Infusing Demographic-Specific Applications into a Digital Logic Adaptive Learning System

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Abstract

This paper describes the development of a novel web-based adaptive learning system to improve student mastery of digital logic concepts while considering the demographics of the individual student. Adaptive learning is a pedagogical approach that dynamically alters the difficulty of content based on an ongoing assessment of the student's capability. This technique is becoming more popular with the advancement of web-based learning solutions and increased student enrollment. Using this type of e-learning environment has the potential to address background deficiencies of students that lack the necessary prerequisite skills coming out of high school. This type of system also has the potential to challenge top performing students and free up instructor time during class for active learning exercises. This paper also presents the novel concept of broadening the impact of an adaptive learning system by tailoring the material to the demographics of the students. This can be as simple as the wording used in the problem or posing the problem as a relevant example of interest to a particular student group. This approach has the potential to enhance a student's perception of the value of the content. This leads to increased content retention and improves student motivation to excel in the course. This paper will discuss the work being conducted at Montana State University in developing and deploying adaptive learning modules at a diverse set of universities to collect data on how different student groups use and are impacted by the materials.

Introduction

With the recent increase in college enrollments, instructors are struggling with how to effectively teach large introductory-level engineering courses. What makes this problem even more complex is that entering college freshman typically have a wide-range of background preparedness in science and math, which increasingly requires individual instruction. In most cases, reducing the instructor-to-student ratio to solve this problem is impossible due to constrained university budgets. While supplementary instruction techniques such as tutoring, peer advising, and student success coordinators have shown promise, they still rely on human personnel. This limits their ability to effectively scale with the enrollments being seen nationwide in universities.

Using e-learning environments to supplement face-to-face instruction has received great interest of late due to the promise of a scalable, low-cost, method to personalize instruction and address background deficiencies of incoming freshman. An adaptive e-learning system is an exciting pedagogical tool that can provide individual instruction to students by dynamically altering the difficulty of content based on an ongoing assessment of the students' capability. In its simplest form, an adaptive learning system is a bank of online quiz questions on a particular subject, each with an associated difficulty level. As students answer questions, the difficulty of the next question either increases or decreases based on the students' response. In a more comprehensive form, supplemental instruction can be provided as students answer questions incorrectly. This provides individual instruction to address background deficiencies. Additionally, more thought-provoking material can be presented to students that consistently answer questions correctly. This provides a technique to challenge the top students and prevent boredom in the course. Individualized, computer-based, adaptive learning has been shown to be nearly as effective as a live instructor guiding the student through the material when implemented carefully [1,2]. Most course management systems (i.e., Desire2Learn, Moodle, Blackboard) support question banks that are dynamically assigned based on difficulty and continual student assessment. Additionally, textbook publishers are beginning to offer learning systems that can provide multi-media rich instruction materials based on student performance on assessment quizzes. Thus, the infrastructure to exploit adaptive learning systems for personalized instruction is becoming a reality.

One of the more exciting aspects of personalized adaptive learning systems is that additional knowledge about the material can be stressed beyond the technical theory. This allows the material to be put into context with a broader view of how it is used. This can be used to stress the application of the material, which has been shown to improve student understanding and increase interest in the subject. When students see how the material is relevant to their own lives, their motivation to study the material increases [3,4]. While stressing the application of the material has been a technique employed in STEM education for the past decade, the challenge is that the application stressed may not be relevant to every student in the class. An adaptive learning system provides the opportunity to have a broad range of application-based examples that can be dynamically used depending on questions posed about student interests. Furthermore, the type of examples used can stress characteristics about the content not typically addressed by existing quiz banks. Highlighting items such as how the material contributes to the overall public welfare of society, or how the field that uses this material serves others, can change the perception that a student may have about an entire profession. This is especially important when trying to increase diversity in a field such as engineering as it has been shown that women and first generation college students tend to choose careers that are more *other-oriented* [5]. While engineering is a field that certainly *does* contribute to public welfare and help others, it is commonly not perceived as so. As such, adaptive learning has the potential to have a much broader impact on education and professional development than just technical training.

Motivation

In our work, we are developing a comprehensive, adaptive learning framework for digital logic content taught at the freshman and sophomore levels. Our unique contribution is that once the baseline system is created, we will augment it with learning content that provides applications of the material relevant to specific student demographics. It is our hypothesis that providing demographic-specific examples of the material will improve student understanding. One of the overarching goals of this work is to simultaneously increase the motivation of underrepresented minorities to persist in a STEM degree program. This will have a direct impact on the number of STEM degrees granted in the U.S. Increasing the number of STEM degrees has become a national priority over the past decade. Numerous reports by agencies such as the National Academy of Engineering [6] and The National Science Board [7] highlight how the U.S. is being outpaced in the production of engineering degrees relative to emerging countries. Part of the issue is retention. Indeed, only 60% of all students in the U.S. entering an engineering degree program are able to achieve graduation in 6 years [8] and at our university, Montana State, a similar pattern emerges with only 52% of engineering students able to achieve graduation in 6 years [9]. Furthermore, not all students are equally likely to pursue or persist in engineering. For example, in 2011, 83,000 engineering bachelor's degrees were awarded in the U.S.; however, only 18.4% of these degrees were awarded to women [10]. At MSU, again, a similar pattern emerges with only 14.2% of engineering degrees going to women [9]. Currently, women represent 50.8% of the U.S. population [11]; thus women are the largest underrepresented group in engineering. Broadening the participation of all students, especially women, will have the largest positive impact on the number of engineering degrees being produced in the U.S.

One of the most key predictors of persistence is a student's experience of interest [12] as even highly competent students drop out of science and engineering majors citing "lack of interest" in the field [13]. One technique to increase interest is to use examples that the students are familiar with. This approach has shown great success in the *Everyday Examples in Engineering (E^3s)* program [14,15], in which problems are simply posed using material that the student body is familiar with as opposed to classical examples that don't relate to today's students. This approach doesn't change the content, or difficulty of the problem, it simply uses different examples that are more relevant to the students. As an example, consider the following example of how to calculate how long a battery will last.

Example 1. Calculating How Long a Battery Will Last	
Concept	• DC Power Consumption
Problem Statement	• A 9v battery is has a capacity of 500 mAh. If you are driving a circuit that consumes 20mW of power, how long will the battery last?

This problem is stated in the typical manner, but has little relevance to the student. A better way to pose the same problem is to use an application that the student is familiar with, such as a smart phone.

Example 2. Calculating How Long a Battery Will Last (2)	
Concept	• DC Power Consumption
Problem Statement	• Your smart phone consumes 1W of power. Its rechargeable battery has a capacity of 1000 mAh. If you charge your phone overnight and then disconnect it at 8am when you go to class, at what time will you run out of power?

Posing the problem in this way uses an example that each student is familiar with. Furthermore, this example is relevant to the students since each of them as had their phone run out of power at some point. Wording of the problem can also be used to stress other aspects of engineering, such as its contribution to public welfare and how it helps others. Consider the following example.

Example 3. Calculating How Long a Battery Will Last (3)	
Concept	• DC Power Consumption
Problem Statement	• A pacemaker consumes 1nW of power. Its battery has a capacity of 100mAh. How long will the pacemaker operate before it needs to be replaced?

This example may not be directly relevant to each student in the class, but it illustrates how the content can be presented as one that *helps others* and contributes to public welfare. This stresses the *communal* value of engineering, which has been shown to be an important factor in the motivation of underrepresented groups, particularly women, to persist to graduation.

Notice that each of these three examples ask questions about the same concept. The only difference is the application that is used. The practicality of simultaneously using different forms of the same content is made possible by an adaptive e-learning system and is the novel contribution of our work.

Our Adaptive Learning System

The adaptive learning course materials being developed at Montana State University are for a sequence of digital logic courses found in every accredited computer engineering program in the U.S. Since the materials are deployed most broadly in this project using the existing courses at MSU-Bozeman, the MSU course names and numbers are used to describe the content for the remainder of this paper. The two courses that are impacted by this project are *EELE 261 – Introduction to Logic Circuits* and *EELE 367 – Logic Design* [16].

The adaptive learning system being developed in our work fall into three primary categories: skill development tasks, formative assessment, and summative assessment. For the skill development tasks and formative assessment, four levels of competency are defined: deficient, beginner, competent and advanced. Learning activities exist (both tasks and formative assessment) that correspond to these levels in order to facilitate the adaptive learning approach.

Skill development tasks are items that are assigned to the students in order to increase their level of understanding of a topic. Skill development tasks consist of reading assignments in HTML format and/or print textbook, instructional videos using the Camtasia Relay Screen Capture tool [17], working practice problems with solutions provided, and performing laboratory exercises. Videos and reading assignment tasks are used to develop cognitive skills. Practice problems are used to develop affective skills. Laboratory exercises are used to develop both affective and psychomotor skills. Each task corresponds to one of the four levels of competency defined above.

Formative assessment is accomplished using automatically scored quizzes within the course management system. For each level of competency, a statistically large number of quiz questions is created. When a student is assessed, the tools are pulled from the large pool in a randomized fashion. This addresses academic dishonesty, which is a significant concern for web-based courses. Quiz questions are created for each of the learning modules that assess multiple knowledge domains at each of the four levels of competency. Cognitive skills are assessed using auto-graded multiple choice questions. Affective skill assessment are measured using a combination of auto-graded multiple-choice questions, auto-graded circuit analysis questions with numerical entry fields and uploaded circuit design files. The automatically graded questions are implemented in a generic text-based file format, which can be imported into any course management system. The questions are developed based on widely accepted concept inventories for computer engineering courses [18-21].

Summative assessment is performed at the end of each learning module through an automatically graded exam administered in the course management system. Students are notified of their score on each module exam.

The adaptive learning algorithm is shown in the following flow chart. For each learning outcome, an initial set of tasks is assigned (e.g., videos, reading assignments, practice problems, lab exercise). These tasks represent the traditional items that are assigned in a course without adaptive learning. An initial assessment quiz is given to measure the level of student understanding. The performance on this assessment will determine the current level of understanding and put the student into one of the four levels of competency (e.g., deficient, beginner, competent and advanced). Students categorized as *deficient* are given a series of additional tasks to build their background information. An interim quiz will then be given to determine if they are ready to move into the *beginner* category. If they are, they then must complete a set of tasks at the *beginner* level. If they are not deemed ready, they are given additional *deficient* level tasks. This iterative process continues until the student passes the interim quiz and moves into the beginner category. The same process is used for students in the beginner category with the exception that the tasks are at the *beginner* level and the interim quiz assesses whether they are ready to move into the *competent* category. Students deemed competent by the initial quiz (or reaching competence by working through deficient and/or beginner level tasks) are qualified to take the module exam. Students may optionally choose to receive more training at the *competent* level. Students deemed *advanced* by the initial quiz (or reaching advanced by working through competence level tasks) will also be qualified to take the module exam or do optional training at the advanced level. This process provides inherent formative assessment and tracks the progression of each student as they learn the content matter. All interim quizzes used for formative assessment are ungraded and exist to dynamically adapt the difficulty of the material and track student progression. It is at the discretion of the instructor if the module exams count toward the students' course grade.

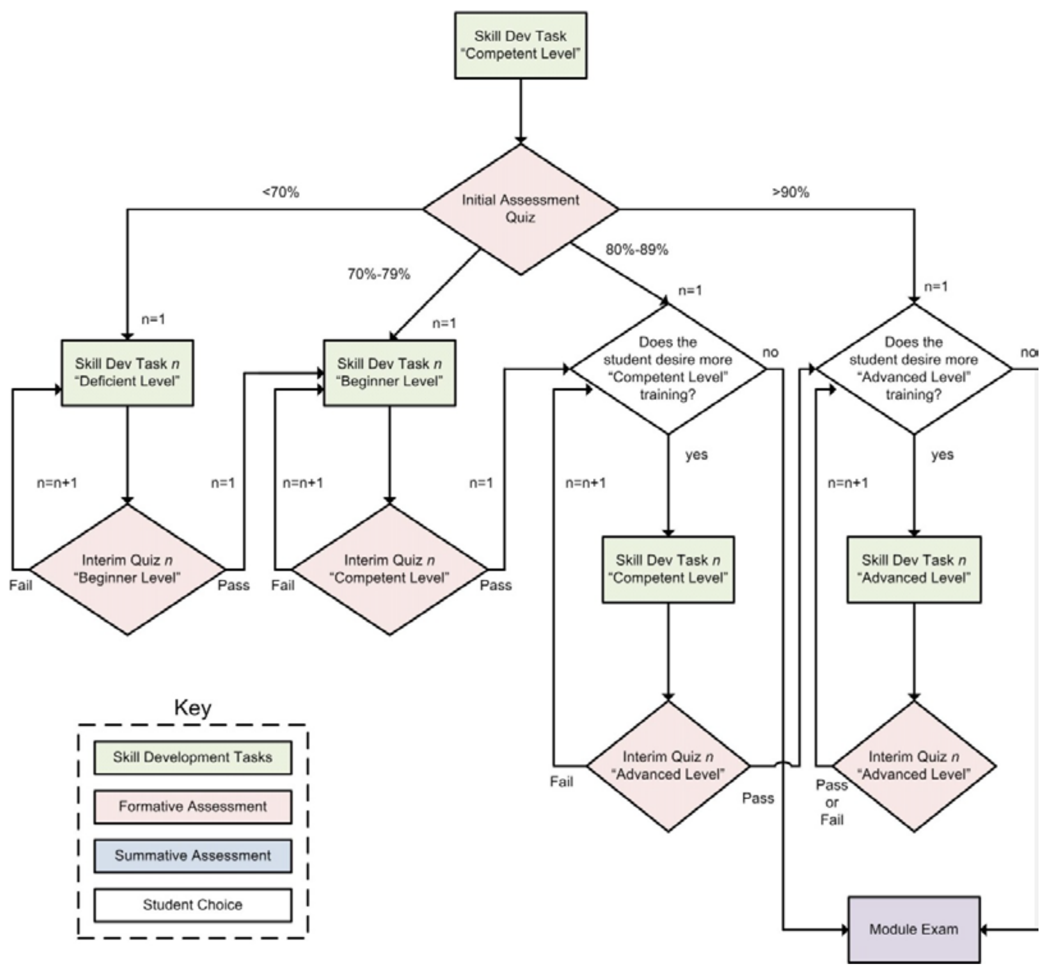

Figure 1. Adaptive Learning Algorithm.

Current Project Status

During 2015, our team has developed all of the baseline (i.e., traditional) content for both courses covered in this work. This includes a new textbook, associated lecture videos, and over 600 quiz questions. During the fall semester of 2015, the material is being used to collect a baseline of student performance across all of the learning outcomes being measured. In 2016, the material delivery will be changed to an adaptive learning format and outcome data will be collected. This will measure how effective the adaptive learning format is in improving mastery of the topics. In 2017, demographic-specific examples will be integrated into the system. The material is being used at Montana State University in 2015 and will be pushed out to three other colleges in Montana (MSU-Billings, Flathead Valley Community College, and Salish Kootenai Tribal College) to collect data on a more diverse population of students. Data is only collected on students who sign a voluntary consent form that allows their demographic information to be pulled from university records and correlated to their performance on the learning modules. All data is coded for anonymity.

Conclusion

This paper presented work underway at Montana State University on building an adaptive learning framework to facilitate mastery of digital logic concepts while simultaneously personalizing the instruction for the students based on their demographics. An overarching goal of this work is to increase diversity in engineering. Research has shown that underrepresented minorities, especially women and first generation college students tend to choose and persist in fields that have communal value (i.e., helping others and contributing to public welfare). The way in which the material is presented and the type of examples used have a direct impact on how important a student perceives the information. Thus in this work, we aim to present demographic-specific content and examples for each student that makes the material relevant to the individual.

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