n = \frac{\sum_{i=n}^{i=N} B_i \left(\frac{L_n}{B_n} - \sum_{k=1}^{k=n-1} \frac{C t_k}{\sum_{j=N}^{j=N} B_j} \right)}{C}$$

This results in the unequal bandwidth convergence formula:

$$t_n = \sum_{i=n}^{i=N} B_i \left(\frac{L_n}{C B_n} - \sum_{k=1}^{k=n-1} \frac{t_k}{\sum_{j=k}^{j=N} B_j} \right)$$

To find the total time t_{total} for all of the files to traverse the network

$$t_{total} = t_1 + t_2 + t_3 \dots t_N$$

$$t_{total} = \sum_{n=1}^{n=N} t_n$$

As before t_{total} = Total length of files transmitted divided by the channel capacity.

This can act as a check on the results by noting that this is the case after the transmission of a group of converging nested files.

A Test of the Unequal Bandwidth Convergence Formula

Assuming $L_1 = 100\text{MB}$, $L_2 = 180\text{MB}$ $L_3 = 500\text{MB}$

and that $B_1 = 4\text{MB/s}$, $B_2 = 6\text{MB/s}$, $B_3 = 10\text{MB/s}$, and that $C = 10\text{MB/s}$

Substituting into the unequal bandwidth convergence formula, the file transmission times are:

$$t_1 = (20 \times 100) / (10 \times 4) = 50\text{s}$$

$$t_2 = 16((180 / (6 \times 10)) - (50 / 20)) = 16(3 - 2.5) = 8\text{s}$$

$$t_3 = 10(((500 / (10 \times 10)) - (8 / 16)) - (50 / 20)) = 10(5 - 0.5 - 2.5) = 10(2) = 20\text{s}$$

$$t_{\text{total}} = t_1 + t_2 + t_3 = 50 + 8 + 20 = 78\text{s}$$

Also $t_{\text{total}} = (L_1 + L_2 + L_3) / C$ as the channel capacity is fully utilised over the whole time that the files are sent.

Therefore $t_{\text{total}} = (100 + 180 + 500) / 10 = 780 / 10 = 78\text{s}$ as expected. This situation is shown in table 12.

Table 12 Transmitted Files: Lengths, Overall Transmission Times and Bandwidths.

File	File length (MBs)	Total time to transmit file (s)	File Bandwidth (MB/s)
F_1	$L_1 = 100$	$t_1 = 50$	$B_1 = 4$
F_2	$L_2 = 180$	$t_1 + t_2 = 50 + 8 = 58$	$B_2 = 6$
F_3	$L_3 = 500$	$t_1 + t_2 + t_3 = 50 + 8 + 20 = 78$	$B_3 = 10$

It should be noted that B_3 was chosen to use the whole of channel capacity C . If this were not the case then the bottleneck would not occur in channel C and the formula would not apply for this situation as it was based on the assumption of full use of the channel for the whole period of time under consideration. This situation also implies that no packets are dropped. Future research is envisaged where packet dropping is built into the model.

APPENDIX E

THE FRACTIONAL CHANNEL CONVERGENCE FORMULA

In Quality of Service (QoS) situations or other situations where it may be more convenient to consider the bandwidth as a fraction of the channel capacity C then the following formula can apply. Considering the situation in which only two files are sharing a channel where File F_1 of length L_1 has bandwidth equal to the fraction f of C and the other file F_2 of length L_2 then has bandwidth equal to $(1-f)$ of C .

If the two files are sent across the channel with nested file transmission times then again

$$t_n = \frac{\text{Remaining length of the } n\text{th file to be transmitted} \\ \text{when the channel is being shared by } n \text{ files}}{\text{Channel bandwidth available to the } n\text{th file}}$$

Time t_1 = the time for the file L_1 to cross the network

$$t_1 = \frac{L_1}{f C}$$

t_2 = the time for the file the remainder of L_2 to cross the network after a time t_1

$$t_2 = \frac{\text{Length of the 2nd file} - \text{Length of 1st file} \\ \text{multiplied by the ratio of the bandwidth} \\ \text{of the 2nd file to the bandwidth of 1st file}}{\text{Channel bandwidth available to the 2nd file}}$$

$$t_2 = \frac{L_2 - ((1-f)/f) L_1}{C}$$

$$t_2 = \frac{L_2 - ((1/f) - 1) L_1}{C}$$

$$\frac{L_1 + L_2}{C} = t_2 + t_1$$

$$t_2 = \frac{L_1 + L_2}{C} - \frac{L_1}{fC}$$

The expected the total time:

$$t_{\text{total}} = t_1 + t_2$$

$$t_{\text{total}} = \frac{\text{Total length of the file to be transmitted}}{\text{Channel bandwidth}}$$

$$t_1 + t_2 = \frac{L_1 + L_2}{C}$$

Hence acting as a check on the result.

APPENDIX F

THE EQUAL BANDWIDTH CONVERGENCE FORMULA AND THE HARMONIC MEAN

When considering equal bandwidth convergence as in appendix C the author noticed similarities between the equal bandwidth convergence formula and the formula for the harmonic mean. From appendix C the total time = t_{total}

$$t_{total} = t_1 + t_2 + \dots + T_N$$

$$t_{total} = \text{Total length of files}/C$$

$$= (L_1 - L_0)/B_1 + (L_2 - L_1)/B_2 + \dots + (L_N - L_{N-1})/B_N$$

Where $L_0 = 0$ and $B_0 = 0$

$$t_1 = \frac{L_1}{B_1}$$

$$t_2 = \frac{L_2 - L_1}{B_2}$$

The general case is:

$$t_N = \frac{L_N - L_{N-1}}{B_N}$$

$$t_{\text{total}} = t_1 + t_2 + \dots + t_N$$

$$\frac{L_1 + L_2 + \dots + L_N}{C} = \frac{L_1}{B_1} + \frac{L_2 - L_1}{B_2} + \dots + \frac{L_N - L_{N-1}}{B_N}$$

This gives the C as the harmonic mean where:

$$C = \frac{L_1 + L_2 + \dots + L_N}{\frac{L_1}{B_1} + \frac{L_2 - L_1}{B_2} + \dots + \frac{L_N - L_{N-1}}{B_N}}$$

The harmonic mean is one of the many forms of averaging (Fleming & Wallace, 1986; Lilja, 2000; Niwa, 2003) and was included in Euclid's Elements (Euclid, c. 300 BC/1999). It seems a fitting point to end this thesis where modern internetworking experimentation results in a formulation known to the classical Greeks.

APPENDIX G

LIST OF ACRONYMS

AAEE.....	Australasian Association for Engineering Education
AASA.....	American Association of School Administrators
ABC	Australian Broadcasting Corporation
ACJ	Australian Computer Journal
ACLs	Access Control Lists
ACM	Association for Computing Machinery
ACS	Australian Computer Society
AEC.....	Australian Education Council
AGP.....	Accelerated Graphics Port
ALM.....	Assembly Level Manufacturing
AMCIS.....	Americas Conference on Information Systems
AMD	Advanced Micro Devices
APC.....	Australian Personal Computer
ATA	Advanced Technology Attachment Interface
ATM.....	Asynchronous Transfer Mode
AIS	Association for Information Systems
AITP.....	Association for Information Technology Professionals
ALM.....	Assembly Level Manufacturing
AMCIS.....	Americas Conference on Information Systems
ARP.....	Address Resolution Protocol

ASEE.....	American Society for Engineering Education
ASICs.....	Application Specific Integrated Circuits
AVA.....	American Vocational Association
BAP.....	Bandwidth Allocation Protocol
BCS.....	British Computer Society
BIOS.....	Basic Input Output System
bps.....	bits per second
BRI.....	Basic Rate Interface
CATE.....	Computers and Advanced Technology in Education
CBA.....	Competency-Based Assessment
CBL.....	Computer-Based Learning
CBMG's.....	Customer Behaviour Model Graphs
CCIE.....	Cisco Certified Internet Expert
CCNA.....	Cisco Certified Network Associate
CCNP.....	Cisco Certified Network Professional
CCTA.....	Central Computer Telecommunications Agency (UK)
CD-ROM.....	Compact Disc-Read Only Memory
CHS.....	Cylinder, Head, Sector
CIM.....	Computer Installation and Maintenance
CIR.....	Committed Information Rate
CMBGs.....	Customer Model Behaviour Graphs
CMOS.....	Complementary Metal Oxide Semiconductors
CNA.....	Certified Novell Administrator
CNAP.....	Cisco Network Academy Program
CNE.....	Certified Novell Engineer
CNS.....	Computer and Network Support

CNT.....	Computer and Network Technology
CPU.....	Central Processor Unit
CRT.....	Cathode Ray Tube
CRO	Cathode Ray Oscilloscope
CS.....	Computer Science
CSE	Computer Science Education
CSIDs.....	Client/Server Interaction Diagrams
CSM.....	Computer Systems Management
CT	Computerized Tomography
DDR SDRAM.....	Double Data Rate Synchronous Dynamic Random Access Memory
DEET	Department of Employment, Education and Training (Australia)
DETYA.....	Department of Education, Training and Youth affairs (Australia)
DFD	Data Flow Diagram
DfEE	Department for Employment and Education (UK)
DIMMs.....	Dual In Line Memory Modules
DNS.....	Domain Name Server
DOS.....	Disk Operating System
DRAM.....	Dynamic Random Access Memory
DS	Digital Signalling
DVDs	Digital Versatile Discs
DWDM	Dense Wave Division Multiplexing
ECC.....	Error Correcting Code
ECU	Edith Cowan University
EDO	Extended Data Out
EHT.....	Extremely High Tension

EIDE	Enhanced Integrated Drive Electronics
EIGRP	Enhanced Interior Gateway Routing Gateway Protocol
ENDEC	Encoder/Decoder
ENIAC	Electronic Numerical Integrator and Computer
ESEE	European Society for Engineering Education
FCS	Frame Check Sequence
FCHS.....	Faculty of Computing Health and Science
FDD.....	Floppy Disk Drive
FE.....	Further Education (UK)
FEU	Further Education Unit (UK)
FPM.....	Fast Page Mode
fps.....	frames per second
FSB	Front Side Bus
FTP	File Transfer Protocol
GUI	Graphical User Interface
GPSS	General Purpose System Simulation
HDD	Hard Disk Drive
HE	Higher Education
HMSO.....	Her Majesty's Stationery Office
HTTP	Hypertext Transfer Protocol
HTTPS	Secure Hypertext Transfer Protocol
IARC	International Agency for Research on Cancer
IASTD	International Association of Science and Technology for Development
IBM	International Business Machines
ICs.....	Integrated Circuits

iCOMP	Intel Comparative Microprocessor Performance Index
ICT	Information and Communication Technologies
IDE.....	Integrated Drive Electronics
IEEE	Electrical and Electronic Engineers
I/O	Input/Output
IP	Internet Protocol
IS	Information Systems
ISA	Industry Standard Architecture
ISDN	Integrated Services Digital Network
ISO	International Standards Institute
IT	Information Technology
ITiCSE	Innovation and Technology in Computer Science Education
JRPIT	Journal of Research into Information Technology
LAN	Local Area Network
LB	Local Bus
LSI.....	Large Scale Integration
MBs.....	Mega Bytes
MB/s.....	Mega Bytes per second
mps.....	Megabits per second
MCA	Micro Channel Architecture
MCQs.....	Multiple Choice Questions
MCSE.....	Microsoft Certified Systems Engineer
MIMD	Multiple instruction stream, multiple data stream
MIPS	Millions of Instructions per Second
MIS	Management Information Systems
MISD.....	Multiple instruction single data stream

MFLOPS	Millions of Floating point Operations per Second
MOVEET	Ministers of Vocational Education, Employment and Training (Australia)
MPUs	Microprocessor Units
MRI	Magnetic Resonance Imagery
MSDs	Material Safety Datasheets
MSI	Medium Scale Integration
MSIS	Master of Science in Information Systems
NARST	National Association for Research in Science Teaching (USA)
NATFHE.....	National Association of Teachers in Further and Higher Education (UK)
NBEET.....	National Board of Employment Education and Training (Australia)
NCC	National Computing Centre (UK)
NCVER.....	National Centre for Vocational Education Research (Australia)
NCVQ	National Council for Vocational Qualifications (UK)
NDM	Network Design & Management
NFER	National Foundation for Educational Research in England and Wales (UK)
NFS	Network File System
NIM	Network Installation and Maintenance
NOS.....	Network Operating System
NSF	National Science Foundation (USA)
NT	New Technology
NVQs	National Vocational Qualifications (UK)
OC	Optical Carrier
OECD.....	Organisation for Economic Co-operation and Development

OHS.....	Occupational Health and Safety
OPNET	Optimized Network Engineering Tools
OS	Operating System
OSI	Open Systems Interconnection Model
OSPF	Open Shortest Path First
OU.....	Open University (UK)
PC.....	Personal Computer
PCBs	Polychlorinated Biphenyls
PCI	Peripheral Component Interconnect
PDU's	Protocol Data Units
PING	Packet Internet Groper
PIR	Peak Information Rate
PLA	Programmable Logic Array
PR.....	Performance Rating
QoS	Quality of Service
RAM	Random Access Memory
RAS.....	Remote Access Server
RCDs.....	Residual Current Devices
RDRAM.....	Rambus Random Access Memory
RF.....	Radio Frequency
ROM	Read Only Memory
RSVP.....	Resource Reservation Protocol
RTT	Round Trip Time
rps.....	revolutions per second
SCIS	School of Computer and Information Science
SSAD	Structured Systems Analysis and Design Method
SATA	Serial Advanced Technology Attachment Interface

SCSI.....	Small Systems Computer Interface
SDRAM	Synchronous Random Access Memory
SI.....	Systems Internationale
SIGAda.....	ACM Special Interest Group on Ada Programming Language
SIGCOMM	ACM Special Interest Group on Data Communication
SIGCSE.....	ACM Special Interest Group on Computer Science Education
SIGCPR.....	ACM Special Interest Group on Computer Personnel Research
SIGMETRICS.....	ACM Special Interest Group on Measurement and Evaluation
SIMD.....	Single instruction stream, multiple data stream
SIMMs	Single In-line Memory Modules
SISD.....	Single instruction stream, single data stream
SMEs.....	Small and Medium Enterprises
SMT	Surface Mounted Technology
SPEC.....	System Performance Evaluation Co-operative
SRAM	Static Read Only Memory
SSADM.....	Structured Systems Analysis and Design Method
SSI.....	Small Scale Integration
STDM	Statistical Time Division Multiplexing
STP.....	Spanning Tree Protocol
TAFE.....	Tertiary and Further Education (Australia)
TCP	Transmission Control Protocol
TFTP	Trivial File Transmission Protocol
tps.....	transactions per second
TTL	Transistor-Transistor Logic

UDP.....	Universal Datagram Protocol
UICEE.....	UNESCO International Centre for Engineering Education
UNESCO.....	United Nations Educational Scientific and Cultural Organisation
USB.....	Universal Serial Bus
UPT	Unshielded Twisted Pair
VAD.....	Voice Activity Detection
VESA	Video Electronic Standards Association
VDU.....	Visual Display Unit
VGA	Video Graphics Array
VLAN	Virtual Local Area Network
VLSI.....	Very Large Scale Integration
VoIP	Voice over Internet Protocol
WAWISR	Western Australian Workshop on Information Systems
WAN.....	Wide Area Network
WDM	Wave Division Multiplexing
WHO.....	World Health Organisation
ZPD	Zone of Proximal Development