A Progress-Based Online Assessment System For First-Year Networking Classes

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Abstract - This paper presents a progress-based online assessment system, the Network Assessment Management System (NAMS), for first-year networking classes. The design of the system incorporates the Mastery Learning principles. It emphasizes personalized content delivery based on a student’s learning aptitude, course comprehension measurement, and learning progress rules. Students with different learning abilities can use it to master the same course subjects, while spending different amount of time studying these subjects. Instructors can use the system for pedagogy analysis and student performance evaluation. NAMS organizes course subjects to support bottom-up approach of teaching following the OSI network model. It is possible to modify it to support top-down approach of teaching. The implementation of the system employs the Learning Advancement Management System (LAMS) we introduced previously for supporting multiple progress-based e-learning systems with Web services. The development of the system provides insights for building progress-based online learning systems for technology education.

Index Terms – first-year networking, learning performance assessment, progress-based E-Learning, OSI network model

INTRODUCTION

Progress-based E-Learning systems deliver personalized course contents based on each student’s learning aptitude following the mastery learning principles [1, 2]. The pedagogy design of these systems involves learning aptitude assessment, course comprehension measurement, and learning progress rule activation. Our previous implementation of progress-based E-Learning systems mainly focuses on language learning courses [5, 6]. In this paper, we present a progress-based online assessment system, the Network Assessment Management System (NAMS), for first-year networking classes. The implementation of NAMS employs the Learning Advancement Management System (LAMS) for supporting multiple progress-based E-Learning systems with Web services [4].

Mastery learning is a system or method that requires learners to demonstrate attainment of specific objectives upon completion of a learning task. It emphasizes outcomes-mastering a subject or topic, usually at a minimum of the 70th percentile level and quite often at the 90th percentile level. It represents a method or system for using assessment as an effective learning tool. Mastery learning has received extensive study previously [12, 13, 14]. It is effective in a variety of learning situations from simple rote memory established purposefully to permit higher order learning to higher order learning itself [15]. Students in first-year networking classes need to memorize basic concepts, e.g., the protocol layers, acronyms, contents of protocol data unit (PDU) in various protocols. With solid knowledge of the basic concepts, students will be more effective in learning more challenging topics such as network analysis and design in classrooms. The NAMS is a scalable system that makes mastery learning available to students in first-year networking classes. It also provides a basis for applying and studying mastery learning in engineering education.

A course subject is a knowledge point in a course. A course typically constitutes a set of course subjects. A course with hierarchical subject structure organizes course subjects into a sequence of subject categories. Each subject category constitutes a part of the course, and contains a set of course subjects. Each subject is uniquely identified and belongs to at least one subject category. The sequential relationship among subject categories corresponds to a student’s learning sequence, and in turn, progress in the course. The ordering of the subject categories in a course is part of the course design as practiced in developing regular courses. In the NAMS, each assessment question is a subject. Each subject belongs to one of the subject categories such as OSI Network Model, TCP/IP Network Model, Signal Transmission, Ethernet Protocol, TCP/IP Protocol, Electronic Mail Protocols, etc.

A progress-based E-Learning system contains instruction material for each subject, and assessment tests on students’ comprehension of each subject. It tracks each student’s performance on assessment tests as the learning performance data. The system uses these data to deliver in real-time personalized course content that reflects each student’s learning progress.

Incorporating progress-based E-Learning pedagogies in the NAMS provides several unique features that are not available in existing E-Learning systems. First, the NAMS emphasizes full comprehension of course materials. It directly provides students opportunities to learn from failed assessment questions repetitively. Students not only know which subjects they failed, but can also use the NAMS to learn those subjects. Second, the NAMS enforces sequential order of learning
activities based on the course structure. Students must exhibit sufficient competency on current subjects before moving to new subjects. It provides a concrete learning order for students to follow, rather than letting students move randomly from one subject to another subject without having the pre-requisite knowledge of the new subject. Finally, the NAMS automatically preserves each student’s learning state for the long term. Students can have multiple study sessions, spanning multiple days or weeks, to complete their learning in the course. The NAMS automatically reconstructs the current learning state at the start of each new study session of a student. The preserved data also provides the basis for reporting and analyzing each student’s learning progress.

Our implementation of the NAMS employs the LAMS, a standalone system that manages learning performance data for progress-based E-Learning systems. It stores student learning performance data collected from E-Learning systems, and enables these systems to deliver progress-based personalized content. The LAMS provides Web services for integration with multiple E-Learning systems. Figure 1 shows the use of the LAMS with several E-Learning systems.

The NAMS targets students in first-year networking classes for after-class studies on topics taught in class by an instructor. To make after-class studies effective, students must closely follow the same learning sequence as in the classroom. They also need instant tutoring and knowledge reinforcement when they misunderstand course topics. Unfortunately, students usually cannot get adequate help from instructors in after-class studies. Instructors also need effective tools to measure and tutor after-class studies, especially for large classes. The NAMS is an ideal solution that enables students to conduct effective after-class studies, and allows instructors to measure them.

The rest of the paper contains four sections. Section 2 introduces progress-based E-Learning process. Section 3 presents pedagogy design. Section 4 describes content design. The final section discusses implementation and future work.

THE PROGRESS-BASED E-LEARNING PROCESS

The foundation for progress-based E-Learning systems is the digital representation of a student’s learning performance in a course. Our representation of a student’s learning performance in a course is mainly at the subject level. It includes the learned subjects, lost subjects, and the furthest studied subject category of a student. A subject is lost if the student has studied the subject but has not fully comprehended it (e.g., failed assessment test on it). A subject is learned if the student has fully comprehended it (e.g., passed assessment test on it).

A progress-based E-Learning system collects learning performance data while each student is studying the course subjects. The term lesson refers to one online study session of a student. In each lesson, a student will study some new or previously studied subjects and then take assessment tests on these subjects. The test results trigger updates of the student’s learning performance data. By tracking all lessons of a student in a course, the progress-based E-Learning system has complete knowledge of the student’s learning progress in the course. Using this knowledge, it delivers course content to the student based on the student’s learning velocity, knowledge retention patterns, and learning progress rules.

The information contained in a lesson includes a lesson identifier, a student identifier, its start time, last update time, and the current learning performance data in the lesson. Each new online session starts a new lesson. A student can only have one online session in a course at any time. The length in time of each lesson varies depending on the length of the online session it represents. When a new lesson starts, its learning performance data is the same as that in the most previous lesson. The learning performance data then changes with the student’s learning activities in the new lesson.

To capture student’s learning performance in each lesson accurately, a progress-based E-Learning system should frequently conduct assessment tests on new and previously learned subjects. The test results indicate if a subject is lost, a lost subject is relearned, or a new subject is learned. Each system may have unique strategies to conduct assessment tests and interpret the test results. Figure 2 illustrates a typical progress-based E-Learning process.

**FIGURE 2**

The NAMS presents each assessment question as a subject to the student. If the student enters a wrong answer to the question, the question is lost. The NAMS will present the
correct answer to the question before the student can navigate to the next question. It will test a lost question several times later, and will treat the lost question as relearned if the student passes the test each time. If the student enters the correct answer to a new question, the new question is learned. It will then present the next question to the student.

It is possible to use the concept of data cube in data warehouse technology to model the learning performance data of all students in a course. As illustrated in Figure 3, the dimensions of the data cube are students taking the course, student lessons, and subject categories with each member category containing subjects as its sub-members. The measure in each cell in the data cube is a Boolean value indicating a student’s comprehension state on a subject in a lesson. Not all cells contain meaningful measures since students may start a course at different times, and may take different number of lessons to complete a course.

The data cube provides a framework for analyzing learning performance data and measuring learning aptitude of a student. The learning velocity of a student is the number of new subjects studied in a unit of time. The knowledge retention measurement of a student may include the percentage of lost subjects in all studied subjects, subjects that are lost repetitively, and number of lessons or length of time before passing some subjects. The learning habit measurement of a student may include average time length of lesson, and data on peak/dip performance lessons. A peak performance lesson has big increase in new subjects and small increase in lost subjects. A dip performance lesson has small increase in new subjects and big increase in lost subjects. It is also possible to compare measurements of an individual student with the aggregated measurements of a group of students.

The NAMS allows students to view their own learning performance measurements. It also allows students to view details of their own lessons. Students can use these measurements to adjust their learning behavior for optimum performance. For the dimension of subject category, it allows drill-down or roll-up view of the data on subjects or on subject categories.

It should be noted that although we use data warehousing concepts to illustrate the representation and analysis of learning performance data, the actual processing of learning performance data is much more efficient than typical data warehouse applications. This is because the number of lessons a student has in a course is relatively small. Also, it is always possible to break a course with large number of subjects into several courses with smaller number of subjects. Thus, a progress-based E-Learning system can use student learning performance data in real-time to deliver personalized course content to each student.

**Progress-Based Pedagogy Design**

The NAMS uses a list of current study subjects to deliver assessment questions as course subjects to a student. It removes a question from the list if the student passes assessment tests on the question. It adds more questions to the list if its size drops below a threshold value. The NAMS uses learning progress rules to add questions to this list. The preconditions of a learning progress rule are data on student learning aptitude and course comprehension. The actions of a learning progress rule are subject selection actions. We first discuss course comprehension measurements that trigger learning progress rules.

Course comprehension measurements focus on a student’s overall knowledge of course subjects. A simple measurement for courses with hierarchical subject structures is the category comprehension ratio of a subject category, which is the percentage of learned subjects over all subjects in a subject category. A high comprehension ratio indicates good comprehension of the contents in a subject category. The course designer assigns each subject category in the course with a comprehension ratio threshold value. The appropriate threshold value for the subject category is dependent on the course outcome requirements. If a student’s comprehension ratio of a subject category rises above the threshold value, the student has learned content in the subject category well.

A variation of the category comprehension ratio measurement is the weighted category comprehension ratio measurement. It is suitable for courses whose subjects have different significance. The course designer assigns each subject a significance value as a numeric value indicating the significance of the subject in the category. Subjects with high significance values are more important for students to learn in the course. The weighted category comprehension ratio is the percentage of total significance values of learned subjects over that of all subjects in a subject category. It captures more accurately on students’ comprehension of important subjects in a subject category.

Subject selection actions in learning progress rules include actions for introducing new subjects and actions for bringing back studied subjects. On actions for introducing new subjects, the Category-Forward action always introduces a fixed amount (e.g., 3) of randomly picked new subjects in the furthest studied subject category. If the subject category does not contain enough new subjects, it gets new subjects from the next subject category. The Optimized Category-Forward action is similar but gets new subjects with the highest significance values, rather than randomly.

Actions for bringing back studied subjects include actions for repeated study of lost subject and actions for review of learned subjects. For actions that enhance study of lost subjects, the Category-Backward action always gets a fixed amount of randomly picked lost subjects within or closet to
the furthest studied subject category. Actions for reviewing learned subjects are similar to those that enhance study of lost subjects. The Category-Review action gets a fixed amount of randomly picked learned subjects, not lost subjects, within or closest to the furthest studied subject category. The optimized version of Category-Backward and Category-Review actions are similar but get lost and learned subjects with the highest significance values. When bringing back previously studied subjects (either learned or lost), it is preferable to start backward from the furthest studied subject category, not forward from the first subject category. This avoids re-introducing easy subjects learned at the beginning of the course, and makes the learning process easier as newly studied subjects are brought back first. However, it is also useful to have actions that extend regular or optimized Category-Backward and Category-Review actions to get subjects in all subject categories up to the furthest studied subject category. We call these Course-Backward and Course-Review actions as they get subjects from all subject categories from the first to the furthest studied.

The NAMS adds new, lost, and learned subjects to its list of current study subjects if the size of the list drops below 10. It uses the category comprehension ratio as course comprehension measurement. It uses Category-Forward action to add new questions, and stops introducing new questions when a category comprehension ratio is below 70% and all questions in the category are either learned or lost. It uses Category-Review action to select learned questions for review, and Category-Backward action to select lost questions for enhanced study. The NAMS implements and activates these learning progress rules directly in software programs.

A major part of progress-based E-Learning course pedagogy design is to identify learning progress rules for the course. The main objectives are to ensure the student comprehends course subjects well, and the pace of learning is compatible with the student’s learning aptitude. When there is no sufficient data on the student’s learning aptitude and course comprehension (e.g., start of a new course), the system simply uses a default rule whose action is to introduce several new subjects. The NAMS requires comprehension rate of each subject category to be at least 70% before a student can study subjects in new subject categories. It will repetitively present lost subjects in a subject category if the student’s comprehension rate of that subject category is below 70%. The student will spend more time studying the lost subjects, and ultimately bring up the comprehension rate. A possible risk of this strategy is that a student may terminate the learning session out of frustration with the repetitive presentation of the lost subjects. However, the student still needs to study those lost subjects in a new learning session started later.

The NAMS could add other learning progress rules in future releases. For example, it can support rules that allow students with strong learning aptitude and comprehension of course subjects to learn faster. One such rule is to add more new subjects, not review subjects, to the list of current study subjects if a student’s category comprehension ratios do not drop dramatically. The decision on the number of new subjects introduced is dependent on the length of the course and the average student learning velocity in the course. There are also rules that reinforce learning for students with unsteady knowledge retention patterns. One such rule selects more review subjects, with Course-Backward and Course-Review actions, if a student’s category comprehension ratios swing up and down.

### COURSE CONTENT DESIGN

The creation of course content involves identifying subject categories in the course, creating assessment questions in each subject category, and creating explanations for question answers. The approaches and processes are the same as in developing a regular first year networking class for classroom-based teaching and learning. We now describe some of our work in these areas.

Our general principal for selecting subject categories in NAMS follows the ACM Computer Engineering curricula [9]. The following is a list of course areas for computer networks (CE-NWK) in the curricula. The current release of the NAMS partially covers the core areas in this list. A future release will fully cover all the areas. The subject categories in the NAMS correspond to the detail topics in each of these areas listed in [9]. Table 1 shows the subject categories and their descriptions. The Seq field in the table represents the ordering of the subject categories in the NAMS. This ordering supports the bottom-up approach of teaching following the OSI network model [10]. The NAMS allows updating of Seq values for subject categories. It is possible to rearrange the ordering of subject categories in the NAMS to support the top-down approach of teaching following the OSI network model [11].

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<th>Content Description</th>
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<td>Network Basics</td>
<td>WAN, LAN, MAN, VPN, Intranet, Extranet, public and private networks</td>
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<tr>
<td>2</td>
<td>Network</td>
<td>Broadcast, point to point, connection-oriented, connection-less, duplex, half duplex, simplex</td>
</tr>
<tr>
<td>3</td>
<td>Bandwidth</td>
<td>Bandwidth and data size measurement, bandwidth calculation using B=S/T</td>
</tr>
<tr>
<td>4</td>
<td>OSI Network Model</td>
<td>Network layering, network protocols, PDU, encapsulation, 7-layer network functions</td>
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### Session S2H

The creation of course content involves identifying subject categories in the course, creating assessment questions in each subject category, and creating explanations for question answers. The approaches and processes are the same as in developing a regular first year networking class for classroom-based teaching and learning. We now describe some of our work in these areas.

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### Session S2H

The efficient storage and access of student learning performance data are essential for implementing progress-based E-Learning systems. The NAMS uses the Learning Advancement Management System (LAMS) for storing learning performance data. The LAMS stores student learning performance data collected from the NAMS, and enables it to deliver personalized progress-based learning content. The main advantage of using the LAMS is the simplicity in implementing and maintaining the NAMS.

The NAMS itself maintains the course database containing the instruction material for each subject in the course, as well as the subject category information. The information stored in the LAMS includes students in the course and the lessons of each student. The NAMS delivers course content (tests on questions) directly from its course database. It retrieves and updates the lesson information in the LAMS for each student learning session. Since the NAMS stores course materials and the LAMS stores learning performance data, this separation makes it more efficient to develop and manage course materials.

When a student’s new learning session starts, the NAMS retrieves the latest lesson of the student from the LAMS, and creates a new lesson as current lesson in the LAMS. It then generates the list of current study questions, and presents each question on the web page. When the student enters the answer to a question, the NAMS checks if the answer is correct. It uses this information to update the list of current study questions, and the current lesson information in the LAMS. From the student’s perspective, the NAMS is an intelligent learning system that adapts to student’s own learning aptitude.

The current release of the NAMS only supports very simple learning progress rules. However, the principles and techniques employed in its implementation are applicable for developing progress-based E-Learning courses in other engineering disciplines. It is necessary to evaluate the effectiveness of NAMS according to the six educational objectives at the cognitive domain that includes knowledge, comprehension, application, analysis, synthesis, and evaluation [3]. Although our field experiences with the NAMS in helping students in first-year networking classes are still fairly limited, we believe it is effective in helping students to gain knowledge and comprehension of the key concepts. One future extension of the NAMS is to add contents to assess if students achieved the other four objectives in first-year networking classes. It is also interesting to study the effectiveness of using the NAMS as exam-cram training tool for students taking professional certification exams.

Progress-based E-Learning systems may apply different learning progress rules to support students with different

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### Table 1: The NAMS Subject Categories

<table>
<thead>
<tr>
<th>Subject Category</th>
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</tr>
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<tbody>
<tr>
<td>TCP/IP Network Model</td>
<td>5-layer network functions, testing with ping and tracert, sample applications, OSI vs TCP/IP</td>
</tr>
<tr>
<td>Network Cables</td>
<td>Coaxial, UTP, crossover, straight-through, rollover, single-mode and multi-mode fiber cables, SC and ST connectors; Network wiring, star, ring, bus</td>
</tr>
<tr>
<td>Signal Transmission</td>
<td>Digital signals, Time synchronization, Manchester encoding; Analog signals, AM, FM, PSK; Multiplexing, TDM, FDM, Spread Spectrum</td>
</tr>
<tr>
<td>Error Detection</td>
<td>Parity check, checksum, CRC</td>
</tr>
<tr>
<td>Media Access</td>
<td>Token ring, bus, Aloha network</td>
</tr>
<tr>
<td>Ethernet basics</td>
<td>MAC address, frame, timing, CSMA/CD algorithm, collision, broadcasting, hub, switch, identification and segmentation of collision/broadcast domains</td>
</tr>
<tr>
<td>Ethernet Switching</td>
<td>MAC address learning: switching mode, store-and-forward, pass-through, segment-free; loops and redundancy, spanning-tree algorithm; VLAN</td>
</tr>
<tr>
<td>Wireless LAN</td>
<td>802.11 protocols, 802.11 frames, CSMA/CA algorithm, WLAN topology</td>
</tr>
<tr>
<td>IP Protocol</td>
<td>IP address, address class, special addresses, address configuration; Packet, route selection, loop prevention, fragmentation and reassembly</td>
</tr>
<tr>
<td>IP subnet</td>
<td>Network mask, subnet creation</td>
</tr>
<tr>
<td>IP configuration</td>
<td>DHCP, ARP, proxy-ARP, default gateway, static routes</td>
</tr>
<tr>
<td>Internet Routing</td>
<td>Autonomous systems, intra-domain and inter-domain routing, routing protocols</td>
</tr>
<tr>
<td>Hands-on router configuration</td>
<td>Router architecture, Cisco IOS, CLI, Exec mode, router file management, interface configuration, router configuration</td>
</tr>
<tr>
<td>Routing protocol algorithms</td>
<td>Distance-vector, OSPF</td>
</tr>
<tr>
<td>TCP and UDP</td>
<td>Segment, ports, congestion control, error recovery</td>
</tr>
<tr>
<td>Application protocols</td>
<td>NAT, DNS, FTP, TFTP, Telnet, SMTP, IMAP, POP3, MIME, HTTP</td>
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The subject category **Hands-on router configuration** in the NAMS supports first-year networking classes that incorporate Cisco’s CCNA lab sessions. If such sessions are not part of the class, disable the subject category by assigning a negative value to its Seq field. The NAMS will ignore subject categories with negative Seq values. The values in the Seq fields do not have to be continuous. The NAMS only considers these values as representing a sequential order between subject categories.

The NAMS also tracks other information about subject categories not shown in Table 1. For example, there is a Comprehension Threshold percentage value for each subject category. A student’s ratio of learned subjects over total subjects in a category must be above its threshold percentage before the student can learn the subjects in the next category. As discussed in the previous section, the threshold value for each subject category in NAMS is 70 percent. The NAMS allows adjustment of these threshold values to raise or lower the learning outcomes in the course.

The assessment questions in the current release of the NAMS are multiple-choice or true-false questions. We create most of the questions by using existing textbooks on networking [10, 11]. There are explanations for the answers to the questions. The NAMS currently contains over 200 assessment questions. A future release will contain more questions and more elective subject categories such as network management [7, 8]. We also plan to enhance it with capabilities to automatically create questions on IP subnets. The NAMS provides an authoring Web interface that allows an instructor to enter or edit the subject categories, questions, questions solutions, and explanations to question solutions.

### IMPLEMENTATION AND FUTURE WORK

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learning aptitude. It is interesting to investigate the intelligent selection of rules to orchestrate the learning process for each individual student. It is also interesting to identify new learning rules that improve the learning performance of students. The NAMS currently presents assessment questions as multiple-choice questions. We plan to enhance it with more question presentation methods such as fill-in-blanks with drag-and-drop items, term matching, and quiz games. To allow more E-Learning systems to employ progress-based pedagogy, it is also necessary to study techniques to simplify the implementation of these systems.

Our initial deployment of the NAMS will be a supplementary teaching system for a first-year networking class taught by an instructor in regular classrooms. It is a supplement, not a replacement, of a regular first-year networking class. We plan to use it in an online first-year networking class taught by an instructor on the Internet once the system is more mature. Students in the online class still need to be physically present in network labs for hands-on projects. When there are sufficient experiences and interests, the NAMS can be available on the Internet as a subscribed service to other schools in the future.

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