Toward Smart Content in Adaptive Learning Systems: Potential, Challenges, and Solutions

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Abstract - This paper proposes a novel adaptive learning system – Structured Adaptive Individualized Learning System (SAILS), which incorporates several educational theories to help engage, motivate, and cognitively stimulate students throughout an introductory computer science course. SAILS will provide remedial material as well as interventions, specifically geared towards the specific user, and periodically assess students to measure the knowledge gained. Incorporated in SAILS is a novel concept called, ‘Smart Content’. Based on the student’s profile and the student’s proven successful grasp or lack of understanding of the topic presented, the content gets “smarter” by updating particular stored features associated with the content. The student’s profile will be updated and captured as a point of reference for other similar students to determine the content features that should be updated. SAILS will provide content to similar students by analyzing the content features and past student’s profile. By comparing current profiles and content features, the system would adjust the content the student receives based on its ability to detect when a student has truly mastered a specific topic or when additional practice is required in areas where the student is weak.

Keywords: Adaptive Learning System, Smart Content, Preferred Learning Styles, Computer Science Education, Psychometrics, Bloom’s Taxonomy, Learning Analytics

1. Introduction
The steady growth of technology would lead one to assume that the computer science pipeline would be overflowing with new interested recruits, and computer science programs would be graduating hundreds of thousands of students annually. The graduation rates, however, show this is not the case [1, p. 429]. One of the possible causes is that a large number of computer science (CS) students struggle and fall behind in their course work, due to a lack of prior computer science exposure and a lack of understanding of course content [2, 3]. This has led to entry, engagement, retention, and graduation issues in university computer science departments across the country [4, 5, 6, 1]. The ultimate goal of learning is for one to analyze a new situation and transfer knowledge from a past or similar situation to that new problem and develop a solution. This often does not happen in CS [2, 5]. The phenomenon of “knowledge transfer” is an essential part of the learning process. Knowledge transfer happens when a student is introduced to a new concept and the student gains a strong enough understanding of the material to be able to either apply that knowledge to a different topic or is able to apply the information to a future issue/problem. CS students are not, sufficiently grasping and understanding the computer science coursework, and adequately transferring their knowledge of foundational concepts to the application phase of learning [5]. Educators, therefore, cannot inspire and cultivate innovative minds to succeed in a competitive world [7, 8] when their students continually confused about content and lack the fundamental foundation and confidence needed to be successful computer scientists. Addressing these issues must be done in a way that makes computer science cognitively stimulating, enjoyable, more motivational and easily understandable for all interested students. Adaptive learning systems were created to be a personalized tutor for the community of learners [9, 10] and can address engagement issues. Although adaptive learning systems are currently in use in some academic settings, to completely appreciate the full potential of these systems, they need to expand on theoretical and practical concepts from the education field and accurately track the student’s learning progression. One theoretical concept from education that would be useful for creating content and assessment in CS is categorization using Bloom’s Taxonomy.

1.1 Cognitive scaffolding using Bloom’s Taxonomy
Bloom’s Taxonomy [11] was developed to help teachers and instructional designers guide students through lower order thinking skills up to higher order thinking skills. Activities developed using Bloom’s revised taxonomy are based on five categories (remember, understand, apply, analyze, evaluate, and create), and associated objectives that students should navigate through in order to reach higher order thinking skills. In order to effectively develop those higher order thinking skills, content must be taught in a way that is meaningful to the students. Meaningful teaching should not be haphazard. It should be associated with developing learning outcomes for lectures, activities, and tasks that are relevant to the students and their interests [12, 13]. Meaningful learning involves relating new information to existing information [14, 15, 13] and should not involve rote memorization. Meyers [16] describes three strategies for creating meaningful learning: 1) assess early, assess often – to gauge what students know; 2) let students get their feet wet; 3) welcome student input
for your content and assignment. These three strategies also help to scaffold the students by gauging what they know, allowing them to actively participate in their learning by applying what they have learned, and letting them explain any unclear concepts or steps throughout the process. In turn, this will help increase self-efficacy as well as challenge the learners when they start incorporating the high order thinking skills. Utilizing Bloom’s Taxonomy will also help instructors develop assessment questions for students at their particular level on the taxonomy.

1.2 Cognitive scaffolding in computer science

Instructors may believe that a student is incapable of learning computer science. In fact, the issue could be the student just does not have the required background information needed to grasp the concepts being taught. This could be due to a lack of exposure leading to the student misunderstanding. Thus, the accurate conclusion is the material presented did not match his cognitive scaffolding level. Johnson and Fuller [17] conducted a study of categorization of modules in computer science assessments using Bloom’s Taxonomy and found there were disagreements about the level of categorization of the modules. There was difficulty because it was not clear whether the material being assessed in the study was in fact taught at the particular level on Bloom’s taxonomy. The authors believe that the focus of assessment in computer science appeared to be at the application level. However, they believe the equivalent application level for computer science might be more critical than other fields that evaluate at the same level on Bloom’s Taxonomy. In [18], Thompson et. al. provides a detailed analysis of Bloom’s Taxonomy and its application in introductory computer science exams. They found difficulty mapping programming questions to the description of the original taxonomy. At the end of the study the authors found that it was beneficial to have the instructors who taught the course involved in the categorization of exam questions. Much work still needs to be done in the area of placing content and assessments in correct categories that are on students’ cognitive levels and associate levels of difficulty for the categories. The focus should be to scaffold and build the student throughout the course in the areas that will be assessed. It should also be clear what category each of the assessment questions belongs, as well as which category the remediation content being covered belongs on Bloom’s Taxonomy. The categorization of content and assessments will help in developing an learning situation that is manageable and meaningful to the student. It is important that the process of acquiring knowledge and evaluating true learning be meaningful and properly guided to ensure that the knowledge is stored in the student’s long term memory [19, 20].

1.3 Psychometrics

Psychometric evaluation is used as a way to assess questions to ensure the scores created from using the assessment are valid and reliable. Questions that have been psychometrically evaluated also ensures that the questions are fair to the students taking the assessment and not biased. The idea behind knowledge acquisition in computer science is to ultimately be able to think critically and solve problems. Critical thinking should incorporate transfer of knowledge [15, 21] from one computer science related situation to another in order to solve the problem [22]. This involves finding the link between past situations and the possible application it has to the current situation. However, because knowledge is a trait that cannot be fully observed, it is difficult to identify if a student has acquired the knowledge when content has been taught. Employing psychometric assessments in an adaptive system is a way in which a professor can better measure knowledge acquisition. Psychometrically-sound assessments will help in determining knowledge acquisition, because the assessments have questions that reliably and validly measure specific knowledge [23]. It is important to assess students in this way to help determine where they are and what should be done to get them where they should be at certain check points in a course. Many times concepts in computer science are taught, but it is unclear whether knowledge has truly been attained nor whether the assessment is a true gauge the acquired knowledge. Knowledge acquisition and valid and reliable assessments are vital to helping students with knowledge transfer and usher them through the computer science pipeline and into successful career paths. This paper discusses some theories that would be beneficial to use in computer science classes and presents an adaptive learning system that will incorporate them. Section two of this paper gives a literature review on existing adaptive learning systems with preferred learning styles and the challenges that currently exist. Section three will discuss Cognitive Scaffolding using Bloom’s Taxonomy and psychometric assessment (using valid and reliable assessments to measure knowledge). Section four will cover SAILS.

2. Adaptive learning

Adaptive learning systems are software systems that present different content to learners in response to the student’s performance. Being effective and efficient computer science faculty involves having the ability to assess and manage each students’ cognitive development. Faculty members are expected to take time to make the entire learning experience meaningful for the student, answer student questions, and address concerns in real time. If these expectations are not met the effectiveness of learning diminishes [24]. Properly identifying each student’s varying needs can be overwhelming to keep track of. The reality is that most courses reduce to a “one-size fits all” approach. Adaptive learning systems can reduce the work load of faculty while increasing the individualization of students’ learning [25] by changing content and delivery for a user based on their learning profile [7]. By using an adaptive learning system the teacher would not have the arduous task of, knowing each student’s area of struggle,
their current knowledge level on various content, and being cognizant of students’ varying approaches to learning.

Adaptive learning systems have gone by several names (i.e. Adaptive Hypermedia System (AHS), Adaptive Educational Hypermedia Systems (AEHS), and Technology Enhanced Learning Environment (TELE)) [26, 27, 28, 9] and have been partially driven by a realization that tailored learning cannot be achieved on a large-scale using traditional, non-adaptive approaches [29]. One approach to adapting learning to a user is based on their learning styles.

2.1 Preferred learning styles and their use in adaptive systems

Adaptive systems that use learning styles also employ various techniques to adapt to a student model [30, 10], such as, fragment sorting [31], customized system interface, and adaptive selection of learning objectives [32]. Kolb [33] believed that learning should be looked at in terms of the process involved instead of the behavioral outcome expected. For example, ideas from the experiential learner, are formed and reformed as opposed to fixed and immutable elements of thought. With the apparent differences in the way students learn, using an adaptive system that provides content based on preferred learning styles both personalizes and enhances the learning experience for the student by presenting material in a manner that is more appealing and effective [10]. It gives the students the opportunity to participate in their learning which in turn will reinforce the knowledge they have acquired. Preferred learning styles are the ways in which a learner prefers to receive and grasp content best. There are over 70 learning style assessments developed [26]. Although adaptive systems using preferred learning styles is not a new concept [28, 9], it still remains widely underutilized. However, not everyone agrees with the concept of preferred learning styles [34]. Rohrer and Pashler [35] state that there is no sufficient evidence (validity) to prove the learning styles truly exist. Contrary to Pashler et. al.’s claims [34, 35], Felder and Spurlin [36] describe statistical methods used to analyze and validate the Felder-Silverman model. In addition, the authors identify what the Felder-Silverman Index of Learning Styles is, as well as, what are the uses and misuses of the model. Felder and Spurlin also point out that learning styles are not reliable in terms of indicating strengths and weaknesses. There are four dimensions of the Felder-Silverman Learning Style Index, and of the four dimensions, Hwang et. al [37] used the Sequential-Global dimension in an educational computer game. They had two versions of the game and provided questions to students in the study. A sequential learner is one that prefers information presented in linear and orderly steps; they prefer step-by-step in order to see the big picture. Global learners prefer information present as a whole; they want to have the big picture in order to solve the problem. The questions presented in Hwang et. al.’s games were related to either the sequential or the global styles to ascertain the student’s learning style. Based on the results of the questions they presented either the sequential or global version of the game to the student. They found that students learned best when presented with the version of the game that was based on their learning style. The concept of developing a system that can adapt to learning styles serves as a great tool to handle student differences, however, the current systems still fall short as they are not able to determine if knowledge has been acquired nor if knowledge transfer has occurred.

2.2 Remediation and adaptive learning systems

When students in computer science get tutored, a human tutor applies different approaches depending on the student’s focus area to ensure that the student understands the concepts being covered. However, in a classroom setting the remediation approaches for all students who find themselves falling behind are generally the same, which may result in loss of interest from some students. Outside the classroom, the same reading materials are recommended, and the same assessments are given to all students no matter what foundational information is needed by the individual student. Therefore, all concepts are covered in the same way to every student. This “one size fits all” remediation approach has not been proven to be effective. While some students catch up with the rest of the class, many others remain unengaged. Those who remain unengaged by this remediation style continue to fall further behind [10]. Remediation should be tailored and administered with consideration of the students’ differences.

2.3 Challenges and possible solutions

Various differences in individuals require diverse methods of acquiring knowledge and dissemination of the knowledge [38, 39, 40]. After reviewing the literature we noticed that some existing gaps must be addressed. To mitigate the gaps, an effective adaptive learning systems would immensely benefit the student if: 1) the content is presented to the student based on their learning style; 2) the content presented is evaluated to ensure that true transfer of knowledge is taking place and continues to take place throughout the student’s interaction with the system; and 3) the remediation and intervention content has been correctly categorized and tailored the student. This will help students as well as instructors tailor remediation efforts for each student. To mimic the remediation efforts of human tutors, adaptive systems should be tailored to the specific skill level of the individual student. This means covering applicable content that is needed for that specific student, and presenting it in the student’s particular learning style. This form of remediation should only be applied to other students when there are enough similarities in the student profiles. To ensure successful interaction and effective learning, sufficient metadata needs to be collected and assigned to the content and the student’s profile. In the following sections, we give a review of educational components that are important to address the gaps and how those components are currently being implement in computer science.
3. SAILS – Structured Adaptive Individualized Learning System

A Structured Adaptive Individualized Learning System (SAILS) is a proposed supplemental system to classroom instruction. SAILS will serve as a means to adapt to students’ current learning level and ability and guide each student through high order thinking in an introductory computer science course. The ultimate goal of SAILS is to shift some of the workload off the teacher, and focus on ensuring that proper scaffolding of computer science concepts is taking place for each individual student. At the commencement of the course, each student will take the Felder-Silverman Learning Style Index to determine his/her preferred learning style. Throughout the course, material (remedial, intervention, and general conceptual information) will be presented to the student primarily based on his/her assessed learning style and additional supplemental material will be presented using least preferred learning styles.

3.1 Preferred learning style in SAILS

Felder believes in order to build mental dexterity it is vital that students learn based on their preferred learning style coupled with a least preferred learning style in order to become well rounded learners [41]. This is called, “teaching around the cycle”. When presenting remediation/intervention material, SAILS will present the content using the student’s preferred learning style coupled with at least one least preferred style to keep with the concept of “teaching around the cycle”. When a student is aware of his/her learning style they are more confident about how to best tackle a new or challenging topic [42]; therefore SAILS will provide students with the results of his/her assessed Felder-Silverman Learning Style Index. According to Felder the more aware a teacher is of the learning style preferences of students, the better equipped (s)he will be to effectively convey the material. Learning how to benefit from the differences in their own learning style is important to the student’s academic success.

3.2 Remediation vs intervention

The goal of SAILS is to provide dynamic individualized paths to success by presenting personalized interventions. The distinction between remediation and intervention is the point at which the material is presented. Remediation material is provided to students who are behind or failing. Intervention material is provided as a way to intervene before the point of failure. Providing interventions early enough will help build students’ self-efficacy, therefore it is important to collect sufficient data to determine when intervention is needed.

3.3 Valid assessments

SAILS will incorporate psychometrics by developing various psychometrically-sound assessment questions associated with each cognitive scaffolding category. Implementing an adaptive learning system that incorporates psychometrically evaluated questions will serve as a way to measure whether the computer science concepts are truly being transferred in the way that is intended. This will help easily determine the student’s skill level and the knowledge that has been acquired. Each assessment item will have an associated level of difficulty as well as a designated category on Bloom’s Taxonomy. This will help steer students through successful intervention paths and the remediation of each student.

3.3.1 Cognitive scaffolding

In an effort to properly scaffold the learner, all materials in SAILS (assessment questions and remedial/intervention) will be evaluated and placed in a specific cognitive category on Bloom’s Taxonomy. The system will evaluate the learner’s profile and present the appropriate material to the learner. This will ensure that the students are learning and being assessed based on their own cognitive level and will be able to end the semester on the expected level based on the learning outcomes of the course.

4. Conclusion and future work

The goal of computer science is to get students to eventually create and contribute to the field. SAILS aims to build/scaffold the student so that by the end of a course they will have the ability, confidence, and willingness to create and contribute to the field of computer science. Content in SAILS will have metadata representing features that will be captured and updated frequently and used to scaffold similar students.

4.1 Adapting via Smart Content

SAILS will be adapting and presenting material to students using ‘Smart Content’. All content in SAILS will have metadata associated with it and a score that will help make the content smarter. Smart Content will aid in the analytics and proper distribution of content to appropriate student profiles. During the commencement of the data collection process, SAILS will focus on distributing remediation materials to the students who are failing. The student will then be assessed after they have reviewed the remediation materials presented to them. The metadata associated with the remediation material will be analyzed. The outcome of the analysis will determine whether the material was effective or not for that student. The metadata will then be updated and depending on the score, will be an indication of whether or not the remedial material will be distributed to a student with a similar profile. Once the system has been trained and has enough analytics to support distribution of material to students given a particular profile, interventions will decrease the need for remediation. SAILS will make use of the collected analytics and flag students who are in a set danger zone. To help build student self-efficacy in the course, the system-designated interventions will be provided to the student before he/she reaches the point of failure. These interventions will be supplemental multimodal material presented in the student’s preferred learning style, their current category on Bloom’s Taxonomy, and periodic validated assessments that will help determine knowledge of the topic. These interventions will be presented to the student based on the intervention’s proven ability to
improve other similar students’ success paths. The interventions provided to the student will build/scaffold the student where they are on Bloom’s Taxonomy and take them through to the higher order thinking skills. The analytical data will help steer future students through successful intervention paths, and reduce possible need for remediation. The result of SAILS will help the professor get a clearer view of individual and overall students’ weak topic areas. The abstract nature of computer science will make this challenging, but not impossible. SAILS’ use of Smart Content, psychometrics and Bloom’s Taxonomy would benefit both the teacher, by helping the teacher set questions that measure the knowledge acquired at the students’ current level, and the student by helping to truly guide their learning. This will help to ensure that the assessment questions in each category are reliable, fair, and valid and result in the student’s success in the course.

5. REFERENCES


