Representing Patterns of Learning as a Function of Course Opportunities

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ABSTRACT

Expanded articulation of demonstrable competencies and a burgeoning demand for security analysts increasingly responsive to rapidly evolving conditions have brought to foreground a need to revamp core curriculum in the area. Once such effort has emerged at one university where a faculty member in computer engineering technology, network communications, and computer science has developed a novel pedagogical strategy that teaches network security through protocol behavior and trust point observations. This paper used a single course case study to explore the engagement patterns of learning associated with this novel curricular approach to learning secure design of networks. This exploratory study's findings lay important foundation for understanding the ways in which students are making use of multiple forms of experiential engagement. While homework exercises, perhaps conceptually the most traditional form of engagement, were accessed largely at a one opportunity per student count, practices and much more importantly labs were used in much more frequent ways. In particular, labs display a positive engagement patten in that they demonstrate students' choices to access early and in a sustained variety of topics. Importantly, these opportunities are active in their mechanism for learning, which connects with a strategy previous empirical literature has positively reinforced.

KEYWORDS

Interactive Learning, Computer Science Education, Scaffolded Learning, Computer Networks

1 INTRODUCTION

Expanded articulation of demonstrable competencies and a burgeoning demand for security analysts who are increasingly responsive to rapidly evolving conditions have brought to foreground a need to revamp core curriculum in the area. Specifically, federal and agency guidelines prompt instructors to consider differently their approach to cybersecurity education in order to better prepare graduates [4, 10, 13, 15, 16].

Once such effort has emerged at the University of Houston where a faculty member in computer engineering technology, network communications, and computer science has developed a novel pedagogical strategy that teaches network security through protocol behavior and trust point observations [9]. Specifically, this undergraduate class is designed to introduce the concept of trust protocol points and guiding principles through a scaffolded set of learning opportunities available to students in a semi-autonomous opportunity to learn. The course combines lectures, hands-on labs, homework, auto-graded practices, exams, and a final project to allow multiple opportunities for students to master material (see [9] for full description).

This paper uses a single course case study to explore the engagement patterns of learning associated with this novel curricular approach to learning secure design of networks. Specifically, the study seeks to answer the following research questions: What patterns of learning engagement do students demonstrate? What pedagogical tools associate with these patterns?

2 THE ROLE OF EXPERIENTIAL LEARNING OPPORTUNITIES

Abundant literature documents the definitions and benefits of experiential learning in knowledge development [3, 8, 11, 14, 17]. As a generic representation, Table 1 presents a scale of learning typologies. As it indicates, learning experiences move from more concrete to abstract where experiences also vary from more active to ones where students function largely as receivers of information. As Bersteinger et al. summarize, "primary learning essentially occurs through active/concrete doing, whereas secondary learning occurs when a passive receiver interprets abstract information communicated by another through spoken words, written text, graphic images or gestures" [2, p. 37].

Table 1. Generic Scale of learning typologies [13].

Concrete/Active		Abstract/Passive	
Student as actor		Student as receiver	
Do an activity	Watch an activity	Hear about an activity	Read about an activity

In a related literature, research has identified the utility of teaching and learning through multiple strategies toward student learning. In his seminal work, Howard Gardner [7] posited a theory of multiple intelligences where learners differ in their capacity and preference for different forms of information processing based on the kinds of intelligence they demonstrate. Taken together, these bodies of research suggest the need for varied learning opportunities where at least part of those experiences ground in experiential learning.

2.1 Conceptual frames guiding engagement through experiences

Complex Adaptive Systems Theory (CAS) guides this study's understanding of engagement patterns and the instructional tools that associate with them (Figure 1). First, CAS suggests that knowledge develops through novel encounters with information and other opportunities to ultimately formulate a set of rules to guide understanding. Key to this process is the role of feedback where knowledge developers have opportunity to adapt their

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understanding based on attempts and useful response to those attempts. At its core, CAS assumes the presence of an organizational structure that shapes and is shaped by knowledge formation. In the case of this study, the classroom itself serves as the “human organization” where the students are encouraged to “innovate by producing spontaneous, systemic bouts of novelty out of which new patterns of behavior emerge. Patterns which enhance a system's ability to adapt successfully to its environment are stabilized and repeated; those that do not are rejected in favor of radically new ones, almost as if a cosmic game of trial-and-error were being played. Complexity is, therefore, in part, the study of pervasive innovation in the universe” [12, p. 196].

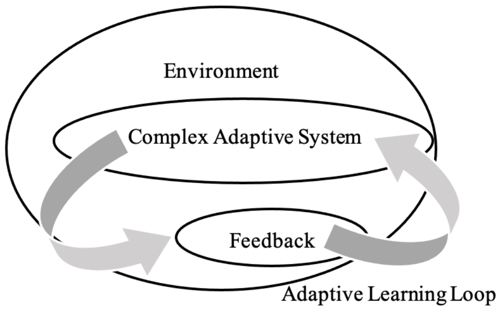

Figure 1. Complex Adaptive System (CAS) Model [16].

At the individual level, then, learning “is a process of emergence and co-evolution of the individual, the social group, and the wider society. Emphasis is placed on the relationship between elements, rather than the elements themselves” [12]. Through this frame, then, the current study seeks, then, to understand how engagement represents an evolution of novel to more sophisticated encounters with new information.

3 DATA AND METHODS

3.1 Participants and Learning Experiences

Data for this study were drawn from 58 students taking a 16-week undergraduate introduction to networking course offered in Fall 2020. Students completed 9 homework exercises throughout the duration of the course and received a full completion grade for any complete first attempt (regardless of correctness of answers). Because the purpose of the assignment was to serve as a developmental opportunity for learners to assess their understanding and work toward mastery in a low-stakes format, they were also provided feedback on the accuracy of each of their responses. Subsequently, students were permitted to return to any items they answered incorrectly and attempt them again (with new randomly generated data). The primary goal of the homework–in format and in function–was to provide an opportunity to strengthen their capacity to do well on the laboratory assignments, exam, and ultimately the assigned project.

Students also engaged in labs and practice over the course of the study. Labs, which are not graded, are opportunities intended to aid in homework submission. A lab manual web page provides detailed instructions and provide another opportunity through a different format to continue to engage in work toward mastery of a set of discrete but scaffolded concepts leading toward a comprehensive understanding of network security. Finally, practice opportunities are directly linked to discrete learning outcomes assessed in the homework and provide yet another space and structure for students to grapple with what they understand and what remains unclear with respect to specific competencies they are expected to develop.

Data for this study derive from the usage patterns for each of these opportunities, including assignment and date accessed.

3.2 Analytical Approach

This study descriptively represents patterns of engagement. Specifically, it aggregates the number of times a particular learning opportunity was accessed in total and by month. For labs and practices, Chi Square statistics were calculated to assess differences in distribution by opportunity and by month.

4 FINDINGS

Findings are organized around key aspects of the course: homework; labs; and practice opportunities.

4.1 Homework Exercises

Homework exercises were accessed a total of 534 times throughout the semester (M=59, SD=8.16). Figure 2 presents the distribution of engagement counts by homework exercise topic.

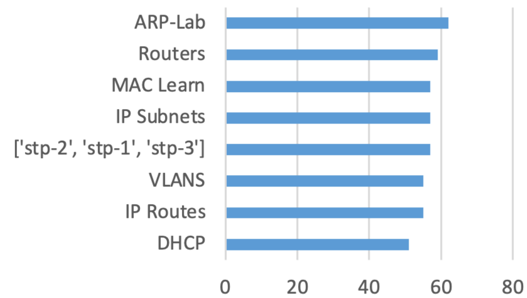

Figure 2. Fall 2020 ELET 4421 Exercises - Engagement Counts.

As can be seen, most exercises were accessed a similar number of times (on average, approximately 1 time per student in the class). In seeking to understand the extent to which students engaged and reengaged with homework exercises over time, Figure 3 in presents counts by week.

Two important observations are noted. First, not surprisingly, students engaged in most substantial numbers nearest the time when the exercise was on the syllabus related to topic of discussion. That said, for most exercises, distribution of access occurred over at least a 2- and sometimes a 3-week period. This is an important observation in that it suggests a fluidity of engagement among students with respect to learning opportunities. Second, as evidenced by the inclusion of “redisplaying current exercise module,” execution of that command occurred more often during the initial weeks of the class. The gradual decline in redisplay suggests that as they learned to navigate the system, the need for re-execution waned.

4.2 Labs

Patterns of engagement in lab opportunities, in contrast to homework exercises, identified that this learning strategy was far more accessed overall and varied in relationship to particular units. Overall, labs were accessed 1881 times, an average of 32.4 times per student in the class. The mean number of times accessed per lab unit was 125 (SD=111.41). The next several subsections (4.2.1-4.2.4) briefly describe key labs before the paper turns to findings.

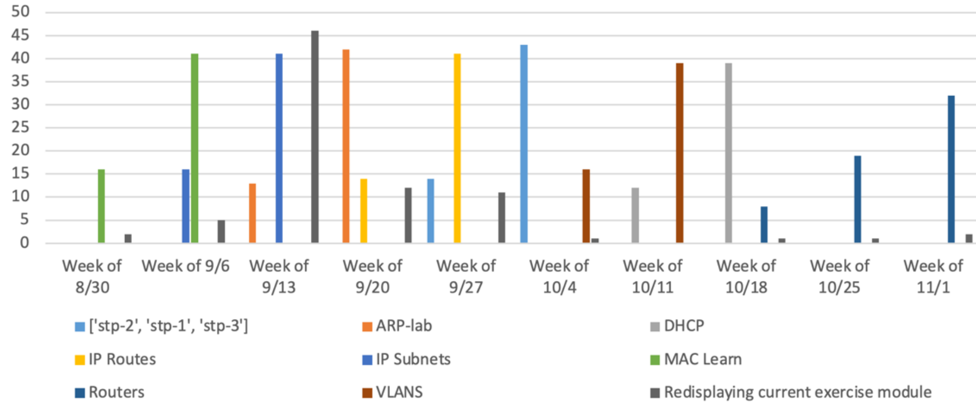

Figure 3. Exercise Engagement Counts by Week.

4.2.1Layer 2: Ethernet Lab

Broadcast domain concepts, layer 2 forwarding and MAC address learning functionality in Ethernet networks is covered through the four lab modules: Ethernet bridge MAC learning, ARP, VLANs and a host connected to a bridge (Figure 4). The observations are composed of sending and monitoring of packets on host interfaces, examination of bridge layer 2 tables, and bridge port configurations. Students are able to conduct experiments on network topologies that in turn allow them to verify the knowledge they are gaining while also new experiences are provided in network state observations, troubleshooting, and analysis of network topologies and protocols through packet traces and protocol behavior.

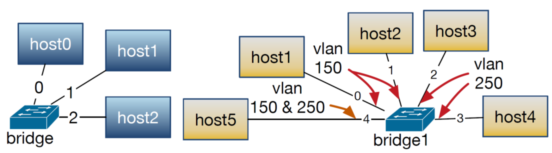

Figure 4. Ethernet bridges provide layer 2 connectivity and when port VLANs are configured, layer 2 isolation. The representative topologies that are used in the lab modules are included here.

4.2.2 IP Subnetting and Routing, Address Resolution Protocol

IP subnet assignment and bit math are introduced with example topologies and exercises that emphasize the calculations of IP subnets and host addresses within a subnet (Figure 5).

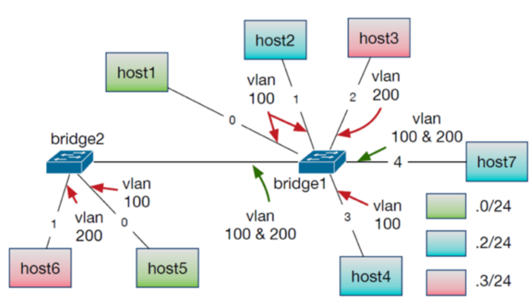

Figure 5. IP subnets are assigned inside two broadcast domains to hosts that are also isolated in the layer 2 broadcast domain.

Routing is introduced in representative topologies illustrated in the Figure 6 with router devices that forward between subnets as well as subnet addresses assigned to hosts with route tables that reflect the network state and configuration for reachability.

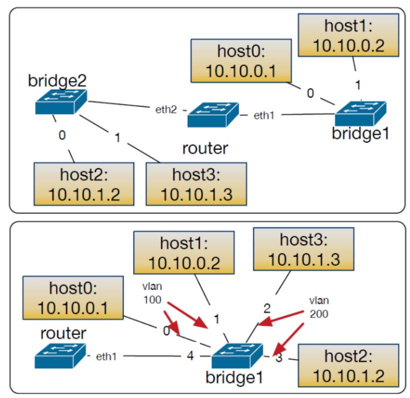

Figure 6. Routing and routers are utilized in the lab modules that cover ARP, IP routing, and route tables.

4.2.3 DNS and DHCP

Typical services that run in a network are DHCP and DNS. The services are included in the representative topologies shown in Figure 7.

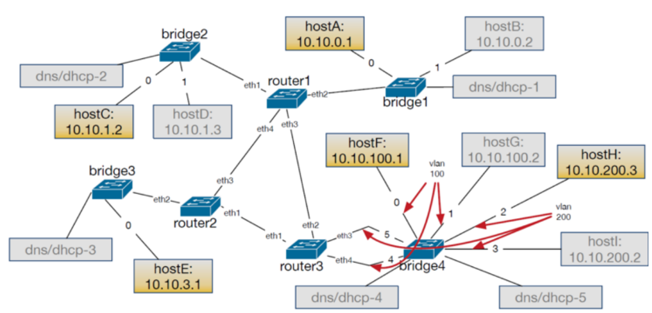

Figure 7. A number of subnets along with naming services are instantiated in network topologies.

The host interfaces are configured using the services in the network. Sample name resolutions are achieved to gain experience and firsthand understanding of the function and innerworkings of DNS protocol in the network.

4.2.4 Projects: Network Troubleshooting

The course final activity is culminating project where critical thinking is required to complete. Students are presented with networks that have misconfigurations. They are asked then to test reachability to identify the misconfigurations in the network devices and end hosts (See Figure 8). In the process, they are required to use the lab investigation methods they learned throughout the semester during the lab activities. They apply their knowledge of how network devices behave and what protocol observations they need to make to identify the misconfigurations. The students are also provided with the vendor-agnostic methods to correct the misconfigurations on their individual networks. The second phase of the project activity requires that the misconfigurations are corrected and full reachability is achieved in the submission phase.

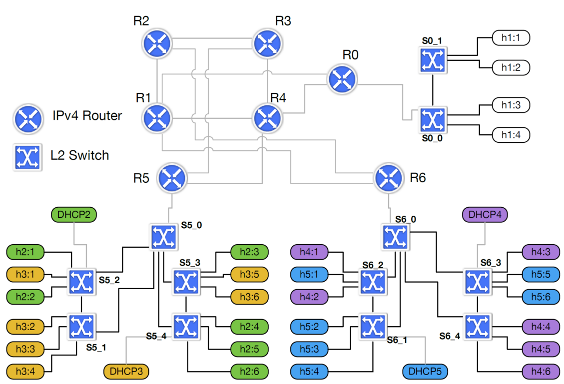

Figure 8. A topology that is pre-configured with typical misconfigurations is provided during the lab in order to teach network troubleshooting skills and reflect on the learnings in the previous labs.

4.2.5 Engagement Data

As reinforced in Figure 9, lab engagement ranged from 10 (STP Typology C) to 474 access records (Mismatch Typology Found; not displayed in Figure but happens when a student has forgotten to delete their existing topology from a previous lab and tries to build the next lab). The majority of labs were accessed between 72 and 141 times (an average of 1.24 and 2.43 times per student).

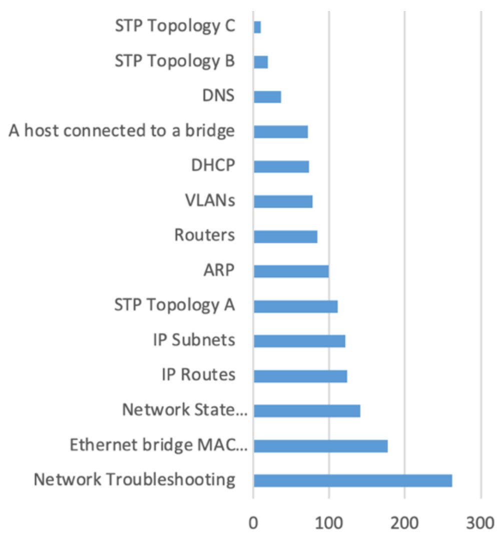

Figure 9. Fall 2020 ELET 4421 Labs – Engagement Counts.

When again considering patterns of engagement over time, Figure 10 identifies students engaged almost half (7 of 15) of the labs in the first month of the semester.

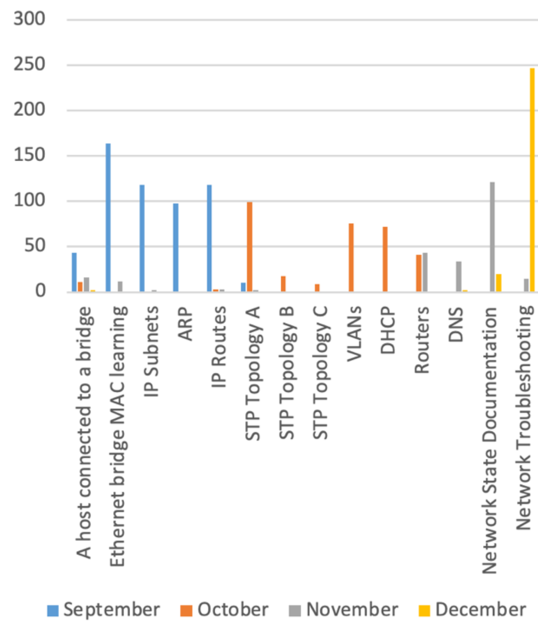

Figure 10. Fall 2020 ELET Labs – Engagement Counts by Month

Similarly, 8 of the labs were accessed in October. Students engaged with fewer labs (6) in October, and only 3 labs were accessed in December. This difference in total access counts across months is statistically significant ($\chi^2(3) = 650.36$, $p < .001$) as is the difference across months by specific lab ($\chi^2(42) = 3227.72$, $p < .001$).

4.3 Practice

Practice opportunities were engaged 949 times throughout the course of the semester with an average count of 38 encounters per discrete practice (SD=12.13). Similar to homework exercises, most practice opportunities, looking across the broader topical areas, were accessed between 98 and 121 times (between 1.69 and 2.09 times per student). Figure 11 presents the distribution across aggregated topical areas, indicating Loading ARP Practice as most accessed (189 times).

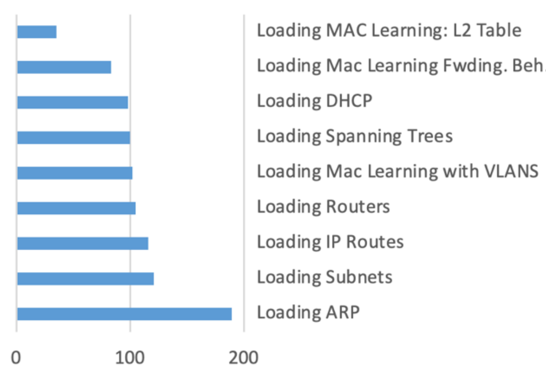

Figure 11. Fall 2020 ELET 4421 Practice Counts Aggregated by Major Topic Area.

Figure 12 presents access counts by month and identifies that all practice areas were exclusively or almost entirely accessed in November. Students are able to practice as soon as they submit a homework, which makes this finding especially important.

While practice on a topic becomes available immediately after homework is submitted, during the week leading up to the exam (in mid-November), all the items are made available. As such, it is important to understand weekly access patterns for practice during the concentrated month of engagement. Figure 8 displays counts, by week, for the month of November.

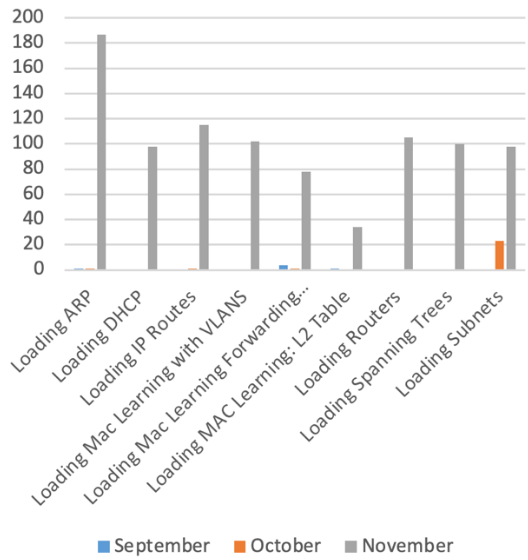

Figure 12. Practice Aggregated by Major Heading and by Month.

As can be seen, all the practice opportunities were accessed predominantly within a single week (week of November 7). Similarly, a majority are being visited or revisited (but at a lower count relative to the week of November 7) during the week of October 31.

5 DISCUSSION, IMPLICATIONS FOR PRACTICE, AND FUTURE RESEARCH

5.1 Discussion and Limitations

This exploratory study's findings lay important foundation for understanding the ways in which students are making use of multiple forms of experiential engagement. While homework exercises, perhaps conceptually the most traditional form of engagement are accessed largely at a one opportunity per student count, practices and much more importantly labs are used in much more frequent ways. In particular, labs display a positive engagement patten in that they demonstrate students' choices to access early and in a sustained a variety of topics. Importantly, these opportunities are active in their mechanism for learning, which connects with a strategy previous empirical research has positively reinforced.

The findings related to the ways students are engaging in practice is also an important one. In connection with the ways in which a complex adaptive system works, students are taking feedback (provided through original homework) to seek additional opportunities to refine understanding. Practices are equipped with an auto grader (correct/incorrect) that gives immediate feedback when utilized. However, the findings of this study suggest that rather than associating that extended learning more proximal to the original exposure, students are waiting until an externalized mechanism (i.e., the exam) prompts a need or desire for deeper understanding.

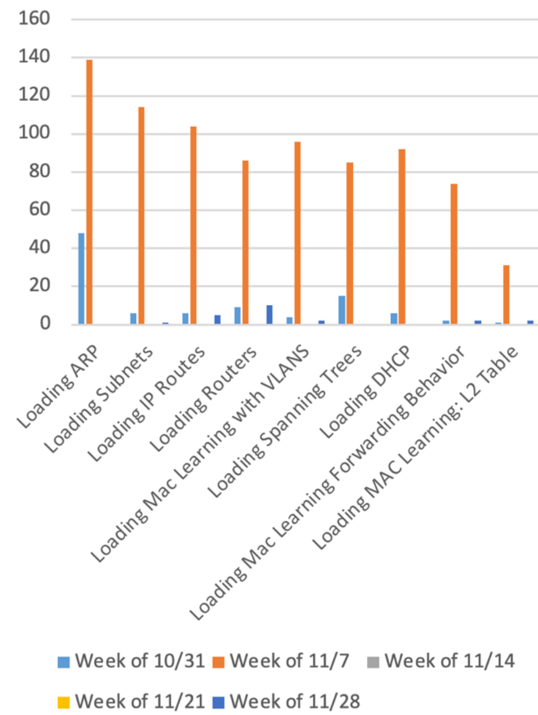

Figure 13. Practice Aggregated by Major Heading and by Week for Month of November prior to the Course Semester Exam.

In considering prior work [1, 5, 6] that underscore the importance of scaffolded learning opportunities tied closely (both in time and content) to initial exposure, this study suggests that more work may be needed to ensure that students are understanding subtopics/ concepts clearly and in a way that strengthens their overarching learning possibilities. While this study serves an important purpose, it is bound by several constraints. First, it looks only at a single course in a semester that was contextualized by COVID 19. That notwithstanding, it offers interesting insight into the ways in which students engage with a connected set of complementary learning opportunities.

5.2 Implications for Practice

This study positively reinforces the utility and importance of providing multiple pathways for students to learn content material. Building on the work of this instructor, findings identify that when made available, students will engage with different forms of curricular presentation and for at least some, will revisit those opportunities multiple times. Further, the findings suggest that opportunities that are low stakes (e.g., without serious grade consequences) may be especially important in allowing students the active space needed to master concepts.

5.3 Implications for Future Research

This study lays important foundation for future research in this area. Specifically, subsequent studies might usefully understand with finer grain individualized patterns of student use connected across course learning opportunities as well as the ways in which those usage patterns connect with various outcomes (e.g., grades, satisfaction, sense of agency).

6 CONCLUSION

Work continues to be needed to ensure that we are providing and understanding the utility of various learning opportunities toward the larger academic outcomes of interest. In the field of network security, the generation of highly skilled graduates able to engage the work effectively has never been more needed. This study reminds us that the pathway to a strong workforce begins with the classroom.

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