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State Model Diagrams as a Pedagogical Tool—An International Evaluation

S. P. Maj and D. Veal

Abstract—**State model diagrams (SMDs) have been successfully used as the pedagogical foundation of network technology curriculum. SMDs selectively integrate relevant output from network devices by means of tables. SMDs are modular and hierarchical, thereby providing top-down decomposition by means of levelling, allowing a complex network to be partitioned or structured into independent units of an amenable size so that the entire system can be more easily understood. An overview of the entire network or increasing levels of detail may be obtained while maintaining links and interfaces between the different levels. Furthermore, SMDs allow technical detail to be introduced in an integrated and controlled manner, thereby supporting student learning at both introductory and advanced levels. In effect, as students progress they do not have to learn a new conceptual model; rather they can build upon and extend their existing knowledge. This paper evaluates the use of SMDs for teaching network technology to international students whose first language is not English. This study was further extended to include an evaluation of SMDs, as a teaching tool, by Cisco academics within the Asia/Pacific region.**

Index Terms—**Internetworking technology, routers, state model diagrams, switches.**

I. Introduction

DIFFERENT but valid approaches are available to teach internet-working curricula—quantitative (engineering) or software/algorithmic (computer science) [1]. However, an alternative, employment-driven demand is for a practical 'hands on' approach to teaching switching and routing technologies. In the late 1990s Cisco invested US$25 million in the Cisco Network Academy Program (CNAP). The CNAP curriculum is designed both for college, university students, and practicing professionals. The Cisco Certified Network Associate (CCNA) award assumes no previous knowledge of networking but leads to the more specialized Cisco Certified Network Professional (CCNP) award. The CNAP website provides multimedia training materials, simulations, and assessments. However, the use of vendor-driven curricula, particularly within the university sector, has both its advocates and its critics [2]–[4].

The Cisco curricula primarily deals with open systems interconnect (OSI) layer two and three devices such as switches, routers, wireless access points, PIX firewall, etc. The operating system running on devices such as routers and switches is the internetwork operating systems (IOS) which uses a hierarchical text-based command line interface (CLI). Device management may require a number of different CLI commands, many of which may be complex and provide unnecessary data. The CLI is a useful tool for practicing professionals but requires considerable expertise. Hence, it is problematic for novice students. The associated graphical user interface (GUI) appears not to be widely used. The CCNA and CCNP curricula are based primarily on the CLI. Furthermore, an extensive analysis of the CNAP curriculum found that the main emphasis was on remembering rather than learning. The curriculum emphasizes device configuration rather than understanding and also encourages self-learning. Significantly the CNAP curriculum tends towards a "black box" approach [5] that is contrary to constructivism, a major educational theory today that has been extensively tested in the fields of science and mathematics education [6], [7]. According to the constructivist approach, students are encouraged to construct knowledge rather than simply receive and store information [8]. However, if students are not provided with a conceptual framework, their own models will be typically incomplete, inconsistent, and incorrect. Abstraction may be used to assist the student's conceptualization process in order for them to arrive at a valid, useful, and workable model upon which more complex and detailed models may be constructed.

II. Abstraction—The State Model Diagrams

The ACM/IEEE Computing Curriculum 2001 listed abstraction as one of the twelve recurring concepts fundamental to computing [9]. Models based upon abstraction, are therefore, a means of controlling detail. Ideally, models should be diagrammatic, self-documenting, easy-to-use and in hierarchical top-down decomposition to control detail. Leveling is the property by which complex systems can be progressively decomposed to the level that is meaningful, while still maintaining consistent links to other levels. Maj proposed state model diagrams (SMDs) for modeling switches, routers and associated protocols [5]. Using a single SMD, one can manually extract from the different CLI outputs only the data directly relevant to device status and succinctly describe device operation [10]. For example, to determine the operation of a router, information needed includes interface Internet Protocol (IP) and medium access control (MAC) addresses; interface line status; interface line protocol status; address resolution protocol (ARP) details and routing table entries. Actual output, from an operational router, for one CLI command is as follows.

Router1#show ip route

Codes: C—connected, S—static, I—IGRP, R—RIP, M—mobile, B—BG, D—EIGRP, EX—EIGRP external, O—OSPF, IA—OSPF inter area, N1—OSPF NSSA external type 1, N2—OSPF NSSA external type 2, E1—OSPF external type 1, E2—OSPF external type 2, E—EGP, i—IS-IS, su—IS-IS summary, L1—IS-IS level-1, L2—IS-IS level-2, ia—IS-IS inter

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Router1

OSI	Implementation
Layer 3	Routing table; ARP table; Interface / IP address
Layer 2: Datalink	Interface / Line Protocol / MAC address
Layer 1: Physical	Interface / Line status

Layer 3 — Routing table

Route learnt by	Destination IP	Administrative distance	Metric value	Next-hop IP	Entry age	Interface
C	192.168.1.0/24					Fa0/1
C	192.168.3.0/24					Fa0/0
R	192.168.3.0/24	120	1	192.168.2.2		Fa0/0

Layer 3 — ARP table

IP address	MAC address	Interface
192.168.1.1	000c.30e2.e501	Fa0/1
192.168.2.1	000c.30e2.e500	Fa0/0
192.168.2.2	0012.01a1.cda1	Fa0/0

Layer 3

Interface	IP address
Fa0/1	192.168.1.1/24

Interface	IP address
Fa0/0	192.168.2.1/24

Layer 2: Datalink

Interface	Line Protocol	MAC address
E0/1	Up	000c.30e2.e501

Interface	Line Protocol	MAC address
E0/0	Up	000c.30e2.e500

Layer 1: Physical

Interface	Line status
E0/1	Up

Interface	Line status
E0/0	Up

Fig. 1. State model diagram of a router (RIP).

area, ⋆—candidate default, U—per-user static route, o—ODR, P—periodic downloaded static route. Gateway of last resort not set
C 192.168.1.0/24 is directly connected, FastEthernet0/1
C 192.168.2.0/24 is directly connected, FastEthernet0/0
R 192.168.3.0/24 [120/1] via 192.168.2.2, 00:00:03, FastEthernet0/0

A single SMD can be used to represent the main data extracted from these four separate CLI commands are linked to the appropriate OSI and TCP/IP layers (Fig. 1). Other protocols may also be modeled using the SMDs [10]. For example, the more complex open shortest path first (OSPF) routing protocol may be modeled using the same SMD as the RIP protocol. Such modeling can be achieved by simply including two more tables (adjacency and topology) and designated router (DR)/backup designated router (BDR) details for each interface. In order to accommodate this level of detail on a single diagram the ARP and OSI layer 1 and 2 details may be excluded (Fig. 2). While some differences exist, the SMDs of a router running RIP and OSPF are similar and potentially useful because new knowledge may be incrementally applied. By selectively including and excluding specific tables, SMDs can be used to represent complex protocols, or indeed multiple protocols, operating on a single device. In order to accommodate a protocol operating with a large number of table entries, multiple instances of the SMD may be used.

Furthermore, SMDs allow a complex network to be partitioned or structured into independent units of an amenable size so that the entire system can be more easily understood [10]. A level 0 SMD consists of a map of the different devices and their interconnections, often referred to as a topology map. Specific devices may be selected from such a map to obtain the associated level 1 detail, etc. An overview of the entire network or increasing levels of detail may be obtained while maintaining links and interfaces between the different levels. Work to date indicates that this model is platform independent [10].

SMDs allow networking concepts and technical detail to be taught using a single common template. Technical details may be progressively included while maintaining conceptual integrity by means of hierarchical leveling. SMDs may, therefore, support student learning at both introductory and advanced levels.

In effect students do not have to learn a new conceptual model; rather they can build upon and extend their existing knowledge. In this context new knowledge reinforces existing knowledge. Currently, SMDs are completed manually; however, they have also been implemented as a hyperlink model allowing simple navigation between different devices and their associated protocols.

III. Previous Pedagogical Evaluations

Within the field of educational research different schools of thought have their advocates and critics. In contrast to pedagogical research based on student grades, the constructivist approach focuses more upon students' conceptual models. According to Ben Ari [8]:

> The science-teaching literature shows that performance is no indication of understanding. CSE research like Madison's, which elicits the internal structures of the

Router1

Routing table

Route learnt by	Destination IP	Administrative distance	Metric value	Next-hop IP	Entry age	Interface
C	192.168.1.0/24					Fa0/1
C	192.168.3.0/24					Fa0/0
O	192.168.3.0/24	110	2	192.168.2.2		Fa0/0

Interface	FA0/0
IP	192.168.2.1/24
Area	0
Process ID	1
Network type	BROADCAST
Cost	1
Router ID	192.168.2.1
Priority	1
DR	192.168.3.1
BDR	192.168.2.1

Neighbour table

Neighbor ID	Pri	State	Address	Interface
192.168.3.1	1	FULL/BDR	192.168.2.2	FA0/0

Topology table

Router Link States - Link ID	Route Link States- ADV Router	Net Link States – Link ID	Net Link States – ADV Router
192.168.2.1	192.168.2.1	192.168.2.2	192.168.3.1
192.168.3.1	192.168.3.1		

Fig. 2. Router (single area OSPF) state model diagram—level 2.

> student, is far more helpful than research that measures performance alone and then draws conclusions on the success of a technique. A student's failure to construct a viable model is a failure of the educational process, even if the failure is not immediately apparent.

Therefore, different but valid methods by which student learning may be evaluated are available. Over a number of years SMDs have been evaluated as a pedagogical tool based on attempts to measure conceptual changes within students. This work has focused on two curriculum streams, namely Cisco certification courses (CCNA and CCNP) and two postgraduate units (CSG5106 and CSG5206). Both these units (CSG5106 and CSG5206) include many of the technologies taught within the CCNA. All instructional material (lectures and workshop exercises) in both of these units (CSG5106 and CSG5206) is based on the SMDs. Instruction was provided on how to extract the relevant details from the CLI commands to complete the diagrams. In effect students were concurrently taught device operation using the SMDs and device programming using the CLI. These two curriculum streams (Cisco- and SMD-based) were evaluated by Maj [5] who found:

> Postgraduate students, whose learning was based upon the state models, demonstrated a comprehension of devices comparable to a qualified and experienced expert in this field. Furthermore these students performed significantly better than other students both within the same and a different institution.

Maj's study was further extended to determine if there were any differences in longer term learning. Students were evaluated both throughout the semester and then six weeks after their end of semester examination. These results strongly suggested that the use of SMDs had significantly enhance learning [11].

IV. Further Pedagogical Evaluations

The SMDs are essentially language independent. To evaluate this independence students, primarily from India and China studying the two postgraduate CSG5106 and CSG5206 were assessed. Ten overseas students, from a class of about thirty, volunteered to provide detailed feedback and critical evaluations. From the ten volunteers, nine responded with positive replies, one of which was positive but had reservations; the tenth did not reply. Significantly, some students had little or no knowledge of networking. However, other students had successfully completed professional certification enhanced by commercial experience in networking. Two of the students had successfully completed their Cisco certification, one to CCNA standard, and the other to CCNP standard. The results indicated that even though some students were Cisco trained and qualified, they still appeared to have benefited from instruction based on SMDs. One anonymous comment submitted by a student, verbatim, was as follows:

> I did my CCNA and CCNP certifications in India in the year 2000. Currently, I am doing the networking units coordinated by (name removed) at (name removed). The method he follows to teach the networking principles makes the whole concept more simpler and I am able to get a better holistic picture of the series of events when we configure the different networking devices. Rather than understanding the commands for different scenarios, he gives emphasis in teaching what the cause of the scenario is and how to handle the scenarios.

Overall, student comments suggested that the SMDs assisted learning by explicitly linking key concepts. To further evaluate SMDs as a pedagogical tool, a group of university-based students studying the CCNA were taught switch and a router functionality using SMDs. The standard CCNA curriculum had been employed for the majority of the lectures and workshops.

Students were asked to evaluate the SMDs as a method of instructional delivery via a questionnaire. From a total of 34 responses, 27 (79%) indicated that they would like the SMDs to be used as part of the normal lecture in addition to the standard CNAP. Anonymous comments provided by the students and collected independently included: *"I think understanding the CCNA through the state diagrams is the best method I have ever seen in my life"* and *"I believe I have a greater level of understanding about switches and how they operate after today's lecture then I do about certain topic learnt/lectured from the Cisco material."*

A sample lecture based on the SMDs was given to Cisco academics at the annual Cisco Asia/Pacific regional meeting. The audience consisted of approximately 30 Cisco academics from community colleges and universities. The audience was asked to score both content and relevance of the SMDs as a potential teaching tool within their institution, and to provide additional comments. The content score was 4.62 out of 5 and the relevance score was 4.59 out of 5.

In semester 2, 2003, SMDs were first used as a pedagogical tool in two units, CSG5106 and CSG5206. Over a number of semesters student learning in both units was evaluated and the results published. SMDs are now used as the primary pedagogical vehicle for all lectures, workshops, and assessments in both these units. In semester 1, 2006, the final exam for CSG5206 students were given the CLI outputs for three switches running STP and the IPCONFIG data for three associated PCs. From this data students had to complete an SMD that included not only spanning tree protocol (STP) tables but also a MAC-address-table, i.e. multiple devices and protocols in a single SMD. In a second question students were given the CLI output from only two of five connected routers running RIP and asked to complete SMDs for all devices. A third, similar question, was based on routers running the OSPF protocol. In a fourth question students were asked to complete an SMD given the IPCONFIG outputs of a wireless PC and cable PC connected via a wireless access point (WAP) and a switch. The CLI outputs of the WAP and switch were provided. All results to date indicate that students can use SMDs for problem solving by predicting the correct values, e.g. MAC address, IP address, that should be placed in the empty cells of SMD tables. This finding suggests these students have attained a Bloom's taxonomy objective of level 3. Level 3 [12] is concerned with, *"The abstractions may also be technical principles, ideas, and theories which may must be remembered and applied."* This result did not show up in terms of marks as the university employs norm-referenced based examinations, i.e. marks are adjusted to give a standard distribution of grades.

V. Conclusion

SMDs have been successfully used as the primary pedagogical vehicle for all lectures, workshops, and assessments in networking curriculum. Significantly, SMDs allow networking concepts and technical detail to be taught using a single common template. Technical details may be progressively included while maintaining conceptual integrity by means of hierarchical levelling. SMDs may, therefore, support student learning at both introductory and advanced levels. In effect students do not have to learn a new conceptual model; rather they can build upon and extend their existing knowledge. In this context new knowledge reinforces existing knowledge. Work to date suggests SMDs support higher order learning. SMDs are essentially language independent, and two studies, presented in this paper, suggest that they are particularly useful for teaching international students whose first language is not English. However, further research is needed to investigate this matter in more detail.

References

[1] J. Kurose, J. Liebeherr, S. Ostermann, and T. Ott-Boisseau, "Workshop on computer networking: Curriculum designs and educational changes," presented at the Association for Computing Machinery's Special Interest Group Data Communications Workshop Computer Networking, Pittsburgh, PA, 2002.

[2] C. Abelman, "A parallel universe," *Change*, vol. 32, pp. 20–29, 2000.

[3] S. P. Maj and J. Dharukeshwari, "Vendor based network engineering education—An international comparison," *World Trans. Eng. Technol. Educ.*, vol. 2, pp. 313–316, 2003.

[4] G. Murphy, G. Kohli, D. Veal, and S. P. Maj, "An examination of vendor-based curricula in higher and further education," presented at the 2004 American Society for Engineering Education Ann. Conf. and Exposition, Salt Lake City, UT, 2004.

[5] S. P. Maj and G. Kohli, "A new state models for internetworks technology," *J. Issues Informing Sci. Info. Technol.*, vol. 1, pp. 385–392, 2004.

[6] J. Confrey, "Learning to listen: A student's understanding of powers of ten," in *Radical Constructivism in Mathematics Education*, E. von Glasersfeld, Ed. Dordrecht, Holland: Kluwer, 1991, pp. 111–138.

[7] R. Driver and B. Bell, *Students' Thinking and the Learning of Science: A Constructivist View*. Leeds, U.K.: Centre for Studies in Science Education, Univ. of Leeds, 1985.

[8] M. Ben-Ari, "Constructivism in computer science education," presented at the 29th Special Interest Group Computer Science Education Tech. Symp. Computer Science Education, Atlanta, GA, 1998.

[9] A. B. Tucker, B. H. Barnes, R. M. Aiken, K. Barker, K. B. Bruce, J. T. Cain, S. E. Conry, G. L. Engel, R. G. Epstein, D. K. Lidtke, and M. C. Mulder, "A summary of the ACM/IEEE-CS joint curriculum task force report, computing curricula 1991," *Commun. ACM*, vol. 34, 1991.

[10] S. P. Maj, G. Kohli, and G. Murphy, "State models for internetworking technologies," presented at the IEEE 34th Annu. Conf. Frontiers in Education, Savannah, GA, 2004.

[11] S. P. Maj, G. Kohli, and T. Fetherston, "A pedagogical evaluation of new state model diagrams for teaching internetwork technologies," presented at the 28th Australasian Computer Science Conf., Newcastle, Australia, 2005.

[12] D. R. Krathwohl, B. S. Bloom, and B. B. Maisa, *Taxonomy of Educational Objectives. The Classification of Educational Goals*. London, U.K.: Longman, 1964.

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