A Pedagogical Evaluation of New State Model Diagrams for Teaching Internetwork Technologies

S P Maj, G Kohli, T Fetherston

School of Computer and Information Science
Edith Cowan University
2 Bradford Street, Mount Lawley, 6050, Western Australia

p.maj@ecu.edu.au

Abstract

Curriculum based on internetworking devices is primarily based on the Command Line Interface (CLI) and case studies. However a single CLI command may produce output that is not only hierarchical but must also be interpreted – both represent learning difficulties for novices. It should also be noted that device status requires many different CLI commands. Internetworking curriculum also typically defines devices as 'black boxes' - this is not a good teaching strategy. New state models were designed that diagrammatically integrated relevant output from different CLI commands with protocol finite state information and protocol stacks by means of tables. The diagrams are modular and hierarchical thereby providing top down decomposition by means of levelling. Hyperlinks may be used to navigate between different state tables and diagrams. The models were used as the pedagogical foundation of internetworking curriculum and results compared with control groups who were taught in the standard manner. The students who were taught using the state models clearly demonstrated an understanding that was comparable to an expert in this field. It is well documented in education research that after successfully completing an examination it is not uncommon for the majority of students to demonstrate very poor long term retention of concepts. Students taught using the new state models clearly demonstrated concept retention six weeks after the final semester examinations.

Keywords: Modelling, Routers, Switches

1 Introduction

Net-Centric computing is part of the ACM/IEEE Computing Curriculum 2001 Undergraduate Body of Knowledge (ACM 2001). There are different but educationally equally valid approaches to teaching networking. According to (Kurose and Ross 2000), '*Among the approaches towards networking curricula, one finds the more quantitative (electrical engineering) style of teaching networking versus a more software/algorithmic (computer science) approach, the more "hands-on" laboratory based approach versus the more traditional in-class lecture based approach; the bottom-up approach towards the subject matter versus a top-down approach.*'

Both within Australia and internationally there is a demand for the practical hands-on approach associated with teaching internetworking device technologies. Accordingly some universities have adopted the Cisco Network Academy Program (CNAP) and hence obtain access not only to vendor specific curriculum and certification (Cisco Certified Networking Associate (CCNA) and Cisco Certified Networking Professional (CCNP) but also low cost devices (switches and routers). It should be noted that the CCNP is based upon an educational web site that cost US$25 million to develop and an extensive repertoire of Cisco sponsored textbooks (Cisco 2004).

Based on a market analysis of employer expectations this university implemented the vendor-based CCNA and CCNP curriculum (Murphy, Kohli et al. 2004). Certainly vendor-based education has both strengths and weaknesses; critics and advocates; however this debate is beyond the scope of this paper (Veal 2004). It is not uncommon for a university, as is the case with this university, to use the Cisco equipment not only for teaching the CCNA and CCNP curriculum but also as the basis for teaching other non-vendor specific networking units.

An extensive analysis of CNAP curriculum (on-line and off-line material) found that this type of curriculum primarily teaches internetworking device functionality via case studies using the Command Line Interface (CLI) (Maj, Murphy et al. 2004). The CLI allows the user to determine and modify the status of the various components of a device such as routing table entries, Address Resolution Protocol (ARP) table entries, interface status etc. However a single CLI command may produce output that must be interpreted and also the hierarchical nature of CLI commands is often difficult for novices to understand. Furthermore the status information of the many different device protocols, interfaces etc must typically be obtained by a number of different CLI commands. This may be problematic during teaching when it is necessary to integrate all of this information from a number of different, and possibly complex, CLI commands. Because of this students have problems identifying and understanding the concepts underlying the use of the CLI. It should be noted however that for experienced network engineers the CLI is a very powerful and useful tool.

It was also found that these devices are typically defined as 'black boxes'. While the internal functioning of black boxes can be inferred from input and output behavior, this is not a good teaching strategy. A more efficacious approach may be to provide students with a good conceptual model at the start of their studies. Accordingly Maj et al designed new state models of a switch and a router (Maj, Murphy et al. 2004) (Kohli, Maj et al. 2004).

2 New State Models – Switch and Router

These new state models diagrammatically integrate relevant output from different CLI commands with protocol finite state information and also the OSI-TCP/IP protocol stacks by means of tables (Figure 1 and Figure 3).

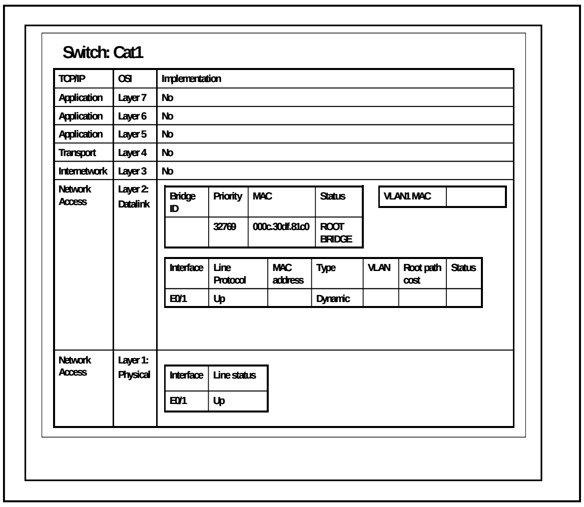

Figure 1: Switch State Model Diagram

Protocol finite state data allows dynamic, transitional states to be capture. For example the Address Resolution Protocol (ARP) exists in one of three states – free, pending and resolved (figure 2).

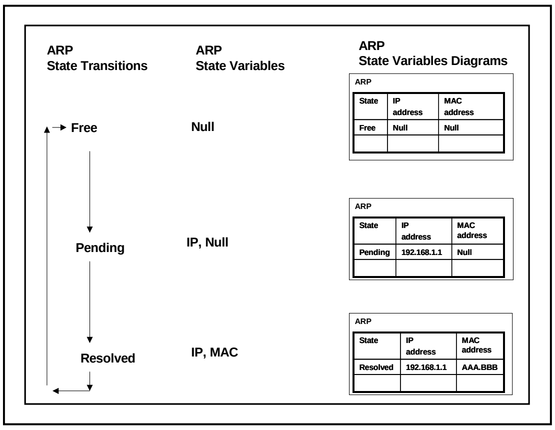

Figure 2: ARP States

In the free state the time-to-live entry has expired; the pending state means a request for an IP entry has been sent but no reply received and the resolved state means the physical (MAC) to logical (IP) mapping is complete.

Specific finite state information can also be captured for other protocols such as Spanning Tree Protocol (STP). It should be noted that Cisco use finite states to explain neighbour acquisition in BGP, route acquisition in EIGRP and also neighbour and route acquisition in OSPF. However this is not integrated with router management at the CLI interface.

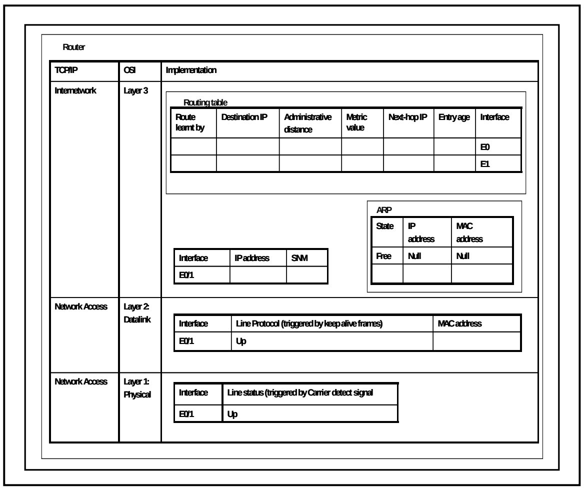

Figure 3: Router State Model Diagram

Each table in these diagrams has clearly defined functionality and is substantially independent from other tables i.e. the tables have high cohesion and low coupling. It is therefore possible to selectively include or exclude different tables. For example, the switch interface line status table (figure 1) may be removed from the diagram thereby allowing the diagram to more easily accommodate other tables associated with Spanning Tree Protocol.

In effect the tables are modular thereby providing top down decomposition by means of levelling. One of the most important features of these diagrams is the ability to construct a variety of different levels according to the level of abstraction required. This means that the initial (level 0) diagram can be consulted to obtain a high level overview of device interconnectivity i.e. what switches and routers are connected together. When details of a specific device are needed, then greater technical complexity for that specific device can be obtained. Obviously the different levels of diagram are consistent. The diagrams may be decomposed to the level that is meaningful for the purpose that the diagram is required. For example, a router OSI layer 1 line status (carrier detect table) would not be decomposed any further – the interface is in effect either up or down. However for a more complex OSI layer 3 protocol such as Enhanced Interior Gateway Routing Protocol (EIGRP) further levels of diagram can be used to include EIGRP Topology and Neighbour tables. Hyperlinks may be used to navigate between not only different devices but also different tables in the same device.

It is possible, using the switch state model, to implement protocols that include: basic switch operation (address learning, forwarding/filtering), Spanning Tree, Virtual

LAN's (VLANs), trunking, VLAN Trunking Protocol (VTP) and Ether-channelling (Maj, Murphy et al. 2004). It is possible, using the router state model to implement protocols that include: all the Interior Gateway Protocols (Routing Information Protocol, Interior Gateway Routing Protocol), link state protocols (Open Shortest Path First) and balanced hybrid protocol (Enhanced Interior Gateway Routing Protocol) (Maj, Murphy et al. 2004).

3 Pedagogical Application

These diagrams were used as the pedagogical foundation of a non-vendor based networking curriculum. The curriculum was designed based on the diagrams to progressively introduce and explicitly link networking concepts. Novice students were given a switch diagram relating the connection functionality to the OSI and TCP/IP model (figure 4). This is directly relevant to student's initial perceptions of a switch - a networking device for connecting together PCs. At this stage students do not 'know' how a switch works. They are also introduced to the CLI interface and a few simple commands. Using these commands it is possible to determine interface details – typically complex and lengthy (figure 5).

In the diagrams, an interface has a layer 1 table (Carrier Detect table) that can be used to determine the physical link status i.e. either up or down based on the carrier detect signal. Each interface has an associated layer 2 table (Line Protocol table) based on the Line Protocol Status which is either up or down based on the Line Protocol status. Every interface has both of these tables. This data is extracted from the associated CLI interface commands.

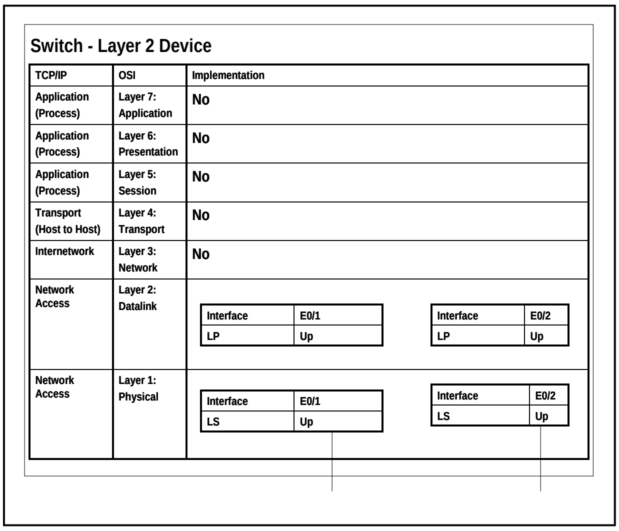

Figure 4: Switch – Simplified OSI and connections

It can be clearly seen that a switch is an OSI layer 2 device with no implementation of any higher level protocols. Accordingly, the diagram may be simplified (figure 6).

```
Device#show interface fastethernet 0/1
FastEthernet0/1 is up, line protocol is up
  Hardware is Fast Ethernet, address is 000c.30df.81c1 (bia 000c.30df.81c1)
  MTU 1500 bytes, BW 100000 Kbit, DLY 1000 usec,
     reliability 255/255, txload 1/255, rxload 1/255
  Encapsulation ARPA, loopback not set
  Keepalive set (10 sec)
  Auto-duplex, Auto-speed
  input flow-control is off, output flow-control is off
  ARP type: ARPA, ARP Timeout 04:00:00
  Last input 23:41:43, output 23:41:30, output hang never
  Last clearing of "show interface" counters never
  Input queue: 0/75/0/0 (size/max/drops/flushes); Total output drops: 0
  Queueing strategy: fifo
  Output queue :0/40 (size/max)
  5 minute input rate 0 bits/sec, 0 packets/sec
  5 minute output rate 0 bits/sec, 0 packets/sec
     536 packets input, 72501 bytes, 0 no buffer
     Received 276 broadcasts, 0 runts, 0 giants, 0 throttles
     0 input errors, 0 CRC, 0 frame, 0 overrun, 0 ignored
     0 watchdog, 164 multicast, 0 pause input
     0 input packets with dribble condition detected
     3005 packets output, 212679 bytes, 0 underruns
     0 output errors, 0 collisions, 2 interface resets
     0 babbles, 0 late collision, 0 deferred
     0 lost carrier, 0 no carrier, 0 PAUSE output
     0 output buffer failures, 0 output buffers swapped out
```

Figure 5: Switch – show interface output

Removal of these non-essential features permits the introduction of the switch MAC address table (figure 7). It can be clearly seen from the diagram that the MAC address table is an OSI layer 2 protocol.

At this stage it is possible to connect PCs to the switch and demonstrate basic switch operation – address learning and address forwarding/filtering. The MAC addresses of the PCs can be entered into the MAC address table and the results confirmed by the CLI command '*show mac-address-table*'.

With a few minor modifications this diagram can be used to teach concepts that include: flooding, broadcasting, micro-segmentation (virtual circuits), broadcast and collision domains, address aging, static and dynamic addressing and VLANs (static and dynamic implementations).

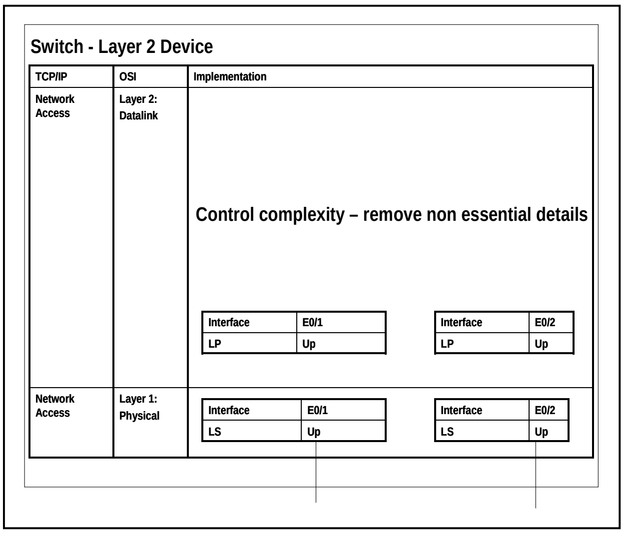

Figure 6: Switch – Simplified OSI and connections

In order to teach Spanning-Tree Protocol (STP) it is necessary to remove extend the interface table details and introduce the Bridge Identification table (figure 8).

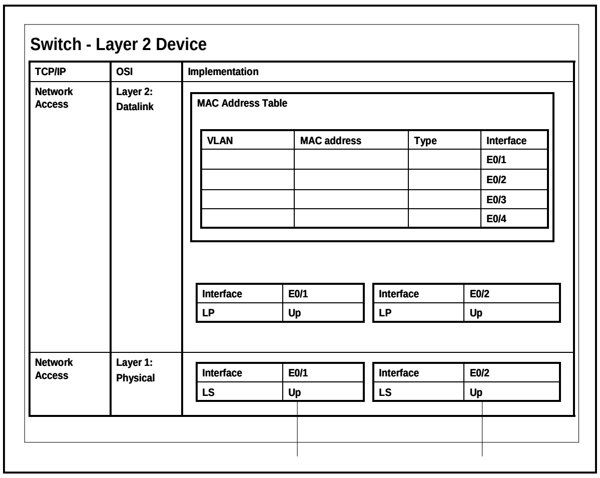

Figure 7: Switch and MAC address table

As an aid to clarity it is possible to remove the MAC address table and layer 1 and 2 interface details (figure 9). Using this diagram it is possible to teach all aspects of STP such as: Bridge Id (priority and address), Bridge status and timers, interface id and priority, switch states, best BPDU etc. The simplified diagram may be reduced in size allowing multiple switch diagrams to be included in a single Power Point slide image. The interaction between the switches and the associated changes can then be viewed concurrently. This concurrency is not possible if only the output from CLI commands is used.

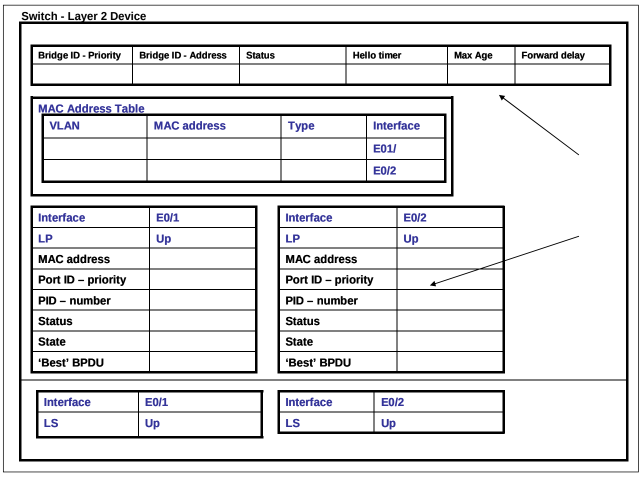

Figure 8: Switch – MAC address table and STP tables

State diagrams of a router were similarly developed and used as the pedagogical foundation of the new networking curriculum.

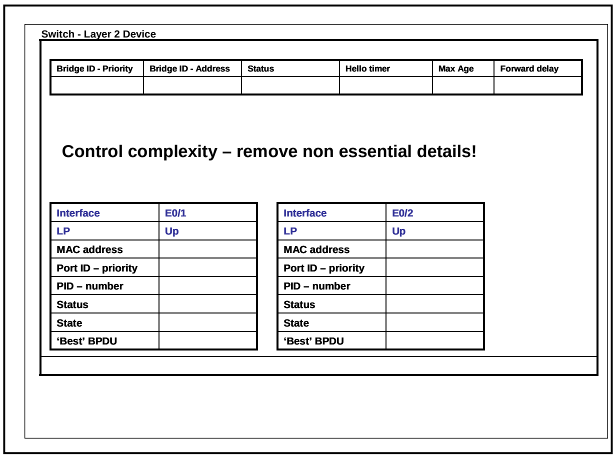

Figure 9: Switch STP tables only

3 Educational Theory

The above approach is predicated on the assumption that students encountering phenomena in computer science classes will construct their own mental model of the concept encountered. This constructivist view recognises that before learning can take place a student must engage with, and process, perceived information. This processing occurs with the assistance or in the presence of recalled prior knowledge and such prior knowledge will include any existing mental models of the student. Such a view of learning accepts that initial constructions of perceived information can be quite limited in breadth and depth and that subsequent building on these ideas to form higher-level conceptual structures requires effort and purpose on behalf of the learner. The process of building better conceptual structures can be assisted by the provision of good models that form the bridge between students' existing ideas and ideas that form part of the body of knowledge of the particular domain. These models are probably essential for understanding complex networking systems, to be able to predict and hypothesise about these systems and in general to be able to understand such systems.

Good mental models that allow the construction of richer ideas are also important as they can assist conceptual change. Research conducted in science education over at least the last 25 years has demonstrated across many contexts that students' existing ideas are often firmly held and unfortunately often wrong. For example Driver and Erikson suggested as long ago as 1984 that students' existing ideas often interfere with instruction and their alternative conceptualisations can hinder further learning (Driver and Erikson 1984).

At about the same time a group of researchers at Cornell University developed a theory of conceptual change(Posner, Strike et al. 1982). Posner et al. applied (Kuhn 1970) ideas about scientific revolutions to individual learning, and derived the following conditions for bringing about conceptual change:

1. There must be dissatisfaction with a currently held conception.

2. The alternative conception must be intelligible.

3. The alternative conception must appear plausible.

4. The alternative conception must appear fruitful.

They reviewed their ideas about conceptual change in 1992 but in both versions the importance of good mental models was apparent. The attributes above give clues as to what constitutes a good (alternative to student's existing) mental model – it must be intelligible, plausible and potentially fruitful.

The ability to recall and explain a concept does not necessarily reflect understanding, nor does it guarantee that students can apply and use the concept in a meaningful way (Julyan and Duckworth 1996). One main goal of teaching is to enable the students to create a valid mental model of new concepts, consistent with formal Computer Networking definitions. The student's mental model should be built on a set of correct pieces of knowledge that are concerned with the learned concepts. Models can be employed as an aid to conceptual understanding. Thomas notes in respect to student difficulty in understanding concepts that: "*The use of diagrammatic representation provides an alternative to just offering more words which may only compound their difficulties*" (Thomas 2000). Gilbert notes that "*a model is a simplified representation of a system, which concentrates attention on specific aspects of the system, Moreover, models enable aspects of the system, i.e. objects, events, or ideas which are either complex, or on a different scale to that which is normally perceived, or abstract to be rendered either visible or more readily visible*" (Gilbert 1995).

Models have been used in science education and the use of the models has been well documented in science education research (Linn and Muilenberg 1996; Gilbert and Boulter 1998). Many authors suggest that providing an individual with a conceptual model of a system before instruction enhances user learning (Moran 1981; Bayman and Mayer 1984; Carroll and Mack 1985). Conceptual models supports superior learning over giving only procedural instruction and this has been noted by (Davis and Bostrom 1993).

Before a conceptual change can take place, the naïve concepts that a students possess have to made explicit (Wichmann, Gottdenker et al. 2003). Good mental models can assist this. For example a switch will have a 'mac-address-table' and router will have 'routing table' and these could be integrated into conceptual model. Mental models provide a powerful mechanism for storing knowledge within the human mind (Norman 1983). Because of the ways in which they can influence behaviour, such structures have a significant impact on virtually all forms of human activity (Barker and van Schaik 1999). Mental models need to utilize abstraction: "*Schemas are conceptual structures and processes which enable human beings to store perceptual and conceptual information about the world and make interpretations of events through abstraction*" (D'Andrade 1992). The mental image of the world around us that we carry in our heads is a model (von Glasersfeld 1992). "*One does not have a city or a government, or a country in his head. One has only selected concepts and relationships, which one uses to represent the real system*" (Forrester 1971) He further states that "*The mental model is fuzzy. It is incomplete. It is imprecisely stated. Furthermore, within one individual, a mental model changes with time and even during the flow of a single conversation*" (Forrester 1994). A student's mental model can be inferred from a concept map provided by them

In learning to construct a concept map, it is important for the students to begin with a domain of knowledge that is very familiar to them and which contains recognisable terms. Since concept map structures are dependent on the context in which they will be used, students doing the networking units should be provided with schemes of networking devices which they can use to learn about how a internetworking device operators. Using a layer based system similar to the OSI model will help students to create a mental schema of the technology they are learning. By doing this one creates a context that will help to determine the hierarchical structure of the concept map. It is also helpful to select a limited domain of knowledge for the first concept maps. In the case of internetworking it should follow a progression from the introduction of the switch concept followed by the routing concept. Switch works at layer 2 of the OSI model and are part of the LAN. On the other hand router works at Layer 3 and are part of both LAN and WAN.

4 Experimental Results

Maj and Kohli conducted a comparison of standard CNAP curriculum to curriculum based on the new state models (Maj and Kohli 2004). A network expert was interviewed and his responses to a series of questions recorded. The expert listed a wide range of different terms relevant to the various technologies. The purpose of the interview was to compare students' conceptions with those of the expert with the assumption that teaching should allow students to learn concepts that would eventually enable them to progress to the expert's ideas. The same questions were given to CNAP students and also students taught using the state models and the results evaluated. The CCNA students were able to provide standard definitions but appeared to lack a detailed understanding of device operation. The more advanced CCNP students performed only marginally better. This indicates that students were just recalling learnt material. The students taught using the state model diagrams were also able to provide accurate definitions. But according to Maj, '*However they clearly demonstrated a far better understanding of device operation*.' Furthermore, '*It is highly significant that the responses of the postgraduate students matched those of the network expert*.' (Maj and Kohli 2004). This indicates a degree of conceptual change and it can be inferred that the model provided may have assisted this. It should be noted that the students taught using the state model had received only 24 hours of instruction compared to the CNAP students who had received over 96 hours of instruction. In a further study by (Kohli, Maj et al. 2004) it was found, compared to the CCNP students, that students taught using the state model:

- Were able to correctly use significantly more terms (e.g. routing table, ARP table, broadcast domain etc).
- Gave significantly more responses that matched those from a networking expert.

These two studies did not however provide any measure of understanding. From education research we know that if students are taught with an emphasis on just learning and recalling facts and not concepts then retention of those facts is quite poor – if they are not constantly used.

Two groups of students were evaluated – CNAP students and those taught using the state models. Both groups were evaluated at the start of the semester, the end of the semester and then again six weeks after the final examinations and hence two weeks into the following semester. All students interviewed had enrolled in subsequent networking units – CNAP students enrolled in CNAP units and students taught using the state model enrolled in further units based on the state model. In addition to answering questions students also had to sketch any diagrams to relate different networking concepts. The following results were found:

Start of semester

- Diagrams provided by the state model students were rudimentary.
- Diagrams provided by the CNAP students were rudimentary and primarily consisted of the Cisco symbols for a switch and a router.

End of semester (before final exams):

- Students taught using the state model correctly provide more terms than the CNAP students.
- Students taught using the state model provided more terms that matched those of a networking expert.
- Diagrams provided by the state model students closely matched those provided during the lectures.
- Diagrams provided by the CNAP students were rudimentary and primarily consisted of the Cisco symbols for a switch and a router.

Six weeks after final examinations

- Students taught using the state model gave the same number of correct responses to those at the end of the semester and the same number matched those of the expert
- The CNAP students correctly gave more correct responses than those at the end of the semester but fewer matched those of the expert.
- Diagrams provided by the CNAP students were rudimentary and primarily consisted of the Cisco symbols for a switch and a router.
- Diagrams provided by the state model students correctly contained a lot of technical detail but there were variations from the diagrams that were used in the lectures.

This indicates that both groups of students learnt the required material equally well. However from the diagrams of the state model students it can be inferred that they have richer conceptual understandings and these were aligned with those of the expert. Consequently they will be more able in future learning to progress towards the end state of the expert's understandings. They are also more likely to retain learnt material as this material is linked to more and better concepts thus enhancing recall.

To further check the use of the state model as a pedagogical tool a one-hour lecture on Spanning Tree Protocol using the state diagrams was given to practicing networking professionals currently undertaking part time studies towards their CCNP qualification at another institution. There was unanimous and clear support for the models. All comments were recorded and were:

'*We should have more of these*.'

'*Nice to have a conceptual model to aid understanding*.'

'*Yes! The diagrams illustrate the process in a very easy to understand format to allow the subject to be learned*.'

'*Excellent, far clearer than any Cisco material*.'

'*Yes, I have learnt more in this period that in the whole of the semester*.'

Conclusions

There is unequivocal research evidence that conceptual models are powerful tools that support learning. Cisco use standard symbols for different devices - there is a symbol for a switch and one for a router. These symbols are used by the CNAP curriculum. However they are only symbols and do not provide detail about the operation of the device i.e. 'black boxes'. Primarily the Command Line Interface (CLI) provides this detail. However a single CLI command may produce output that is not only hierarchical but must also be interpreted – both represent learning difficulties for novices. It should also be noted that device status requires many different CLI commands.

The new state models were designed to diagrammatically integrate relevant output from different CLI commands with protocol finite state information and protocol stacks by means of tables. Many of the major switching/routing protocols have been successfully implemented using these diagrams. Furthermore, their modular, hierarchical characteristics allow a technical detail to be introduced in an integrated and controlled manner thereby supporting student learning both at introductory and advance level. Results to date suggest that students learning based on state diagrams demonstrates a richer conceptual understanding strongly aligned with that of an expert. However further work is needed.

5 References

ACM (2001). Computing curricula 2001 ACM/IEEE Joint Task Force Computer Science Final Report, ACM Press.

Barker, P. G. and P. van Schaik (1999). Mental Models and Their Implications for the Design of Computer-Based Learning Resources. Proceedings of the 4th International Conference on Computer-Based Learning in Science (CBLIS '99), University of Twente, Enschede, The Netherlands.

Bayman, P. and R. E. Mayer (1984). "Instructional manipulation of users' mental models for electronic calculators." International Journal of Man-Machine Studies **20**: 189-199.

Carroll, J. M. and R. L. Mack (1985). "Metaphor, computing systems and active learning." International Journal of Man-Machine Studies **22**: 39-57.

Cisco (2004). Cisco Networking Academy Program, Cisco Systems. **2004**.

D'Andrade, R. G. (1992). "Schemas and motivation." In R.G.D'Andrade and C.Strauss (Eds.) Human Motives and Cultural Models. Cambridge.

Davis, S. A. and R. P. Bostrom (1993). "Training End Users: An Experimental Investigation of the Roles of the Computer Interface and Training Methods." MIS Quarterly **17**(1): 61-85.

Driver, R. H. and G. L. Erikson (1984). "Theories in action: Some theoretical and empirical issues in the study of students' conceptual frameworks in science." Studies in Science Education **10**: 37-60.

Forrester, J. (1971). Counterintuitive behavior of social system. Cambridge, MA, Wright-Allen Press, Inc.

Forrester, J. (1994). "Policies, decisions, and information sources for modeling." In Morecroft, J.D.W., and Sterman, J.D. (Eds.), Modeling for Learning Organizations: 51-84.

Gilbert, J. (1995). The role of models and modelling in some narratives in science learning. The Annual Meeting of the American Educational Research Association, San Francisco, CA, USA.

Gilbert, J. and C. Boulter (1998). "Learning science through model and modelling." In B.Fraser and K.Tobin (eds), International Handbook of Science Education: 52-66.

Julyan, C. and E. Duckworth (1996). A constructivist perspective on teaching and learning science. New York, Teacher College Press.

Kohli, G., S. P. Maj, et al. (2004). Abstraction in Computer Network Education: A model based approach. ASEE, Salt Lake City, Utah.

Kuhn, T. (1970). The Structure of Scientific Revolutions. Chicago, University of Chicago Press.

Kurose, J. and K. Ross (2000). Computer Networking A Top-Down Approach Featuring the Internet. New York, Addision-Wesley.

Linn, M. C. and L. Muilenberg (1996). "Creating Lifelong Science Learners: What Models form a firm Fonduation." Educational Researcher **25**(5): 18-24.

Maj, S. P. and G. Kohli (2004). A New State Model for Internetworks Technology. Informing Science + Information Technology Education Joint Conference, Rockhampton, OLD Australia.

Maj, S. P., G. Murphy, et al. (2004). State Models for Internetworking Technologies. 34th ASEE/IEEE Frontiers in Education Conference, Savannah,GA.

Moran, T. P. (1981). "The command langauge grammar: a representation for the user inteface of interactive computer systems." International Journal of Man-Machine Studies **15**: 3-50.

Murphy, G., G. Kohli, et al. (2004). An Examination of Vendor-Based Curricula in Higher and Further Education in Western Australia. American Society for Engineering Education (ASEE), Salt Lake City, Utah.

Norman, D. R. (1983). "Some observartions on mental models." In D.Gentner and A.Stevens (eds), Mental Models.

Posner, G. J., K. A. Strike, et al. (1982). "Accomodation of a scientific conception. Toward a theory of conceptual change." Scince Education **66**(2): 211-227.

Thomas, R. (2000). Fewer Words, clearer picture: The value of a diagrammatic representation of ideas. Third Biennial Communication skills in University education (CSUE), Fremantle, WA, Australia, Teaching and Learning Centre, Murdoch University, Murdoch, WA, Australia.

Veal, D. (2004). An Investigation into Computer and Network Curricula. School of Computer and Information Science. Perth, Western Australia, Edith Cowan University.

von Glasersfeld, E. (1992). Sensory Experience, Abstraction, and Teaching. Alternative Epistemologies in Education Conference, University of Georgia, Lawrencec Erlbaum Associates Inc Hillside NJ.

Wichmann, A., J. Gottdenker, et al. (2003). Developing a Framework for Conceptual Change within Scientific Inquiry. The 3rd IEEE International Conference on Advanced Learning Technologies (ICALT'03).