Assessment of Discrete Concept Knowledge, Integrated Understanding, and Creative Problem Solving in Introductory Networking Courses

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Abstract

Traditionally, the instructional approach to introductory courses in networking and networking technologies has been to start with an explanation of each of the layers in either the Open Systems Interconnection (OSI) and/or TCP/IP models and then to discuss the various technologies assigned to each layer. It is only after completion of these concepts that networks are discussed with respect to their purpose and the technologies and applications that they employ to deliver services and/or content. Heavy in jargon and acronyms, the nature of this instruction is often foreign to students. As such, teaching the many concepts contained within these layered models without contextual understanding frequently creates a disconnection early in the course and, in some cases, alienates students as they struggle to comprehend the plethora of acronyms within this jargon-rich environment. This disconnection can lead to student disengagement, making it more difficult for them to successfully construct the critical knowledge of the course. In this study, the authors compared offerings of a course in networking technologies using two different methodologies. For two semesters the course was delivered traditionally by first defining the models and then digging into the technologies of each layer before presenting the various networks, their function, operation and application. In the third semester the approach was flipped to first present the networks, thus providing context for the layers and the many technologies contained within them. Student performance is compared, with respect to discrete concept knowledge (network model layers) and integrated understanding (network topology and application) and proficiency in applying these concepts to creatively solve problems and develop solutions. This study indicated that a context based, top down approach improved student understanding of networks, network topologies and networking technologies.

Introduction

Current estimates for retention in engineering and engineering technology are approximately 60%. Even with these numbers being comparable with other majors, retaining engineering students, especially those who will increase the diversity of the discipline, should still be a priority. Previous research has found that students who leave engineering are not doing so because they do not have the necessary skills for success, but because they found the undergraduate experience in engineering to be unsatisfactory [1]. A contributing factor to their dissatisfaction was found to be the manner in which engineering courses were taught. The fact that well-qualified students are leaving engineering has raised concern, and the need for change in engineering education, to retain more students and to better prepare them to face today’s engineering challenges, has been well documented [2-5]. In acknowledgement of the need for change in the traditional methods of teaching engineering, calls for reform have been made by the National Academy of Engineering [4], the American Society of Engineering Education [5] and the National Science Foundation [6]. Each of these organizations has recognized that the traditional practice of educating engineers is failing its students. As put forth by Felder [7]:
Chronic industry complaints about skill deficiencies in engineering graduates, high attrition rates of engineering students with good academic performance records, the worldwide adoption of outcomes-based engineering program accreditation, and findings from both cognitive science and thousands of educational research studies showing serious deficiencies in traditional teaching methods have all provoked calls for changes in how engineering curricula are structured, delivered, and assessed [7].

Despite the many calls for reform, recent qualitative studies of engineering education have revealed that engineering teaching methods have changed very little over the last 30 years [8-10].

Asking engineering educators to change their teaching is no small task. Teaching beliefs have been proven to be well established and resistant to change [10-12]. Additionally, engineering educators have solid engineering identities [13,14] that strengthen their belief that the practice of preparing engineers is working. Finally, many engineering professors see themselves as gatekeepers to the profession [15,16] and in this role they have the ability to determine whom they feel has what it takes to succeed [17,18]. As such, they believe students who are meant to be engineers should just adjust to the teaching methods long associated with engineering and engineering technology and there is no reason to adjust their pedagogical methods. Some engineering educators have even expressed a belief that changing teaching methodologies to increase student attrition would result in a sacrifice of academic standards [19].

Some engineering instructors are willing to consider change, but the authors’ colleagues, positivistic by nature, wanted quantitative evidence that changing the instructional approach can lead to increased student engagement and success in a class. Their skepticism was the impetus for this study which compares student achievement in a networking technology course taught two different ways. Traditionally, the instructional approach to introductory courses in networking and networking technologies has been to start with an explanation each of the layers in either the Open Systems Interconnection (OSI) and/or TCP/IP models and then to discuss the various technologies assigned to each layer. It is only after completion of these concepts that networks are discussed with respect to their purpose and the technologies and applications that they employ to deliver services and/or content. Heavy in jargon and acronyms, the nature of this instruction is often foreign to students. In an effort to improve the student experience in the class, a new approach was taken in which the course was taught with a top down approach. By presenting the networks first, context was provided for the layers and the many technologies contained within them. This study was guided by the following research question:

*Will student success, as measured by test performance, in a networking technology course taught using a top-down approach be higher than in a course taught using a traditional bottom-up approach?*

**Bottom-up approach to learning**

Engineering education has always been based on a “fundamentals first” philosophy. The idea that engineering material cannot be presented until the foundational material is mastered is the model by which many engineering classes are structured. For example, circuits classes begin with an in-depth description of components before moving on to the analysis of small circuits that are often just academic, with no stated function. In digital logic courses, students first learn all of the logic gates and then learn the Boolean algebra reduction techniques (something they
will never use in industry) before they ever put the gates together to form a meaningful digital circuit. For the instructor, this approach makes perfect sense because they know the applications of the foundational material. Engineering professors studied engineering and often worked as engineers in industry, so the practical applications of these lowest level components are second nature to them. Students, however, cannot see the connection between the tedious tasks of analyzing circuits and the application of these circuits in their iPhone™. They are left wondering “why am I learning this?”

The method of presenting students with the low-level facts and expecting them to make logical sense within a single course presents the problems of students learning without connection to something they already know. Reducing the subject matter down to its lowest level was identified by Dewey [21] as an evil of the curriculum. He elucidated that the problem with this is “The subject-matter is evacuated of its logical value, and, though it is what it is only from the logical standpoint, is presented as stuff only for ‘memory’” [21]. Aside from lack of motivation to learn purely fact-based knowledge [22], this method of teaching robs students of the opportunity to construct their own understanding of the material [23].

With the purpose of undergraduate engineering education to produce graduates “ready to enter critical technical fields that are leading the way in innovation, emerging technologies, and anticipating the welfare and safety needs of the public” [24], it is the role of engineering educators to provide an experience that will enable students to become specialists in the field. While chances are they won’t be experts upon graduation, the skills they develop while in college should provide the foundation to become experts once they are practicing engineers. The teaching of engineering from the bottom up, however, works against the development of students’ expertise. One of the six principles of expert knowledge identified by Bransford, et al. [20] is that “expert’s knowledge is not simply a list of facts and formulas that are relevant to their domain; instead their knowledge is organized around core concepts or ‘big ideas’ that guide their thinking about their domain” [20]. Without introducing students to the big ideas or the end applications, they cannot see where the underlying facts fit in. As content area experts, engineering professors understand the big picture, but student novices do not. One of the many drawbacks to learning a topic area starting at the level of facts and formulas is seen in the manner in which students approach problem solving. At the lowest levels, each problem can be solved with a unique formula and students get comfortable using a specific equation to solve each different type of problem. As students are expected to apply that same knowledge at a higher level of abstraction they fail to consider the system as a whole and instead look for the correct formulas that served them well at the lower levels [25]. Approaching problem solving in this manner stands in the way of system level understanding.

From lack of motivation for learning to inability to construct the whole from the sum of its parts, “ fundamentals first” or bottom up learning is problematic for many engineering students. However, as it is the way engineering has traditionally been taught, many engineering professors hold tight to the approach believing students need to know the fundamentals before they can understand engineering applications. After all, engineering instructors are the ones who were successful in spite of teaching methods and, as such, believe they should teach using the approaches by which they were taught [5].
The networking technologies course

Computer Engineering Technology students take a course in networking technologies as part of their required curriculum and Electrical Engineering Technology students take it as part of an elective sequence in a telecommunications engineering technology option. This course covers many network architectures from CATV to residential, business fiber access and wide area networks (WANs). Many of these students have little or no experience with this topic area nor telecommunications in general. They do have the facility when solving equations based on placing the appropriate values into the proper formula. They also have knowledge of board level design as well as function and operation regarding embedded systems. One of the goals of this course is to educate these students with regard to how these embedded systems communicate via transmission lines, transmission formats, switches and routers using protocols that are specific to the topology and application of the networks required. While this course has a significant amount of content related to formulaic problem solving, it also requires analysis that is not formula nor equation driven. The introduction of network models and various networks is often new to these students and a bottom up approach has been the de facto teaching method.

In the bottom up approach the individual layers, described below, are taught first and with respect to the technologies associated with them.

- **Layer 1:** This is physical layer responsible for carrying the electrical, radio frequency or optical energy. It is here that where attenuation, modulation and synchronization, for example, are covered.
- **Layer 2:** This layer is responsible for controlling access to the media, creating frames and controlling errors, for example.
- **Layer 3:** This is the network layer where routing and switching is performed employing signaling and decision making protocols. It is here that quality of service parameters may be set to assure customer service levels.
- **Layer 4:** In this layer end-to-end flow control and overall service quality are maintained.
- **Layer 5 through 7** are often viewed as a single layer, Layer 5, and deal with session control, presentation of the information and the application itself, which is the information being delivered from one point in the network to another or to multiple points to several networks.

Layers 1 and 5 have the greatest numbers of technologies within them. The industry has settled on a core technologies in the middle 3 layers based on Ethernet and Internet Protocol version 4.

Within the 5 layers, there are as many technologies and knowing each one can be a process of memorization. In the traditional (bottom up) teaching of the class, the technologies within each layer were presented first and students merely memorized the formulas associated with each one. Students demonstrated a reasonable amount of proficiency in solving discrete problems in which they were asked to enter values into equations and calculate the results. Student performance and problem solving ability were seen to diminish, however, once the specific networks were introduced in the class. At this point students needed to associate the application of various technologies at each layer to their function within specific networks. Although students knew the
technologies well, they were not able to fluently connect the technologies to the network employing these technologies. The result was that often students did not select the appropriate technology to be employed at a specific layer for the network being considered.

It was for this reason that it was decided to provide context and perspective to the topic by introducing the many types of networks in use today before introducing the underlying technologies. The networks introduced included residential, enterprise and service provider networks all which can be implemented with a combination of wired and wireless technologies. Each network has a specific sets of requirements based on coverage area, distance, security and mixed service level agreements for their users. The hypothesis was that once a student understood network requirements, he or she will then have the perspective, provided by context, to determine the specific technology or technologies which must be implemented. This determination is essential for any successful network design.

The intent of switching to a top down approach was to provide an opportunity for students to appreciate and get excited about the big picture or “end game” first. This “end game” is to create topologies which employ the appropriate technologies to deliver content to residential and business consumers. It was hypothesized that once the needs were understood, students would be more invested in learning the details of every part of the network and the technologies of each layer of the network model. These details are the technologies of the network model which apply specifically and most appropriately to the topology required for the function of the network.

Methodology

This quantitative research study utilized quiz data obtained by means of a convenience sample from three successive offerings of the networking technologies course. The same questions were given to each group. The first two offerings, fall 2015 and 2016, utilized the bottom-up teaching method. Student data from these two offerings were used as the control group. Student data for the treatment group was obtained during the third offering, fall 2017, which was taught using the top-down teaching method.

To examine for differences between the top-down treatment/test group and bottom-up control group, both descriptive statistics and independent samples $t$-tests were performed on each of the two depended variables: Model, which assessed students’ understanding of “Network Model Layer Concepts” and Topology which evaluated their understanding of “Network Architectures and Topology”.

Discussion/Findings

The students in the groups studied are a combination of Computer Engineering Technology (CpET) and Electrical Engineering Technology (EET) students. The majority are CpET students as this course is a program requirement in that curriculum. It is an elective for those in the EET program. At the point in their respective curricula when students take this course, the first semester of the third year, their academic preparation is nearly identical. It is for this reason we feel there was no need to compare student performance with respect to their educational
experience. Students in both groups were in good academic standing at the time they took the course.

Below is the analysis based on in-class quizzes. Written questions were given to the students requiring each to supply written answers to these same questions. Tables 1 and 2 refer to the performance related to the OSI and TCP/IP network model concepts. Tables 3 and 4 refer to performance related to Network Architectures and Topology.

**Model:** For the question on the *Network Layers Model Concepts*, there were 36 students in the test group and 45 students in the control group. The independent-sample *t*-test revealed a statistically significant difference between the two groups (*t*(79) =3.442, *p* < 0.05). The top-down treatment group (M=95.21, SD=6.49) had a mean score nearly seven (7) points higher (M=6.92, SE=2.01) than the bottom-up control group (M=88.29, SD=10.56). This indicates that the top-down approach resulted in increased learning and less variability in the performance within this group. This set of questioning tested discrete concept knowledge as each layer is an independent element to be considered in network design.

**Table 1. Group Statistics – Dependent Variable: Model**

<table>
<thead>
<tr>
<th>Teaching-Technique</th>
<th>N</th>
<th>Mean</th>
<th>Std. Deviation</th>
<th>Std. Error Mean</th>
</tr>
</thead>
<tbody>
<tr>
<td>Top-Down</td>
<td>36</td>
<td>95.206</td>
<td>6.488</td>
<td>1.081</td>
</tr>
<tr>
<td>Bottom-Up</td>
<td>45</td>
<td>88.289</td>
<td>10.559</td>
<td>1.574</td>
</tr>
</tbody>
</table>

**Table 2. Independent Samples Test – Dependent Variable: Model**

<table>
<thead>
<tr>
<th>Model</th>
<th>F</th>
<th>Sig.</th>
<th><em>t</em></th>
<th>df</th>
<th>Sig. (2-tailed)</th>
<th>Mean Difference</th>
<th>Std. Error Difference</th>
<th>95% Confidence Interval of the Difference</th>
</tr>
</thead>
<tbody>
<tr>
<td>Equal Variances Assumed</td>
<td>5.736</td>
<td>.019</td>
<td>3.442</td>
<td>79.000</td>
<td>.001</td>
<td>6.917</td>
<td>2.009</td>
<td>2.917 to 10.916</td>
</tr>
<tr>
<td>Equal Variances Not Assumed</td>
<td>3.622</td>
<td>.001</td>
<td>74.478</td>
<td>.001</td>
<td>6.917</td>
<td>1.909</td>
<td>3.112</td>
<td>4.321 to 10.721</td>
</tr>
</tbody>
</table>

**Topology:** For the question on the *Network Architectures and Topology*, there were 30 students in the test group and 46 students in the control group. The independent-sample *t*-test revealed a statistically significant difference between the two groups (*t*(74) =4.25, *p* < 0.05). Table 3 shows the top-down treatment group (M=84.03, SD=11.48) had a mean score fifteen (15) points higher (M=15.58, SE=3.67) than the bottom-up control group (M=68.46, SD=17.81). This set of questioning tested integrated understanding and proficiency in applying these concepts to creatively solve problems and develop solutions by drawing network topologies to support various applications. The data indicates that the top-down approach resulted in increased learning and less variability in the performance within this group.
Table 3. Group Statistics – Dependent Variable: Topology

<table>
<thead>
<tr>
<th>Teaching-Technique</th>
<th>N</th>
<th>Mean</th>
<th>Std. Deviation</th>
<th>Std. Error Mean</th>
</tr>
</thead>
<tbody>
<tr>
<td>Top-Down</td>
<td>30</td>
<td>84.033</td>
<td>11.482</td>
<td>2.096</td>
</tr>
<tr>
<td>Bottom-Up</td>
<td>46</td>
<td>68.457</td>
<td>17.810</td>
<td>2.626</td>
</tr>
</tbody>
</table>

Table 4. Independent Samples Test – Dependent Variable: Topology

<table>
<thead>
<tr>
<th></th>
<th>F</th>
<th>Sig.</th>
<th>t</th>
<th>df</th>
<th>Sig. (2-tailed)</th>
<th>Mean Difference</th>
<th>Std. Error Difference</th>
<th>95% Confidence Interval of the Difference</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Levene's Test for Equality of Variances</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Topology</td>
<td>3.681</td>
<td>.059</td>
<td>4.245</td>
<td>74.000</td>
<td>.000</td>
<td>15.577</td>
<td>3.670</td>
<td>8.264 to 22.889</td>
</tr>
<tr>
<td>Equal Variances Assumed</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>4.636</td>
<td>.000</td>
<td>73.998</td>
<td>73.998</td>
<td>.000</td>
<td>15.577</td>
<td>3.360</td>
<td>8.882 to 22.272</td>
</tr>
<tr>
<td>Equal Variances Not Assumed</td>
<td></td>
<td></td>
<td></td>
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</tbody>
</table>

Using a bottom-up approach, the instruction first covers jargon and discrete concepts that are initially foreign to students. The challenge is to impress upon them the importance of these technologies and the specific elements that make each unique and necessary for network function. Students simply tried to memorize the concepts without knowing their meaning and could not apply this knowledge at a higher level of abstraction, namely being able to draw appropriate network topologies to support applications [25]. The data shows clearly that this approach is significantly less effective than first covering network applications and supporting topologies. This fundamentals first approach, as discussed in the “Bottom up approach to learning” section of this paper, led to a disconnection and lack of context among students. The students in the test group, received a top-down, context based instructional experience and exhibited deeper knowledge and a superior ability to apply this knowledge to network design [21].

Implications/Conclusion

This study compared two student groups. The control group was not provided the context nor perspective with regard to network applications and their impact on network topologies and architectures before exposure to the technologies of the network model. The test group studied the impact of applications and how these inform appropriate network topologies and architectures before delving into the specific technologies of the network model. The test group exhibited significantly higher mean scores in both MODEL (+6.92) and TOPOLOGY (+15.58). We also see a wider standard deviation for the control group for both MODEL and TOPOLOGY indicating greater variability of test scores within that group. This indicates that the understanding within this group varied more that in the test group. The conclusion here is that the control group, as a whole, did not grasp the concepts as well as the test group.
The data is consistent with the research which suggests that context based learning is more effective than the traditionally approach to engineering education which places importance on a fundamentals first approach. It is clear from this data that a top-down context based instructional method is a more effective way to approach instruction with regard to data communications networking and networking technologies.

References


