SugarAid 0.2: An Online Learning Tool for STEM

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Abstract—We present an online learning tool called SugarAid version 0.2 to assist in the education of students of science, technology, engineering, and mathematics (STEM). We have used the tool in both mechanical and electrical engineering courses with positive results, such as improved written exam scores. SugarAid may be used online at nanoHUB.org with remote computation; i.e. all that is required to use SugarAid is any device with internet browsing capability. The tool is intended to replace or complement course homework, and to provide custom review material that adapts to each student’s learning curve. The tool prepares students for in-class examinations by providing timed exercises, and allows the students and instructor to examine how ABET (Accreditation Board of Engineering and Technology) concepts are being addressed. Immediate grading provides instant feedback to both instructor and students. SugarAid may be configured to display image files, function plots, multiple choice questions, detailed solutions, etc. We have implemented a weakness function in SugarAid that works by remembering exercises answered incorrectly and tests for the retention of such exercises at a later date. Reference material such as lecture notes and data tables may be displayed in SugarAid. The latest version allows students to modify exercises to explore what-if scenarios by, say, replacing a resistor with a capacitor in a circuit. In this paper we describe SugarAid and examine various metrics including a comparison of exam scores by students that did, and did not, use the tool. The exam results, usage data, and survey suggests that SugarAid has a positive impact on students’ performance.

Keywords - computer aided learning, ABET, nanoHUB, interactive learning

I. INTRODUCTION

With increased access to computers, computer-based learning tools in engineering education are becoming viable options, e.g. [1]-[3]. Computer-based homework offers several advantages over traditional paper-based homework as follows: Students are able receive immediate feedback of homework exercise responses instead of waiting for office hours or waiting about a week for the homework to be graded and returned. Adaptive learning may be implemented whereby the tool provides questions with difficulty level depending on individual’s performance of previously answered questions. There can be a larger variety exercises for students that require more practice. There may be the option of displaying highly detailed solutions to exercises. The tool may optimize the study time of the student, and may make available time that faculty usually spend on grading traditional homework. And the tool allows instructors to access instant performance metrics of their students to address such concerns in lecture.

Indeed, computer-based learning tools have been shown to improve student performance compared to traditional learning methods [4]. However, most tools are difficult to adapt to disparate courses, do not emulate test-taking conditions, do not examine retention rates, and do not allow students to explore what-if scenarios in their exercises.

We have implemented such needs in our tool called SugarAid. The newest and most interesting aspect about SugarAid is that it is coupled to a simulation tool. This coupling allows students to modify exercises by exploring what-if scenarios, and allows the tool to automatically create new exercises. Another interesting feature in SugarAid is that it not only pinpoints areas of weakness, but attempts to strengthen those areas. SugarAid also provides immediate detailed solutions, timed exercises to emulate test-taking conditions, and lets the student know when they are ready for an exam. SugarAid is freely available online at nanoHUB.org with remote computation. E.g., SugarAid can be even accessed by using a cell phone with standard internet capability.

The rest of this paper is organized as follows. In Section II we describe the SugarAid framework and its operation. In Section III we discuss the key features of the tool. In Section IV we present the results of its application in a course comprised of ~600 students. And in Section V, we summarize what we have learned and discuss improvement plans.

II. FRAMEWORK

SugarAid is written in MATLAB [5]. Its exercises can be pre-defined questions or interactive simulations. Its multi-disciplinary simulation engine is based on a design, modeling, and simulation tool of ours called PSugar [6], which uses an extremely versatile netlist text syntax to configure components of multidisciplinary systems. Netlists have gained popularity from their use with SPICE (Simulation Program with Integrated Circuit Emphasis) [7]. Our powerful netlist syntax has the following MATLAB cell array format

\[
p = \{ \text{model}_i \} \{ \text{nodes}_j \} \{ \text{parameters}_k \};
\]

where \text{model}_i defines the type of component (e.g. text, resistor, flexure, turbine, etc.), \text{nodes}_j lists the node name(s) associated with the component that is used to position and connect to other components, and the \text{parameters}_k field specifies particular modeling parameters of the component (e.g. the resistance of a resistor element, values for text questions, function calls, etc.).

This work is sponsored by the NSF-supported nanoHUB.
The netlist may be created using a text editor or a mouse-driven graphical user interface (GUI), which greatly simplifies netlist creation. In our GUI, exercises are configured on the computer screen as they are to appear to the end user. The corresponding text netlist is automatically generated from the GUI for subsequent SugarAid use. We show the coupling between SugarAid and PSugar in Figure 1.

**Figure 1. SugarAid PSugar connectivity.** SugarAid provides on-line homework exercises through nanoHUB.org. It includes various features like weakness strengthening, concept review, and an option to modify exercises by exploring what-if scenarios. PSugar is used to simulate the what-if scenarios and to graphically configure exercises for SugarAid.

### III. Usage

In this section we briefly describe how SugarAid is most often used by students, and some of its key features such as Progress, Weakness, Review, Modify, Notes, and Tables.

We show a screen shot of SugarAid in Figure 2. A student typically uses SugarAid as follows. After selecting the appropriate homework file from the Data File pull-down menu, the student clicks the Start button. SugarAid then displays the first problem while the timer begins to countdown. The preferred time for the particular problem is defined within the netlist. Once time runs out, the exercise vanishes and the student may choose to re-try or skip the problem without penalty. To the right of the timer is the Exercise Number and the student's current score for that exercise. I.e. exercises may be repeated to improve scores. To the right of the Exercise Number is the number of exercises that Remain. The remaining buttons on the top row are the Start, Stop, and End buttons. If the student stops the homework session, the student may continue the session where they left off at a later time; however, the numerical values of the exercise may be different. Upon entering the answer for the problem within the Answer field, the student clicks the Submit button. If the answer is correct, the next question is given. Otherwise, a hint or detailed solution is given, and the student has the opportunity to retry the problem (usually with different numerical values). Simultaneously, the incorrectly-answered exercise is added into the weakness data file (discussed below). At any time, students may skip forward or backward through exercises and complete them in any order by clicking the Next or Previous buttons. Although it is possible to obtain full credit for problems in SugarAid by repeating SugarAid exercises until they are correct, the main purpose for the exercises is to prepare students for written exams. Students obtain points for doing SugarAid problem sets as an incentive. I.e., homework is only worth 10% of the overall course grade. In-class written exams and quizzes are worth ~90% of the overall grade.

**Scoring methodology**

Answering a question correctly contributes 1 point to the homework score. Answering a question incorrectly or skipping the question contributes 0 to the homework score. At any instant, students are able to inspect their performance in learning course material in the form of a progress report table. This table plots their latest performance against their best performance, or against the class average, see Figure 3. The progress reports allow students to see which areas need improvement and when they are ready for exams. The students may at any time go back and redo particular exercises to increase their net scores. However, initial attempts must be done by a specified due date as an incentive.

**Weakness**

The weakness function in SugarAid is used to identify and strengthen the areas of weakness of each student. When a question is answered incorrectly, the question is added into the student’s personal weakness database. To test retention, the student accesses the weakness function to answer the questions again at a later time. If the question is answered correctly after 48 hours, then the question is automatically removed from the weakness database.

**Figure 2. SugarAid GUI.** The example above shows a circuit with various elements followed by a multiple choice question. The interface allows students to easily navigate through the various learning mode options. In this particular exercise, the order of the multiple choice answers is random.

**Figure 3. Progress report.** At any instant, students are able to see their performance in learning course material. The first row of blue bars show the scores of the latest attempt, and the red bars shows the maximum score obtained from all attempts.
**Review**

The netlist for each exercise is able to store ABET concepts and difficulty level. The review section of SugarAid lists all the concepts available, and allows students to select problem sets based on concept for refined study. Some of these problems may be of multiple concept type. In this case, such exercises appear under multiple concepts headings. The review section is not graded or timed, which is helpful for students that find particular concepts difficult.

**Modify**

The Modify feature is most interesting. It allows students to modify one or more components of an exercise to examine how the solution varies. This is in stark contrast to printed textbook exercises and solutions that cannot be readily modified and investigated by students.

For instance, activating the Modify feature in SugarAid changes the screen shown in Figure 2 to the editable design screen shown in Figure 4. In this case, a component menu of elements appear which may be used to exchange or add to the exercise. The student may also choose to create an entirely different configuration. The simulated results show voltages and current flow. These simple operations do not require extensive training and can be quickly performed with a few mouse clicks.

We provide this Modify feature so that students are not limited to the problems provided in the homework sets. Using this feature, students can immediately find personal answers to unforeseen questions that may arise, instead of waiting to meet with their instructors or teaching assistants. We think that such a Modify feature helps develop intuition, creativity, problem-solving skills, and a deeper understanding. More study is needed to verify these assertions.

**Figure 4.** Modify feature. Students may modify regularly-assigned homework exercise (or make up an exercise from scratch) to explore what-if scenarios by clicking the Modify button. A menu of various components is to be used to reconfigure the exercise. In this figure, the left-most resistor has been changed to a capacitor (compare with Figure 2). Menu items are also available for thermodynamic components. Upon modification, the solution is computed.

**Lecture Notes and Tables**

Efficient access to data, reference material, or lecture notes is often needed while solving homework exercises. Such features are included in SugarAid. For instance, in Figure 5 we show phase diagram data that is required to solve a thermodynamics problem. Such data tables are the same that would be given in hardcopy form on an exam. Lecture notes may also be available in SugarAid. However, whenever lecture notes are accessed during an exercise, the timer resets and the numerical values in the exercise may change.

**IV. Results**

In this section we present the outcomes of SugarAid used in a mechanical engineering thermodynamics course offered at Purdue University in the spring semester of 2010. The participants of this study consisted of about 600 students divided into five sections. Each section had about 120 students, and each section was instructed by a different professor. One of the five sections was our experimental group, which used SugarAid. The other four sections were our control groups, which did not use SugarAid. The class time of the experimental group began at 12:30pm, and the class times for sections 1 to 4 began at 8:30am, 10:30am, 1:30pm, and 3:30pm, respectively. On examination days, all five sections got together in an auditorium and took the same in-class written exams at the same dates and times. We examine average exam scores between the sections, SugarAid usage data, and an exit SugarAid survey. We were not selective in which data to keep or ignore, so we stored every interaction that the students made with SugarAid. This leaves open the possibility of examining future correlations that we have yet to consider.

**Exam scores**

In Figure 6 we plot the average scores of each exam for each section. The exams include 3 mid-term exams and 1 final. Some sections did not report their final exam scores. As for the three midterm exams, the average exam scores of control groups are 65%, 67.5%, and 66.5% in chronological order. And the standard deviation between the average scores of the control group are 3.8%, 2.9%, and 4.3%, respectively. The corresponding average exam scores of the experimental group
are 78.0%, 80.0%, and 83.0%. That is, the experimental group’s average exam scores were higher on each in-class written exam by an average of 14 percentage points. This is well beyond the average standard deviation of 3.7 percentage points, which we consider as noise in the data. Only one control group (section 4) reported their average final exam, which is 65.8%. The experimental group’s average final exam score is 75.3%. See Figure 6.

SugarAid scores vs. final exam scores

In Figure 7 we show that students who scored more than 90% in all SugarAid homework sets obtained an average score of 79.5% on their final exam, whereas those who scored less than 90% obtained an average of 69.5% on the final exam. This result is not as intuitive as it may seem. That is, it is known that just because a student does well on untimed homework does not imply that they do well on timed in-class exams. We think this is due to the fact that most traditional homework assignments do not emulate a timed test-taking environment, unlike the timed-pressured exercises in SugarAid.

This data suggests that this tool has a positive impact on student performance overall. However, at this time it is difficult to validate that all aspects of the above performances are completely attributable to SugarAid due to numerous uncertain or unknown personal parameters. For instance, such uncertainties might include the various academic background of each student, their course load, study habits, extracurricular activities, socioeconomic backgrounds, the time of the day when their class is offered, the instructor’s teaching style, etc. In this study we assume that this uncertainty lies within the standard deviation range of the 4 control groups, which is an average noise of 3.7 percentage points. Using this assumption, we find that the experimental group that used SugarAid is significantly outside of this noise for all reported exams. This is our preliminary proof-of-concept of a successful application of SugarAid 0.2.

Although the final exam score of the experimental group is still above average, it is lower than the 3 midterm exam scores of experimental group. The reason for this drop in performance is not yet completely understood. Possible reasons that we are considering are: (1) Since the students already received good midterm exam scores compared to other sections, many may have decided to ration more of their energy into preparing for the exams in their other courses. I.e. the highest of either the midterms or the final is weighted more in determining the course grade. (2) The last few homework sets in SugarAid had more multiple choice than subjective questions, which provides initial hints. Fixes to these issues will be applied in the future.

Time of day SugarAid is used

In Figure 8 we show the time of the day that students use SugarAid. In this frequency distribution, we notice that most of the students prefer working at later hours of the day. This time is after the office hours and help-room hours of the professors and teaching assistants. Having a helpful learning tool after hours appears to be beneficial for the students.

Survey results

We implemented an exit survey to identify perceptions of SugarAid. The survey was administered immediately after the semester. About 30% of the experimental group responded to the survey request. Students responded to each question (where appropriate) on a scale from 1 to 4, where 1 = strongly disagree, 2 = disagree, 3 = agree, and 4 = strongly agree. Survey responses are considered as positive experiences if the overall score for a particular question is between 3 and 4, inconclusive perceptions if the overall score for a particular question is between 2.1 and 2.9, and poor responses if the overall score for a particular question is between 1 and 2. In what follows, the mean of the responses is denoted by M and the standard deviation by SD. The survey also included two open ended questions that gave students an opportunity to

![Figure 6. Exam scores. Comparison of scores between the course section that used SugarAid and the four other sections that did not use SugarAid. Students that used SugarAid scored higher than all other the other sections, well beyond statistical noise.](image)

![Figure 7. SugarAid scores vs. final exam scores. This data suggests that students of the experimental group who performed well in all SugarAid homework sets (> 90%) performed better on their final exam by an average of 10 percentage points.](image)
provide written comments. The data analysis includes descriptive statistics.

Considering students’ perceptions of SugarAid in the experimental group it was identified that, overall, students had positive experiences using SugarAid (M=3.3, SD=0.6). Students agreed that the assignments related to SugarAid supported their goals and expectations for the course (M=3.4, SD=0.7) and that using SugarAid made this course a lot more engaging for them compared to courses that only use lectures and readings (M=3.3, SD=0.6). Similarly, students agreed that the homework assignments related to SugarAid were highly relevant to their areas of interest (M=3.1, SD=0.6) and guide them in their thinking when they used SugarAid (M=3.0, SD=0.6).

Students also reported that they were able to comprehend the concepts better by using SugarAid compared to only lectures and readings (M=3.3, SD=0.7), that they did not have trouble completing the assignments related to SugarAid (M=3.3, SD=0.6), that they were able to apply concepts learned in class to solve the homework assignments in SugarAid (M=3.3, SD=0.6), and that they felt very confident with their ability to use the concepts learned with SugarAid to approach new problems (M=3.3, SD=0.6). Likewise, students reported that by using SugarAid they decreased the time they spent in the help room (M=3.5, SD=0.6) and decreased their study time (M=3.2, SD=0.8). Students also agreed that SugarAid is very easy and intuitive to use (M=3.3, SD=0.5).

Interestingly, students agreed or strongly agreed that SugarAid helped them to do better on the exams (M=3.7, SD=0.5) and that they expected their performance in the class was going to be good or very good (M=3.6, SD=0.5). Finally, students were undecided in their perceptions that there were too few problems on SugarAid (M=2.1, SD=0.7) and that they have explored more exercises in SugarAid than it was required for the homework assignment (M=2.8, SD=0.9).

Overall, students had positive responses to the open ended questions. For example, when asked how did SugarAid help them the most during their learning process, students responded with statements such as:

“I felt that SugarAid was a helpful tool. It guided through problems that were very close in regards to the format and difficulty of the exams.”

“It provided instant feedback, normally I must wait until the homework is graded to find out I made an error that I can’t fix.”

Also, when asked how they considered SugarAid may inhibit their learning process most of the students responded that it did not. Few provided statements such as:

“Sometimes it was too much to have SugarAid three times a week plus other homework.”

“At times it felt as if I was given an answer if I was wrong and not as much feedback how to solve the problem.”

Finally, we also asked students what could be done to make SugarAid more useful for their learning in the course. Sample of students’ responses to this question were:

“Make the solutions progressive, so if I don’t get it right the first time, give me a little hint, then if I still struggle with it, give me a little more and so on.”

“Put more details into the answer that explains how to do the problem.”

The overall results of the survey suggests that students find SugarAid helpful to prepare well for the exams. It also suggests that they are interested to use SugarAid as a supplement to the traditional homework exercises.

V. SUBSEQUENT IMPROVEMENTS

Based on the above results and feedback from students, we plan to make several improvements to SugarAid in the areas of the weakness function, various types of review, automatically red-flagging problem areas for the instructor, and adaptive difficulty levels.

To improve the weakness algorithm, one option is to aid the student using a step-by-step solution to pinpoint deficiencies in shallow-knowledge (i.e. concepts and definitions) and deep-knowledge (i.e. problem solving and decision making) [8]. When the student answers a question incorrectly, instead of directly providing the complete solution, the new algorithm will break the question into its fundamental parts and ask the student to identify the respective concepts, equations, and calculations being tested. SugarAid will remember the question for testing the student randomly at a future dates to examine retention. Such an improvement will need to be systematic so that it can be automated. Bonus points can be offered for those students who properly use the weakness algorithm.

Another way to improve the weakness algorithm is to have it analyze the retention rate and style of individual student. That is, each student learns different subject matter at a different rate and style. Some may require daily exposure;
This can be done by providing a predefined relative tolerance red flag those questions and concepts associated with them. attempted incorrectly by a large number of students we plan to areas in lecture. SugarAid, or allow the instructor to address such problem value in SugarAid, and if the number of times a question is answered wrong by the class exceeds this value, then SugarAid can automatically red flag that question and its associated concepts. With this information, we plan to gain a better understanding on what concepts students find difficult and take steps to help students in these such areas within SugarAid, or allow the instructor to address such problem areas in lecture.

Another improvement is to include adaptive testing, where later questions depend on whether previous questions are answered correctly. This benefits both advanced students by allowing them to skip past “easy” problems, and helps students that are not as advanced to suitably build to the proper difficulty level with the addition of more intermediate problems.

We plan to place more emphasis on providing better review capabilities. The current Review feature allows students to select the concept of their interest and provides all questions that utilize the selected concept. Our improvements might provide more review options such as a review based on the level of difficulty, type of problems (i.e. multiple choice, numerical calculations, plots, etc.), and the professor’s choice review for exams.

We plan to examine the amount of time students spend with SugarAid compared to students that do not use SugarAid but obtain the same exam scores.

Last, we continue to implement suggestions from users. I.e. if a student proposes a suggestion in class for SugarAid, if it is a feature that most others want as well, we are usually able to implement the new feature within one or two days. In the future we may add audio content to lecture notes.

VI. CONCLUSION

We presented an online learning tool called SugarAid version 0.2 that assists in the education of STEM. The tool was used in the courses of electronics and thermodynamics. The tool has some unique features that help students do better on exams than traditional homework by over a letter grade. The features include online accessibility, timed exercises, immediate feedback with detailed solution, lecture notes, data tables, a weakness function areas, review capabilities, and an interface to explore what-if scenarios. A survey on students’ perception of SugarAid suggests that they find this tool helpful to prepare for the exams and are interested to use this tool as alternative to traditional homework exercises in other courses as well.

ACKNOWLEDGEMENTS

We acknowledge Wiley & Sons and the authors of Fundamentals of Engineering Thermodynamics, Dr. Michael J. Moran and Dr. Howard N. Shapiro for providing the thermodynamics data tables used in SugarAid. We also acknowledge Dr. Steve Clark of the nanoHUB for helping move our MATLAB tool onto the web.

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