

Board 27: Boardnotes 2.0 in Computer Networking: Organizing and Representing Meaningful Technical Information Graphically for Improving Learning Competencies

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Abstract

The field of computer information technologies in general, and more specifically that of network switching and routing, is filled with abstractions, abbreviations, and acronyms, along with an accompanying assortment of implementation techniques frequently requiring customization. Bridging the divide between theory and practice can be difficult for students as they attempt to build a cohesive understanding of the subject. It also poses a challenge for faculty trying to convey dense, text-heavy technical information using either the conventional chalkboard or presentation software. It is easy for the underlying beauty of the concepts to stay hidden under the jargon-filled landscape. Notes written on the whiteboard or chalkboard by faculty focus on conveying technical content to students, and these may make only limited use of graphical design ideas that can be leveraged for communicating information more effectively. What is needed is a mechanism for engaging both the students' imagination and technical skills while building an understanding of concepts, using technology appropriately, solving technical issues safely, and focusing on the process along the way.

Exploring network switching and routing can be facilitated using the elements and the principles of graphic design. The strategic use of icons, symbols, color, scale, proximity, contrast, groupings, hierarchy, alignment, repetition, balance, along with text annotations in diagrams or tables as part of Boardnotes 2.0, aims to do just that. The repeated usage of these elements encourages students to develop a visual vocabulary of the subject, using both standardized and self-developed graphics as a way for firming up one's understanding about a topic. Boardnotes 2.0 refers to the thoughtful use of selected graphical design elements and principles while communicating technical information using a whiteboard or chalkboard.

Visual representations of network information – whether it be networking models, Ethernet collision and broadcast domains, cabling standards, IP addressing, subnetting charts, network device modes, protocol operation, status views, or autonomous areas – allow for generating both a holistic view of the system and of specific regions within it where focused action may be needed. Being able to simultaneously access both the big-picture view and the zoomed-in one of a system, a sort of picture-in-picture representation, can provide students with increased confidence while working on network design and implementation issues. Requiring students to represent technical information both graphically and textually on class-laboratory worksheets increases engagement with the content. In addition, ways of memorizing the content may be introduced visually, along with strategies that aid the long-term recall process.

Keywords:

boardnotes, diagrams, networking, switching, routing, electronics, systems, visual learning, illustrations, notes

Introduction

In the ever-increasing data-centric environments we live and work in, understanding and expressing ideas visually as well as verbally is part of a critical skillset. Providing students with structured opportunities for class and laboratory activities to sharpen these skills will allow them to better navigate their way in the workforce.

According to [1] experts notice patterns and features in information that may be overlooked by novices. The content knowledge of experts is organized in ways reflecting a deeper underlying understanding of the content, allowing them to flexibly retrieve and apply key aspects of it while solving problems. By providing students with experiential learning opportunities, avenues for working with scaled-down versions of technical problems, they too can begin building contextual understanding, allowing them to notice subtle difference between similar situations. This will allow students to learn the information more effectively and to retain it longer, facilitating better transfer of knowledge and skills from the classroom to the workplace. In [2] emphasis is placed on the importance for learners to organize key ideas into mental models and connecting the model to prior knowledge. They posit that the ability to extract key ideas from new material and integrate it into existing mental models leads to development of mastery over complex content.

In the context of an undergraduate course on computer networking, topics such as configuring, securing, troubleshooting, and managing routing across subnetworks in the computer networking area require the student to develop a practical hands-on understanding of network models, protocols, hardware, cabling, subnetting, routing and switching. This encompasses a large set of theoretical and practical competencies. While there are several resources available for learning about these topics, according to [3, p. 9] commenting on the textbooks used in networking courses, the "contents of these textbooks vary substantially even though these textbooks are used for courses having similar descriptions." They noted that subnetting was not covered in enough detail for student to understand their basics.

Students need to be able to work through practical networking scenarios relying on their grasp of network fundamentals, perform suitable calculations and device configurations referring to text and online resources along with communicate their ideas to peers in an effective way. Often the extensive calculations required for setting up sub networks and advanced topics such as variable length subnet masking, super networks, or the use of client-server configurations, can be difficult to comprehend. This paper provides suggestions regarding the use of graphical design inspired methods for communicating these and similar ideas.

As suggested in [4] a central theme can be used to "glue together" disparate topics as part of a larger puzzle in an advanced networking course. In a similar vein, as part of the Solution-Based Learning (SBL) framework proposed by [5], students are encouraged to develop expanding functionality diagrams for their advanced capstone projects. Students provide a "back-of-the-napkin" sketch as part of the initial project proposal, depicting the proposed specifications which constitute the core and extension phases of their project. The development of these representations require opportunity for practice across multiple classes in the curriculum leading up to the capstone experience. When students are provided with the opportunity to practice representing computer networks or of electrical/electronic systems using annotated diagrams,

procedures and tables, they are more inclined to sketch out ideas for their intended creations as part of project-based courses in subsequent semesters. These ideas can, in fact, also be used in foundational computer networking and electricity/electronics systems courses.

The confluence of learning theory, cognitive science, along with complex technical course requirements suggests the need for organizing ideas, technical or otherwise, in a way that is readily available for review and update, both individually and by groups. Meaningfully annotated illustrations, infographics, and procedures provide us with an additional avenue for doing so safely and effectively, exploring and expressing ways for continuously improving systems.

The rest of the paper is organized as follows: The *Course Background and Teaching Methodology* section provides information about the networking hardware related course. Next, in *Graphics Aided Learning and Teaching* various visual design strategies and techniques for expressing one's understanding is provided, including development of a broad visual vocabulary for students. This is followed by the *Boardnotes 2.0 in Practice* section noting instructor observations about how the teaching of the class has evolved to include strategies that are more conducive to quicker assimilation and longer-term recall of information. Samples of whiteboard notes are provided. It also includes information about practical strategies which may be used for conveying typically used network information. The *Assessment of Student Learning* section outlines both evaluation of student work and feedback provided by the students related to the use of Boardnotes. The *Conclusions* section highlights key ideas for improving student learning in the network devices course which have been successful, and some of the pedagogical implications of the work. It also includes information about the current graphic explorations being tried in the network devices course and across the curriculum.

Course Background and Teaching Methodology

The Network Switches & Routers course at Eastern Kentucky University is a sophomore-level undergraduate course taken by students from network security, computer information systems, and computer science. The prerequisite is a foundational course in networking systems. It meets two times a week for approximately two hours each and includes integrated lecture and laboratory sessions. The laboratory includes ten computer stations with five rack mounted Cisco 1841 and 2960 routers, 3550 and 3560 switches, connected using network cables to computer systems. Students typically work in groups of two students per computer station. The laboratory also includes unmanaged switches to which the computer systems are connected for use with other classes which are taught in the same laboratory. Students have access to the laboratory outside of class time during open laboratory hours supervised by graduate students. The textbook used in the course is *CCENT Cisco Certified Entry Networking Technician study guide ICND1 exam* by T. Lammler, Sybex Press, 2016. While Cisco based network hardware is used in the laboratory, students are encouraged to explore several open-source networking tools as part of class activities.

The course covers the foundations of networking models, cabling, IP addressing, subnetting, network router and switch configuration using the Command Line Interface (CLI), device management including password reset, network monitoring technologies, physical and virtual local area networks, Spanning Tree Protocol (STP), Access Control Lists (ACLs) and Network

Address Translation (NAT). Students test the operation of network devices using proper instruments and procedures.

As part of the course, to better internalize concepts they are provided opportunities to state, elaborate, exemplify, and illustrate selected concepts of network switches and routers. They can explain the function of different network devices used in an internetwork, sketch device symbols and use these to create meaningful network diagrams. They also simulate and physically perform the configuration and operation of network devices, along with troubleshooting networked systems while maintaining safety precautions. As directed, students perform online research for efficiently identifying reliable sources of information; and critically analyze technical articles or multimedia sources related to networking devices. They need to communicate laboratory procedures, testing/troubleshooting steps, and experimental results effectively. In addition to in-class guided activities, students manage their own network racks, with each group assigned to manage a unique network including appropriately sized subnetworks.

Traditionally the course has been taught using presentation materials which summarizes information for each chapter of the text including screen clips of network diagrams and subnetting tables. This has been used in conjunction with simulation software and hands-on laboratory activities. Additional handouts had been provided by the instructor for supplementing existing materials. While this is certainly an appropriate way to discuss key topics related to management of network devices, in order to make the learning more enduring, active ways of engaging the students in the learning process are being explored, inspired in part by graphic design techniques. The use of the whiteboard or chalkboard is now being used extensively as part of instruction instead of relying on presentation software. This allows the instructor to alter the pace of the instruction and actively engages students in the note taking and making process themselves, instead of them passively receiving the information. It allows students to develop personally annotated diagrams of computer electronic network systems, perform calculations, perform small group activities, conduct online research using their mobile devices in the classroom, update diagrams, procedures, and calculations following interaction with peers and the instruction provided in class or through laboratory activities and demonstrations.

Graphics Aided Learning and Teaching

Some engineering and technology students, and faculty members too, may recall sitting in classes with walls of text filling the chalkboard or whiteboard. Often the heavy technical content and the numerous steps involved in showing complex mathematical calculations require the instructor to rely primarily on text with limited or no visuals. Even when visuals are present, it is possible that these are not presented in a way that facilitates learning effectively. Having been at both the receiving and the sending ends of this type of technical communication an observation about the process is that there is limited engagement required of the student. This may be regarded as the original “Boardnotes” way of organizing lectures. It is play on the word “bored” implying also that these instructional notes could be made more interesting, energizing, and immersive.

According to ancient Greek philosopher Plutarch, “The mind is not a vessel to be filled but a fire to be kindled.” Learning with understanding occurs more fully when students attempt to express what they think they know about a topic, and when they explore, expand, and evaluate content

themselves. This is being actively encouraged through ongoing Quality Enhancement Plan (QEP) critical thinking and reading initiatives at Eastern Kentucky University. Allowing students to be active participants in their learning is a key driving force behind Boardnotes 2.0. It is aimed at inviting students to express their understanding in other modalities beyond text. Visual, verbal, and auditory expressions of our understanding allow others to view and hear it, allowing for easier collaboration and growth. It keeps the content center stage while also allowing the light of their growing understanding of the discipline to shine. Learning gets a boost when students try to get the information out into the open and use it to solve problems, make decisions, reach positions or conclusions, consider implications, apply concepts safely, meaningfully and effectively, and create or update systems. In addition to the technical content students also learn – in both subtle and explicit ways – the use of graphical design elements and principles that can promote their learning. The Boardnotes 2.0 methodology facilitates this. Awareness of these guiding principles can enable instructors to leverage their intuition regarding appropriate sequencing of the content for class, creating more engaging and informative lectures. Instructors may also invite input from students for extending their work right here on the board, something rather unheard of in times past.

Elements of graphic design can be used to guide development of a visual vocabulary within the computer networking and electricity/electronics curriculum. These can be used whether we are taking a holistic, big-picture view of a system; examining a sub-part up close; or considering the interconnections between various parts.

According to Stephen Kosslyn, neuroscientist and an expert in the science of learning, "Memory is the side effect of thinking about something." An implication of this is that instead of trying to memorize facts, concepts, ideas, or procedures explicitly, one may approach it indirectly by thinking about how to apply, extend, adapt, exemplify, connect, modify or work with these. The very act of doing so strengthens memory. When done under increasingly realistic conditions memories become pliable and learning connections are strengthened [2]. For example, in the network switching and routing course, by having students use a combination of visuals and key words associated with networking devices such as broadcast and collision domains, subnetting charts, router/switch operating modes, while they work through various technical scenarios, memorization of these concepts can be strengthened. Students can spot patterns more easily by being able to either step back or in closer as needed while solving network design issues. In [6] a visual approach to learning computer algorithms introduces students to visual ways of thinking about solving problems prior to delving into their mathematical underpinnings. Student engagement in specific content areas may be strengthened by introducing visually engaging puzzles derived from it. Doing so allows students to build their intuition about problem solving strategies and has the added benefit of allowing them to potentially interact with peers while further honing these skills.

Technical teaching using a combination of graphics and text, can benefit from the techniques used by graphic facilitators. Within the context of graphic facilitation [7] a greater emphasis is placed on the importance of the process as compared to the product itself (p. 71). This approach can be very useful to students learning how to diagram technical ideas as well. While drawing is an important skill, of equal importance is listening and thinking when it comes to choosing appropriate ways for representing ideas graphically. With regards to drawing Agerbeck [7]

considers the essentials to be: lettering, bullets, colors, lines, arrows, people, boxes, and shading. She states that "every mark has meaning" pointing to the need for considering the implications of any graphical or textual elements we choose to use, whether it be on the whiteboard or in a presentation (p. 164).

While the whiteboard is used as the primary way of instruction in the network hardware devices course at Eastern Kentucky University, it can be informed by best practices in delivering presentations using conventional computer-based software such as Microsoft PowerPoint, Apple Keynote, Apache OpenOffice Impress.

In this paper selected elements of graphic design are used to guide technical instruction: point and line, shape, form, color, texture, and pattern. These are discussed in more detail in the next section of the paper along with illustrations taken from the network hardware and computer electronics courses. Additional design concepts such as alignment, hierarchy, contrast, repetition, proximity, balance, and space play an important role in visual communication as well.

According to [8], contrast, repetition, alignment, and proximity can make the design of slides satisfying and effective for the audience (p. 173). As humans we have evolved to notice subtle visual and auditory differences in our environment. The use of contrast, whether using color, size, shape, texture, position, density, thickness, spacing can help convey content more effectively. Or these can make the content boring and confusing. Repetition of similar graphic elements conveys a sense of cohesiveness about the topic being discussed, an underlying unity. The use of same or similar elements such as symbols, icons, colors signifying specific ideas such as safety in a presentation or even those in multiple presentation can build a sense of cohesiveness which is satisfying. This allows the specific content to be viewed as part of a larger picture, with recurring elements that connect various sections together, rather than it being a jumble of disjointed parts.

While randomness apparently rules elsewhere, during a presentation, whether using software or a whiteboard, graphical elements should be aligned with each other, giving it a cleaner look and feel. The harmonious arrangement of information helps us convey the content more effectively, and for the audience to understand it quickly. Everything an instructor chooses to write on the whiteboard and where it is placed should convey an underlying alignment. Arranging content the way in which we normally access content – moving from left to right, and from top to bottom and across – can keep the focus on the content. Intentionally leaving gaps or blanks at strategic places on the board can serve as a powerful mechanism for encouraging the viewer to fill in the information and thus be more engaged in learning the content.

We are wired to solve puzzles, and this can be leveraged to have students reach for their pens and calculators to solve a given problem, attempting to resolve inconsistencies. By intentionally writing a number that does not quite seem right can help students identify and isolate the practical significance of information.

The principle of proximity positions groups of related items closer to each other. Items positioned at a distance appear to be unrelated while those closer to each other seem to naturally belong together. This also provides the viewer with a visual organizer of the information. Key information about the group can then be extrapolated.

A general understanding of color can be helpful for both the instructor and the students. Specific examples related to the use of color while discussing networking and computer electronics systems will be covered in the next section. The color scheme of black text or illustration on the whiteboard is often the most inexpensive and readily available option at educational institutions. The use of colored, dry erase markers can be helpful in conveying using technical information, focusing learners' attention on specific area, grouping, emphasizing or comparing content.

Figure 1 shows a color wheel, which organizes the hues associated with various colors in a circle. Analogous colors located next to each work go together harmoniously, while complementary colors are located across from each other on the color and can create dynamic contrasts. Artists typically include the colors red, yellow, and blue as primary colors on the color wheel. These cannot be created by mixing any other colors. Mixing the primary colors creates the secondary colors: orange, green, and purple. Tertiary colors are created by mixing a primary and a secondary color. The colors red, orange, and yellow are regarded as warm which advance towards the viewer, while the cooler colors green, blue and purple recede.

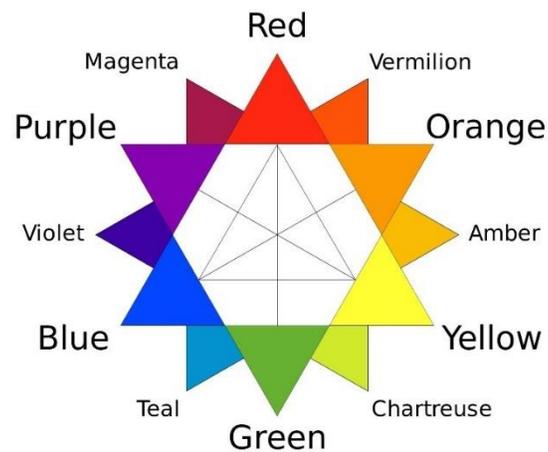


Figure 1. RYB Color Wheel (By Kwamikagami - Own work, CC BY-SA 4.0, <https://commons.wikimedia.org/w/index.php?curid=43056011>)

Each hue has a "value" relative to other colors on the color wheel, with yellow having the lightest value and violet the darkest. As dry erase markers dry out this is equivalent to starting with the darker shade of the color and it becomes successively lighter over time and use. Lighter colors are difficult to read from the back of the room and may not photograph well. Neutral colors such as brown or gray do not appear on the color wheel. These are low in saturation as compared to pure colors at a given level of lightness. Saturation refers to a color's brilliance or dullness and the simultaneous use of multiple brilliant colors may cause these to compete for the viewer's attention [9].

In the technology classroom, a selection of the subtractive colors, specifically the primary ones red and blue are clearly visible from across a large classroom and laboratory. Yellow, owing to its lighter values as compared to other colors, may be used for highlighting key text but not for any lettering or illustrations. Black which is often the most readily available one in a classroom setting offers the highest level of contrast against a whiteboard.

Using multiple colors instead of monochromatic can add dynamism to the class, allowing for students to separate, group, and connect ideas more easily. The instructor may choose to use specific colors for drawing attention to specific features. The use of contrasting colors such as red and green, or orange and blue, can for example, draw attention to recommended or problematic practices. Another aspect to consider is the level of lighting in the room, including natural and overhead one, as the glare can make lighter colors difficult to view or photograph.

Boardnotes 2.0 in Practice

Technical documentation and instructions, along with accompanying mathematical calculations and underlying theoretical explanations, are frequently presented in a textual format. Often text-based instruction is used for building a technical vocabulary. This includes verbal explanations with limited visualization of the content. One reads and thus "hears" the authors words, linking newly learned content with prior learning. As text is most often presented in a linear format, this learning can be predominantly linear as well, unless active learning strategies are used for engaging with the content. The pace and depth of individual learning of new content thus can vary based widely based on ones existing level of prior understanding about the discipline. Ways of readily recalling information and applying existing understanding to the new content can make learning connections stronger.

Documentation and instruction which includes visual elements and graphical explanations allows students to see the content in addition to hearing about it. Using a combination of symbols, icons, illustrations and accompanying annotations they can develop an abstract, big-picture view of the content being covered, and a zoomed in, detailed view can be presented, which could be rich in textual explanations. This lends itself more easily to group discussion and interactions, particularly in a laboratory setting.

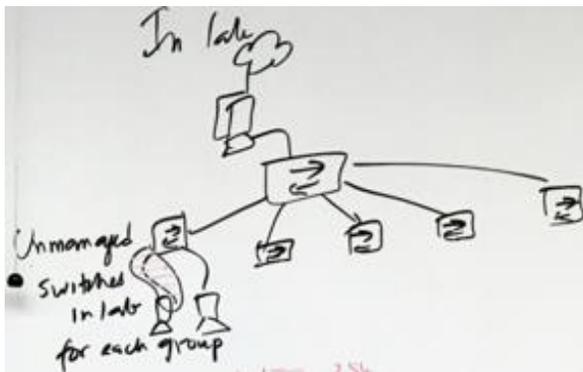
The following graphic elements – point and line, shape, form, color, texture, and pattern – are being used for providing students with a visual and verbal vocabulary associated with network hardware and computer electronics systems.

- ***Point and Line.*** This element provides the first step while converting textual to visual formats. It can be used for easing the anxiety students may feel regarding their ability to draw or sketch. Lines, for example can be used for representing computer systems information such as network boundaries and various types of cabling. These are primary single dimension and may include arrows. Choosing to use solid, dotted, dashed, or other lines distinguishes one type of cabling from another. For example, a solid line could be used to represent a broadcast domain associated with each port of a router, while a dotted line for representing the collision domain associated with each port of a switch. Lines serve to interconnect symbols for various network devices and thus provide us with an overall understanding of the network. A solid line interconnecting a network device with a computer could be used for showing a straight-through Ethernet cable, one with an "x" superimposed on it for a cross-over cable, and another shaped like a lightning bolt for a serial connection.

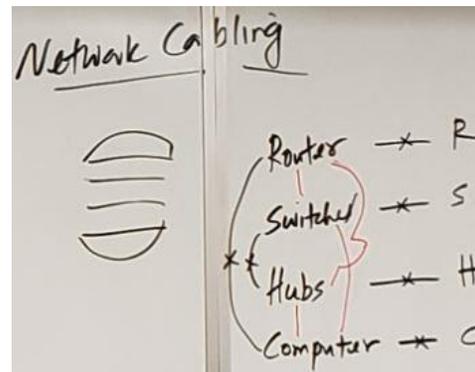
A sample network diagram is shown in Figure 2(a), which is the default layout of the laboratory. The internet connection to the laboratory is through a dual-homed computer

which is running *pfSense* open-source integrated router and firewall software. The laboratory is shared with other electronics and networking classes, and by default has computer systems connected through unmanaged switches. In the network hardware devices course students will transition from these unmanaged devices to managed routers and switches as the semester progresses.

Students set up Ethernet cabling between network devices. Remembering whether the specific network cable is a straight-through or crossover is typically difficult to recall. A visual and rather appetizing cue in the form of a “burger” is suggested, as shown in Figure 2(b), with the router and network interface card (NIC) on the host computer serving as the slices of the sandwich. The hub serves as the protein of choice, and switch the topping. Network devices are arranged according to their location on the OSI model, starting with Router, Switch and Hub, followed by the NIC. From the diagram it is easy to recall which parts go together, the ends connected using crossover cables, as are the two center devices. Similar devices should also be connected using crossover cables matching up the sending and receiving pins. In the diagram straight-through cables are shown using straight lines and cross-over cables with a cross mark.



(a) Lab network



(b) “Burger” view of network cabling

Figure 2. Default network layout of laboratory

- **Shape.** These are primarily two-dimensional representations of a network. These could also include symbols associated with various network devices. Since we use shapes as the principal element while trying to identify an object it is even more fundamental to design than its counterparts: form, texture, or pattern [10, p. 50].

Class worksheets, like the one shown in Figure 3 guide student activities in class. Using their personal computing devices in class students search for and sketch symbols associated with common network devices. Additionally, shapes can be used for representing procedures using flow charts, whether these are sequential statements, conditionals (if-then-else), or repetitions using loops. The visual understanding of shapes learned through graphical and textual in-class activities can help anchor memories for future use. In-class activities also require students to do a reverse lookup of a network device symbol drawn on the board or provided in a worksheet. Students search symbols

Using a standard Class C IPv4 network address such as 192.168.1.0/24 students can see that the broadcast address is 192.168.1.255. This can be noted on the inner boundary of the pizza circle. Excluding the two addresses, one which identifies the network itself and the other for the broadcast address, this leaves 254 addresses which can be allocated to users.

Next, by choosing one bit of the host portion, we can create two subnets. This is shown by cutting a pizza in half, with each half then having its own subnetwork and broadcast address, so $256/2$ or 128 addresses of which $128-2=126$ can be assigned to subnetwork host (excluding the address of the subnetwork itself and its broadcast address).

This process can be continued further by slicing the network pizza into multiple parts. An added advantage of this mechanism is the ease with which Variable Length Subnet Masks (VLSM) can be introduced. Conventional subnet masks use a fixed number of hosts in each subnet, equivalent to slices of the pizza being cut the same size. However, basing the slicing of the pizza network on the actual number of hosts to be assigned per subnetwork can be more efficient. Students have enjoyed taking a slice out the network pizza while creating their designs.

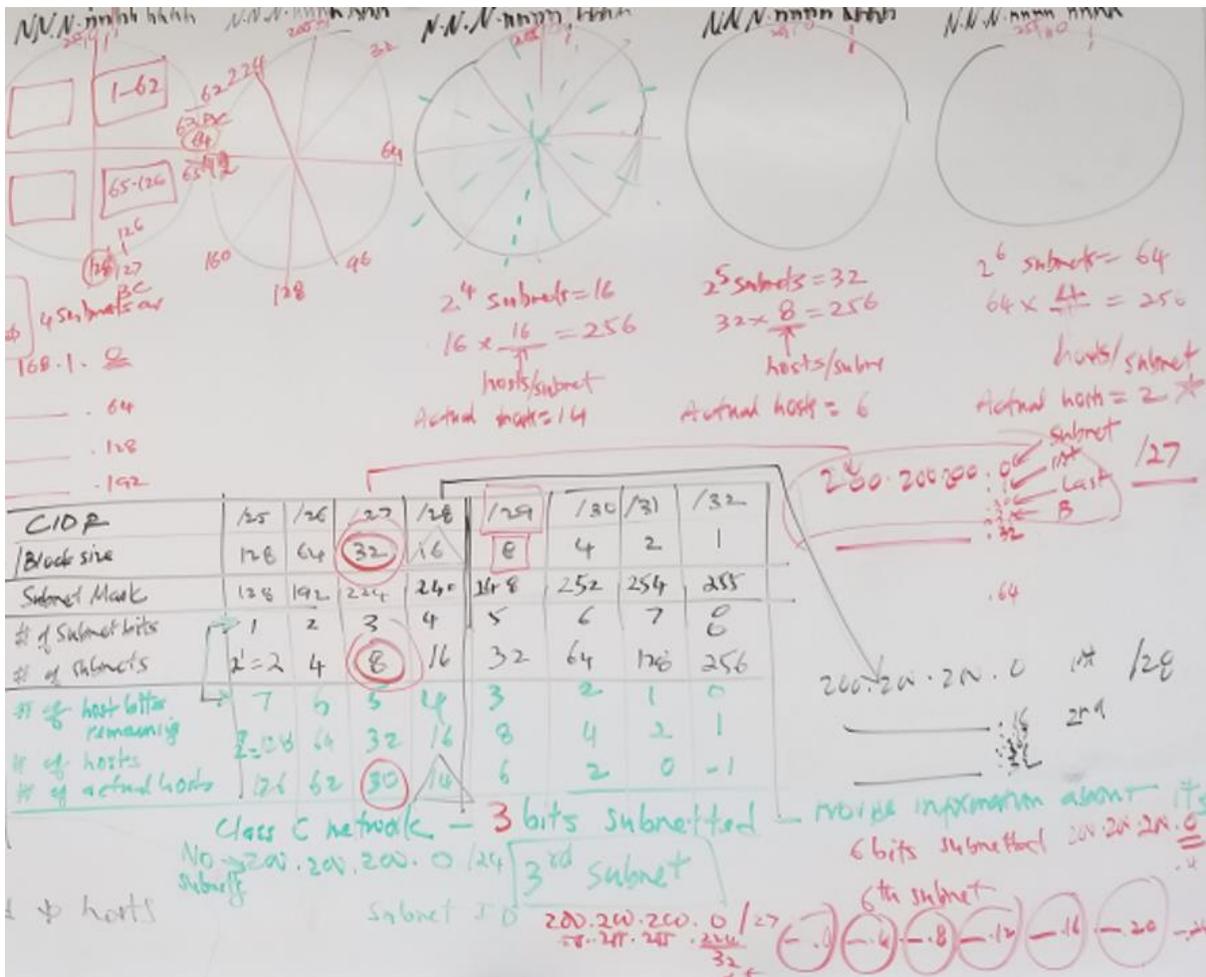


Figure 5. Compact subnetting chart

With this visual explanation of subnetting students can transition to using a subnetting chart, which includes a mix of graphical and tabular elements. As shown in Figure 5 the subnetting chart consists of the following 8 rows:

- CIDR (Classless Inter Domain Routing) notation
- Block size/weight
- Subnet mask
- Number of subnetted bits
- Number of subnets
- Number of host bits remaining
- Number of hosts per subnet
- Number of actual hosts per subnet

Given a scenario, such as needing to create a subnet with no more than 30 hosts, the appropriate element in the table can be quickly identified visually (shown with a red circle in the figure), and this can provide us with additional information such as the CIDR, Block size, subnet mask and number of subnets.

For any given subnet students need to provide the following information:

- Subnetwork address
- Broadcast address
- First usable host (address after the subnetwork address)
- Last usable host (address before the broadcast address)

This can result in a better understanding of network design using a combination of graphical and text tools. They can understand in a very visual why, certain addresses if assigned to a computing device or interface interfere with communications. Additionally, recognizing that most often Class A and B networks are generally sub networked to serve as Class C networks, the conventional subnetting chart can be compacted to a much simpler table.

Whereas in the past subnetting may have been learned in isolation, students can now take the information extracted from the subnet chart and associate it with a network diagram. This intermixing of lines, shapes with text annotation can deepen understanding of the network and help in troubleshooting. For example, if a network host has unintentionally been assigned a broadcast address, that can be easily identified in an updated network diagram, which shows the network address, broadcast address, and the range of allowable IP addresses.

- **Form.** These are primarily multi-dimensional representations, allowing for better visualization of a system operations or user actions. For example, while using the text line telnet protocol to access a remote network device a system administrator may need to temporarily leave a session and open another telnet session to the same or different device. This is shown in Figure 6.

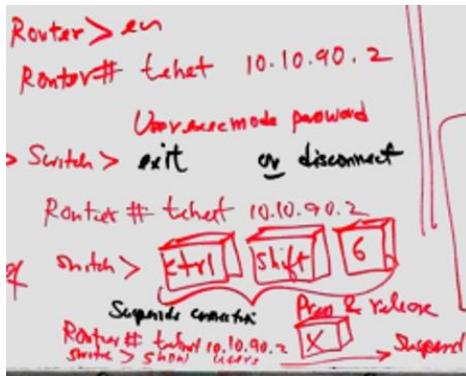


Figure 6. Command Line Interface (CLI) telnet access keyboard sequence

The keyboard sequence [Ctrl][Shift][6] followed by [x] is difficult to remember, and sketching it out on paper, using a 3 dimensional keyboard type shape can serve a cue for action when the students are actually performing the activity in the laboratory.

If available, instructors can show annotated photographs or supplement classroom discussion with live demonstrations or video footage for adding a multi-dimensional feel to the instruction.

- Color.** The use of color can draw attention to specific aspects of an illustration. Just as highlighting text or using bold or italic styles for emphasis draws attention to specific portions of the text; color can direct focus towards specific aspects of an illustration. A new feature being discussed in class when drawn using a different color can immediately call attention to itself. Essential computer, networking, or electronics technology terms can thus be simultaneously introduced and emphasized while maintaining the flow of the class discussion.

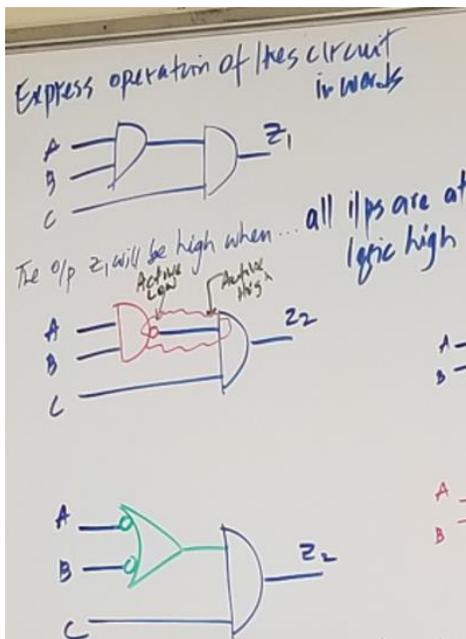


Figure 7. Colors highlighting logic gate connections

For example, one may use red color for safety, green for efficiency, and blue for procedures. Red and green can also be used for contrasting recommended methods. As shown in Figure 7 while interconnecting logic AND gate symbols allows for easier verbalization of an output, when a NAND logic gate is connected to an AND one, expressing the operation of the composite system is difficult. This is because the active Low output of the NAND is being connected to the active High input of the AND gate.

The potentially problematic area is shown using red color in Figure 7. An alternate logic symbol (constructed using de Morgan's Laws, $(AB)' = A' + B'$) resolves this issue visually, converting the Active Highs to Active Lows and vice versa, along with the AND logic gate symbol to an OR logic gate. The recommended updates are shown using green color in the diagram.

There are challenges to using color markers in the classroom. Markers dry out and colored text can be difficult to read based on the overhead and natural lighting in the room. This can be observed in Figure 5. The glare from the board, coupled with penmanship of the instructor can make deciphering the text and illustrations a challenge. While having a range of colored markers available for instructional use would certainly be welcomed by faculty, often departmental budgets or policies may allow purchase of only a selected range of color markers.

- **Contrast.** Our eyes are naturally drawn to visual differences in the environment. As a way of presenting topics for the day, these can be organized using different colors.

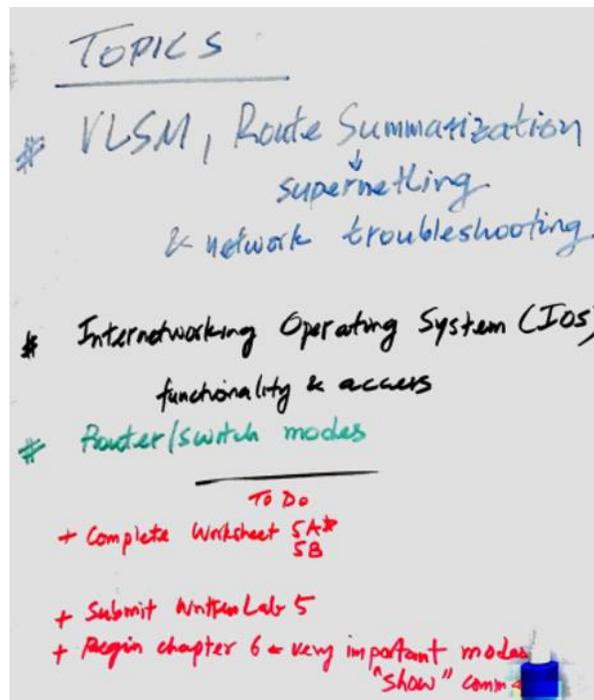


Figure 8. Sample network device class outline

Key questions can be highlighted using complementary colors or those which have a high degree of contrast, such as red and green or yellow and black. The use of warm (red,

yellow, orange) and cool (blue, green, purple/violet) colors can be used to provide a natural contrast. As noted before colors neighboring each other in the color wheel shown in Figure 1 go well together, while those across from each other in the color wheel provide significant contrast. Additionally, warm colors appear to be closer to the viewer and cooler ones recede. Other symbols such as hash marks can be used to make some portions appear in background and others "pop". Figure 8 shows a sample topical outline using different colors, with a To Do list in bright red color.

In order to maintain consistency across a lecture and even across multiple lectures selecting a specific color can help aid in cuing of specific information. By consistently using red for highlighting safety considerations or caution, this can help solidify understanding. Once measures for improving safety have been taken in the system, other procedures can be used, and efficiencies sought.

- **Texture.** While challenging to use texture in the conventional classroom, in laboratory-based classes circulating actual equipment if applicable allows students to handle the device prior to use. Visuals which allow students to do so help evoke the sense of touch and thus provide accesses to deeper emotions. This can serve as a powerful learning tool.

As noted in [9], "perhaps no element of design is more capable of exuding deep emotion than texture." noting also that it is also most often "hidden", with the key to conveying it depending "on one critical element: lighting." (p. 58).

For example, by using visual analogies different perspectives or viewpoints of multiple users can be modeled. Computer network systems designers for example may have a very different perspective from that of the end user: one set emphasizing safety/security first and efficiency, the other convenience and lesser restrictions on access to network resources. As showing in Figure 9 for example students can be asked to visualize a given object, such as a network design, through the perspective of multiple stakeholders and provide information about key concerns or considerations. Since all views exist simultaneously for different users, even if individual users may not be conscious of these; being able to list these multiple considerations, may in itself help clarify the network design process. The use of this hidden visual design element can lead to better intuition about the whole system.

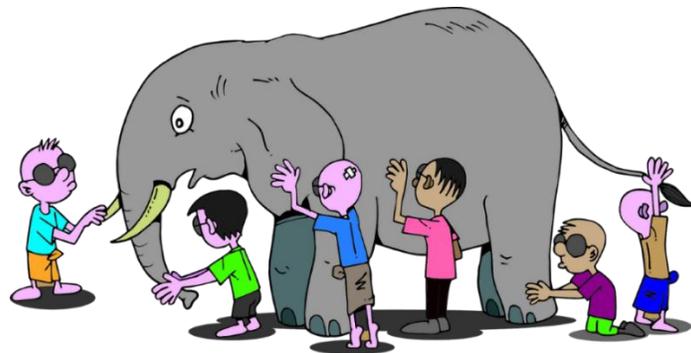


Figure 9. Considering multiple perspectives of a system (By [OpenClipart-Vectors](https://pixabay.com/en/ancient-blind-boys-brain-cartoon-2026111/) from [Pixabay](https://pixabay.com/en/ancient-blind-boys-brain-cartoon-2026111/), <https://pixabay.com/en/ancient-blind-boys-brain-cartoon-2026111/>)

- Pattern.** Structured repeated patterns can be pleasing and help memorize. And changes in the pattern are easier to identify. As shown in the Figure 10 some of the commonly used operating modes of a network router are modeled using diagrams reminiscent of state machine design. In [11] the state machine diagram view is developed further as part of the network design process and used for competency assessments.

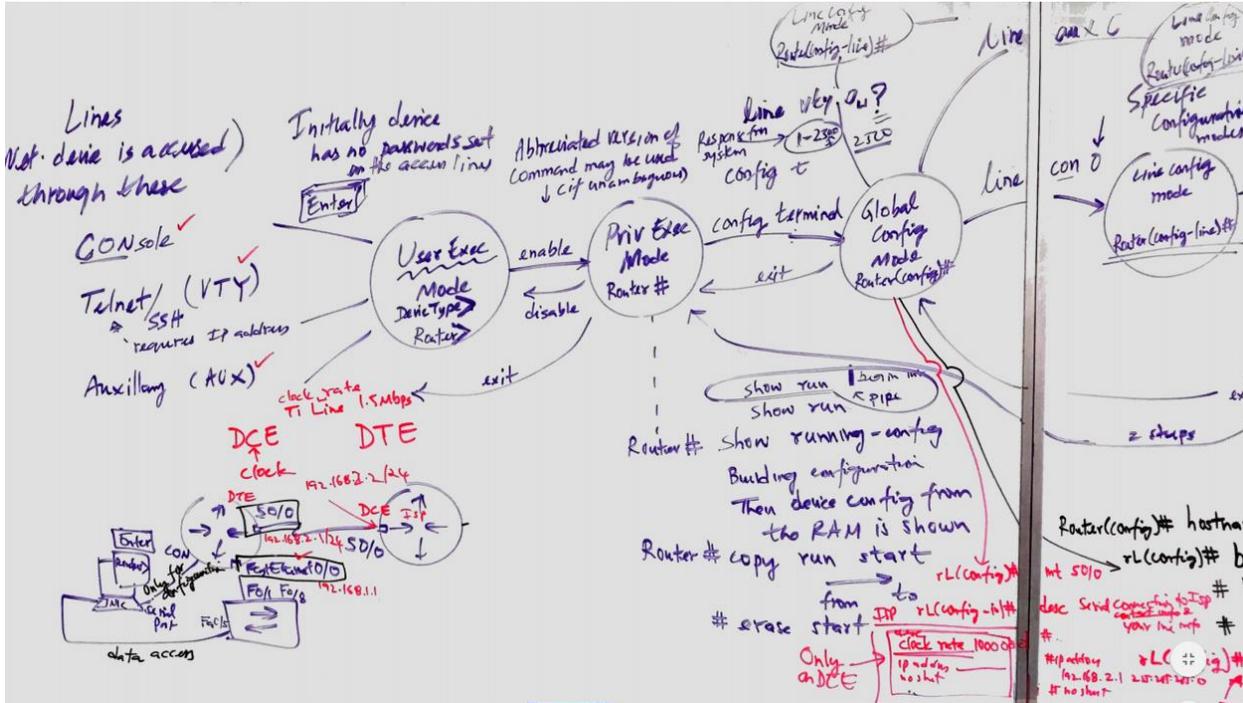


Figure 10. Network device operating modes

Patterns also help reveal structures that embedded within a design. For example, in Figure 11 the operation of basic logic gates can be mimicked by universal gates configured to provide identical functionality. Once students understand the codex for interpreting these modern-day hieroglyphics, the design of computer electronics systems becomes intuitively simpler.

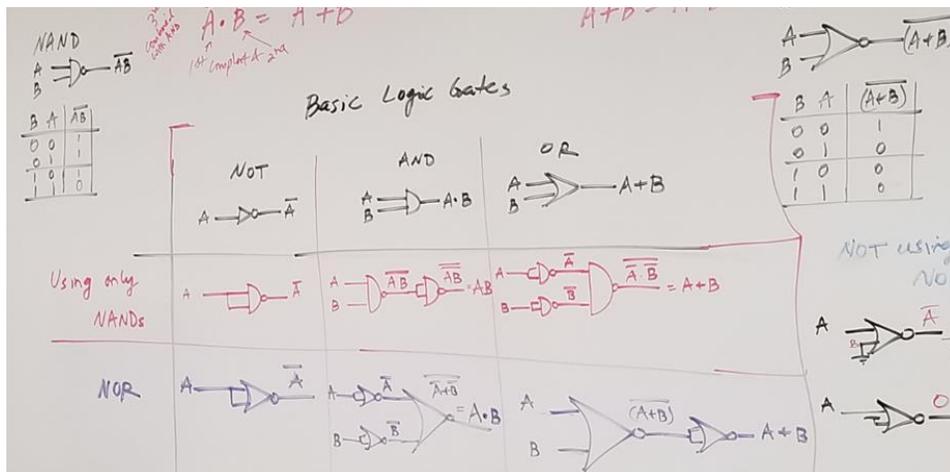


Figure 11. Visual logic gate equivalencies

Other elements of visual design can guide the selection and positioning of elements in network or computer electronics systems. These include:

- Contrast (size, light and dark, etc.);
- Alignment (top/bottom, sides, center);
- Proximity (similar items positioned closer to each other);
- Repetition (consistency of usage of shapes, colors, visual cues across multiple area unified the design);
- Balance (different sides of the layout selected, whether symmetrical, asymmetrical or radial around a center location, arranged to have the same look and feel in terms of sizes, color, shapes, etc.);
- Space (intentional blank, negative, white or passive space draws the eyes to area which are not).

Using a combination of illustrations and text, which grow in complexity as the semester progresses, students build confidence in the network design process. This type of in-class activities primes the mind for learning and applying technical concepts visually.

In prior semesters while teaching the Network Switches & Routers course, and other electronics/networking courses, lecture would typically precede in-class activities. Now, to prepare students for the lecture the in-class worksheets are shared, and students have a short time to preview questions as well as refer to online sources while filling out some of the questions. This questions typically require students to include finding device symbols, update network diagrams, calculate network information or troubleshoot given scenarios.

Once students have had the opportunity to use their mobile devices and had time for some in-class discussions with peers, the lecture gets underway. The whiteboard is used extensively for leading in-class discussions and on occasion online websites are accessed for supplementary information. One of the underlying reasons for using the whiteboard is for allowing students to interact with the symbols and syntax of the discipline. slowing down the pace of the information.

At specific times during the class discussions students can update their class worksheets and following the lecture. Optional or extra credit activities can be added in for students to explore beyond the in-class discussions.

Students often choose to take digital photos of the board notes following each lecture, which typically fills up two large (8'x4') whiteboard panels. This, in conjunction with their in-class notes and worksheets, can help memorize and later recall relevant information.

An interesting aside about the in-class notes is that while these include a lot of annotated graphics, since these have been developed in a sequential manner, they often cover several pages of notes. For a quick synopsis of the in-class discussions several students have taken to photographing the whiteboard after the lecture. These photographs provide a quick recap of the day's discussion. Students occasionally include these notes in their portfolios and may highlight they key areas they are focusing their learning on.

Along with conveying technical information, graphical tools can be used for expanding, exploring, evaluating, and expressing thinking about a topic. In Figure 12 for example, the

"Compass Points" technique [12] can be used for exploring both the logical and technical aspects of any given topic, along with those in the affective domain dealing with feelings and emotions.

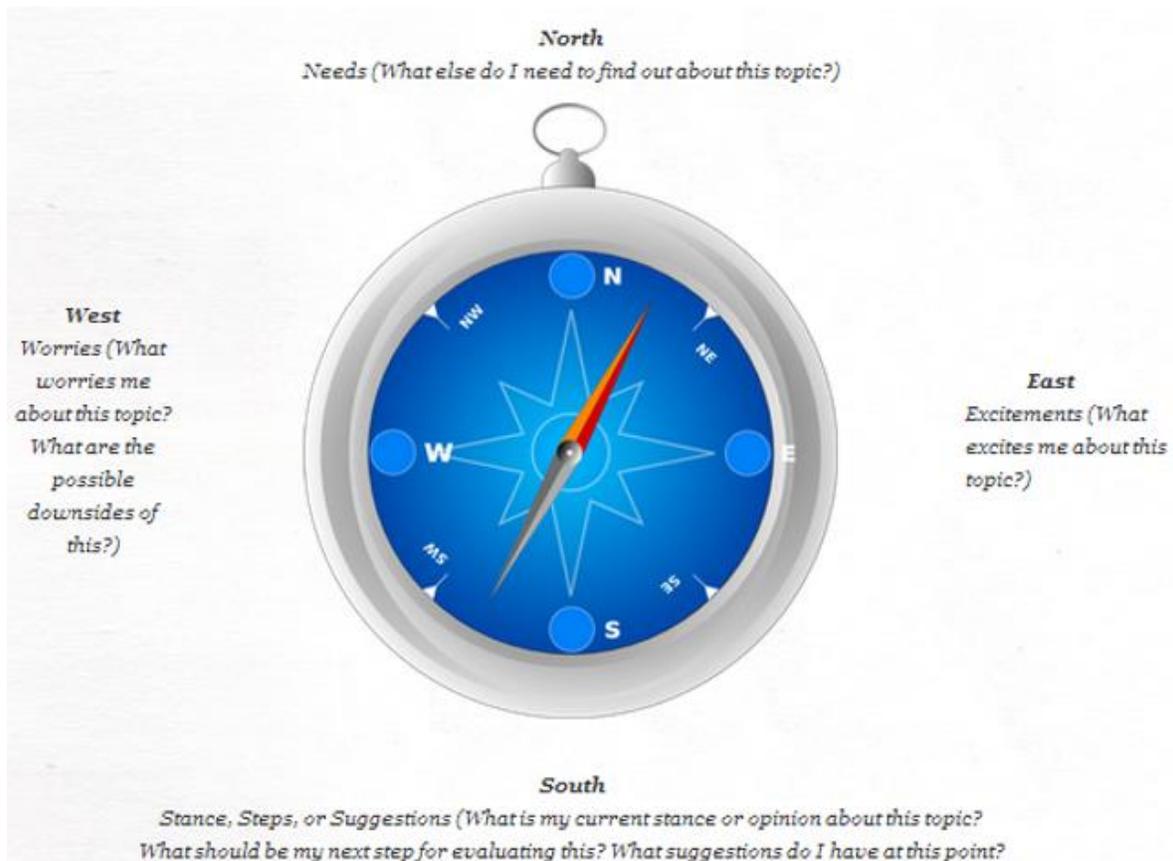


Figure 12. Compass points class activity

This technique makes use of the four cardinal directions of a compass: along the North-South direction one asks questions such as what is Needed (North) and what Steps (South) could be taken; and along the East-West direction taps into emotions such as what is Exciting (East) or Worrisome (West) about the design. These and several other applications of critical/creative thinking techniques created by education experts are available through the qepCafe website [12].

With practice students and faculty will be able to share their thinking about technical topics in clear, vibrant living color, leading to better designs and collaboration. Visual information, in many instances, can be more easily communicated and is thus more actionable than text-based information. Trends in the data can to be spotted more easily and flagged for further action as part of network operations. These graphical tools can help improve students' critical and creative thinking along with technical communication skills more effectively.

Assessment of Student Learning

Assessment of student learning on the final exam in the course includes an objective type section whose format is similar to the questions on the CCENT certification exam; a short answer/design section requiring network planning with subnetting and router/switch configuration; and a group hands-on final exam where students need to design, configure, test, and troubleshoot end-to-end

connectivity involving multiple routers using fixed/variable length subnet mask addressing, static/dynamic routing, use of access control lists (ACLs) to allow and block selected network services such as telnet, FTP, or ping originating from specific hosts. Students are required to provide annotated network diagrams as well as cabling information for their system. The performance and competency-based assessment provides opportunities for students to work individually and in teams cabling and configuring a network using multiple routers and switches. Similar to [4] where a larger VoIP project guides activities through the semester, students in the Network Switches & Routers course are repeatedly reminded about how each section they are learning about through structured theory and practical activities is a key part of the final hands-on design and implementation they must successfully complete. This provides an overarching context for their learning through the semester. Providing students with both a pull-back view of the entire network and a zoom-in view of its individual components allows them to build better mental models of network systems and device functionality. This topic approached through state machines in [11] where for example a router may be modeled as a state diagram and includes information about its routing table, ARP table, and its specific interfaces including IP and MAC addresses. Knowing the capabilities of different network devices, the information devices store in various tables and the interfaces available, allow students to decide on appropriate strategies while solving network design problems and testing their implementations.

Observation of student work in class, as part of individual and small-group activity, along with evaluation of submissions on the assessments indicate their increasing confidence regarding understanding of foundational network design principles. A majority of the students are able to visually express network operations effectively, include suitable annotations, highlight critical addresses, connections, interfaces, and perform network design calculations. Clearly drawn and labeled network diagrams often make implementation and subsequent network setup a lot easier using the command line interface for managed switches and routers. This type of system visualization is helpful as students advance through the curriculum on through their capstone projects.

Students maintain a course portfolio including all class and laboratory worksheets completed in class with instructor initials indicating completion (designated worksheets are submitted for evaluation), simulation, and laboratory reports. The in-class worksheets form a crucial component of student learning. These worksheets are filled out live as the lecture and class activities progress. It involves both individual work and group participation requiring students to sketch, calculate, troubleshoot scenarios, research prompts online, update diagrams, and express ideas graphically as well as textually. This active engagement in the learning process allows students to develop "muscle memory" allowing the sketching of network systems, perform housekeeping tasks regarding router and switch setup using the Command Line Interface (CLI) readily, and when working on a physical system developing a network diagram for aiding its design and development. The portfolio is evaluated at the time of the mid-term and final. Students include a learning statement about their knowledge, skills, and work practices related to network switches and routers has been updated through the semester. This requires students to reflect on their learning process and in doing so they identify both strengths and areas of improvement in these three dimensions. The portfolio creation process includes a positive side effect, something we as faculty hope students learn as part of their time with us: transfer of learning across multiple courses. A student recently commented "...once I got into the swing of

keeping up with this portfolio it has been a great boon for me... I have liked it so much that I even implemented the technique in my other classes....I plan on using here on all in my academic career and potentially my professional career as well.” Students often include photographs of the board notes in their course portfolios in addition to their personally illustrated class notes. Occasionally students will use different colored pens for creating their notes or depict a networking or electronics concept in a unique way. These ideas are shared with the class so that other students can adopt similar note making methods.

Boardnotes 2.0 has been well received, as indicated by both the online course evaluations completed by students and also the feedback received as part of course submissions in which students reflect on their learning of chapter objectives. One of the open-ended institutional course evaluation questions asks students “What did the instructor do that helped you learn?” and “What aspects of this course helped you learn?” Student responses related to the use of board notes has been overwhelmingly positive and has included comments such as:

... drew visual diagrams and lengthy notes.

Excellent lecture with nearly all information on the board

Daily notes and labs

The depth of the lectures, all board notes

The hands on work, the meaningful feedback always provided and how much ... encourages metacognition

I feel having labs which support topics in lecture and the text really helped me retain the information being taught.

had very detailed lectures and plenty of labs

... made learning the content understandable and fun because ... incorporates the topic with whatever lab we were doing that day with many visuals

A student commenting on one of the Network Switches & Routers course submissions related to using Ethernet cabling stated: “*I didn’t realize it was as simple as a “hamburger” to help clear that up!*”, and another remarked about the subnetting process: “*When subnetting it is easiest to look at the charts in my notes, but without my notes its best to make the compact subnetting chart for fast and easy remembrance.*”

Suggestions for changes provided by students included printing out notes of the day. Typically students volunteer to take photos of the board and these are posted online through the learning management system with comments about the key points covered that day. This is especially useful on the days preceding assessments. Students greatly enjoy applying the theory they are learning in both simulation and using the actual hardware. More laboratory time is suggested and we typically have open laboratory time scheduled during the week supervised by graduate students. Since the course may be taken as a technical elective by students from Computer Science, Computer Information Systems, and Physics/Pre-Engineering programs, they have expressed interest in component level analysis. Based on prior preparation for the course, students have occasionally noted that they may: “*...feel overwhelmed with the amount of information we learn in each class session...*” One ongoing challenge with regard to the use of board notes is the visual and cognitive load this process can generate. It is not unusual for completed network diagrams to include configuration parameters, overlaid with Internetwork

Operating System (IOS) commands and diagnostic messages, making the overall notes for the day very information dense. A strategy being considered is initially providing students with partially created zoomed-in network view of the system, and then going over the configuration, IOS commands, and the related diagnostics needed by specific devices. This will allow students to update their network diagrams deepening their understanding. They could then verify the configuration of the entire network using either a simulator or actual networking devices. Visually navigating across multiple scenarios and contexts that can help create more durable memories.

Maxwell Anderson, Director of the Dallas Museum of Art, makes special note of the need for sharpening the sense memory, remarking about the senses that these "are all affected in equal degrees of sensuality, illogic, and reward", including the sense of sight [13, p. 174]. Artistic expressions of the kind students are exploring when they put pen to paper by developing diagrams, brainstorming ideas visually, or making delightful connections between different areas, make the sense memory keener. Their artful expressions can provide students with a glimpse of the underlying elegance of the system and allow the beauty of the ideas on which these are built to shine through.

Conclusions

By initially mimicking and later creating their own representations of various computer network scenarios, students continue the path to building a visual vocabulary for explaining and thus understanding networking at a broader level. This can help them add new information to their mental models of networking which have been converted into tangible representations on paper. This also helps clear up misconceptions that interfere with building a deeper understanding of the subject. Success in performing this may motivate students to try similar visual vocabulary building techniques in other areas. It can enhance the students' abilities to observe current systems, and to spot changes in the system, also allowing them to represent what a mathematical number may mean visually and whether that type of response is possible physically. This type of physical representation of a mathematical expression can build intuition about behavior of networked systems. This can be sharpened further using simulation and practice with actual network devices.

Effective visual representations of network information require one to be able to manipulate ideas, recognize interconnections and weightings between concepts. A visual vocabulary of networking can be partnered with the accompanying textual and mathematical ones. This allows information to be shared and communicated to others, both technical and non-technical users at various levels of granularity. The wealth of information under the visuals can be more readily accessed. Graphic design aided instruction can help computer networking students understand, apply, and design solutions using networking concepts more readily.

Ultimately, skill is developed by testing understanding of topics under increasingly complex situations and under fewer constraints. Representing such systems textually, mathematically, or visually, is challenging. And immensely rewarding. Graphical organizers and visual learning techniques are currently being explored for providing students with templates which they can use across multiple classes with minimal adjustment. These graphical organizing tools are intended to allow expansive explorations, meaningful evaluations, and flexible expressions of topics.

Being able to represent the computer networking system effectively makes development of a solution for it easier, along with its testing, troubleshooting, expanding, managing, securing, and eventually replacing or recycling portions as these ages out. As part of the networking course graphic organizers are being trialed allowing students with opportunities for exploring, expanding, evaluating, expressing, and experiencing computer networking information more effectively. With practice this helps build intuition about expected and anomalous system operations. These learning techniques can be extended to other areas of computer electronics and networking.

Computer networking students are often required to effectively navigate voluminous amounts of both unfiltered data and processed information from a multitude of sources, using these to build and update the mental maps of their knowing about the subject. While the learning of these skills will continue over a lifetime, each course has the potential to contribute in tangible ways towards the larger vision of developing self-directed learners. Developing clearer and accurate mental knowledge maps has the potential for allowing a nuanced understanding of discipline to emerge, helping one make or choose better interpretations, actions, decisions, and solutions. It is also likely to reveal connections spanning multiple disciplines, resulting in broader and deeper learning connections. It can help them read text more attentively and actively, engage both the imagination and technical skills while building better understanding of a topic whether it be for using a given method appropriately, solving an issue safely, suggesting improvement, or viewing a topic from multiple perspectives.

References

- [1] J. Bransford, A. Brown, and R. Cocking, *How people learn: brain, mind, experience, and school*, Washington, D.C.: National Academy Press, 2000.
- [2] P. Brown, H. Roediger, and M. McDaniel, *Make It Stick*. Cambridge, MA: Harvard University Press, 2014.
- [3] A. Al-Rawi, and A. Lansari, "Developing an Effective Network Course Using The Cisco CCNA Exploration Curriculum," in *paper presented at 2009 Annual Conference & Exposition, Austin, Texas, June 14-17, 2009*. Available: <https://peer.asee.org/5250>.
- [4] S. Kulkarni, S, "Using VoIP As A Common Framework For Teaching A Second Course In Computer Networks," in *paper presented at 2010 Annual Conference & Exposition, Louisville, Kentucky, June 20-23, 2010*. Available: <https://peer.asee.org/16502>.
- [5] V. Chandra, "Solution-based Learning (SBL): Using Systems Engineering Principles to Guide Capstone Projects in Technology," in *paper presented at 2016 ASEE Annual Conference & Exposition, New Orleans, Louisiana, June 26-29*. Available: 10.18260/p.25842.
- [6] D. Raviv, Y. K. Nakagawa, and G. Roskovich (2014, June), "A Visual and Engaging Approach to Learning Computer Algorithms" in *paper presented at 2014 ASEE Annual Conference & Exposition, Indianapolis, Indiana, June 15-18, 2014*. <https://peer.asee.org/20018>

- [7] B. Agerbeck, *The Graphic Facilitator's Guide: How to Use Your Listening, Thinking and Drawing Skills to Make Meaning*, Loosetooth.com Library, 2012.
- [8] G. Reynolds, *Presentation Zen: Simple Ideas on Presentation Design and Delivery*, 2nd ed. San Francisco, CA: New Riders, 2011.
- [9] P. Mollica, J. Murphy, J. Stoddard, J. Murphy, and D. Glover (2017). *Artist Toolbox: Color: A practical guide to color and its uses in art*. Lake Forest, CA: Walter Foster Publishing, The Quantro Group, 2017.
- [10] B. Peterson, B., *Learning to See Creatively: Design, Color, and Composition in Photography*, 3rd ed. Amphotoj Books, 2015.
- [11] G. Kohli, D. Veal, S. Maj, and G. Murphy, "The Integration Of State Diagrams With Competency Based Assessment," in *paper presented at 2005 Annual Conference, Portland, Oregon, June 12-15, 2005*. <https://peer.asee.org/14394>.
- [12] V. Chandra, (2012). QepCafe. Available: <https://sites.google.com/site/qepcafe>. [Accessed February 1, 2019].
- [13] Anderson, M. L. (2012). *The Quality Instinct: Seeing Art Through a Museum Director's Eye*. Washington, DC: The AAM Press of the American Association of Museums, 2012.