

# SugarAid 0.2: An Online Learning Tool for Improving Engineering Exam Scores

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**Abstract**— This paper presents an online learning tool called SugarAid version 0.2 to assist in the education of students of science, technology, engineering, and mathematics (STEM). This tool has been used in both mechanical and electrical engineering courses with positive results, such as improved written exam scores and students' positive attitudes toward using SugarAid. SugarAid can 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 know which 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. A weakness function is implemented 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. This paper describes SugarAid and examines various metrics including a comparison of exam scores by students that did, and did not, use the tool. The paper also describes the students' perceptions of the tool, which were found from the detailed analysis of an online survey. The exam results, usage data, and survey results suggest that SugarAid has a positive impact on students' performance and attitudes. Results suggest that students that used SugarAid averaged over a letter grade higher on in-class exams than students that did not use SugarAid.

**Keywords** - computer aided learning, nanoHUB, interactive learning, online engineering education, simulation

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## I. INTRODUCTION

With the pervasive access to computers, computer-based learning tools in engineering education are becoming viable options. Researchers have carried out extensive studies in different fields to better understand the usage of computers to aid the instruction of courses and the impact of these technologies on students' learning. It was repeatedly found that computer-based learning tools helped students to perform better. For example, a survey conducted by Jane Dillard-Eggers et al. on effectiveness of online homework indicated that on-line homework increased student performance and that students believed that using on-line homework was an effective method of study [1]. Furthermore, when compared a hinting e-learning system with human teachers generating hints, Munoz-Merino and his colleagues found that the computer-based system could potentially replace teachers without significant loss of effectiveness in students' learning [2]. In another study, Roman Tarban et al. reported the cognitive analysis of students' response to various learning methods [3]. They observed that students expressed significant cognitive activity on computer screens that require interactions compared to other learning methods.

Following are the advantages that computer-based learning tools offer over traditional paper-based homework exercises: Students are able to 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. By means of learner control, students may be able to direct their own learning experience at their own pace. 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 of exercises for students that require more practice. There may be the option of displaying highly detailed solutions to exercises. The tool may emulate test-taking conditions and improve students' retention rates. The tool may allow students to explore what-if scenarios in their 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.

Many tools are developed to address the above needs. One of the first uses of computers to aid teaching instructions is PLATO [4] which became very popular in its time. After that many tools were developed to assist in the instruction of

various disciplines. For example, Roman Tarban et al. developed various computer based applications for Introductory Thermodynamics [5-6]. Nirmalkhandan N. et al. developed tools that aid in teaching of undergraduate hydraulic engineering courses [7]. Robert M. Nelson et al. developed a web-based design tool that allows students to explore what-if scenarios to their exercises [8]. Though these tools have many of the above mentioned features, most of them may be difficult to adapt to disparate courses, may not emulate test-taking conditions, may not examine retention rates, may not come with all features in a single tool, and may not be accessible through a web-browser.

Recently, a tool called SugarAid was introduced that addresses all the above needs [9]. This paper presents a more detailed account of the tool and detailed analysis of the survey results conducted on students who used the tool. The newest and most interesting aspect about SugarAid is that it is coupled to a multidisciplinary modeling and simulation tool. This coupling allows students to modify exercises by exploring general what-if scenarios, while the tool is able to automatically create new exercises. Another interesting feature in SugarAid is that it not only pinpoints students' areas of weakness in their learning, 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. That is, SugarAid can be accessed through any device that supports internet web browsing, such as many cell phones.

In this study the educational potential of Sugar Aid is explored. Therefore, our guiding research questions are:

*Can SugarAid help students to improve their performance in written exam scores?*

*What are students' perceptions of their use of SugarAid as a tool for their learning?*

The paper is organized as follows. Section II describes the SugarAid framework and its operation. Section III describes the usage and key features of the tool. Section IV presents the results of its application in a course comprised of ~600 students. Section V presents the results of the survey conducted on the students who used SugarAid. Section VI provides a discussion of the findings from Section V. Section VII discusses plans to improve features of the tool. And Section VIII summarizes what the authors learned in this investigation.

## II. TECHNOLOGICAL FRAMEWORK

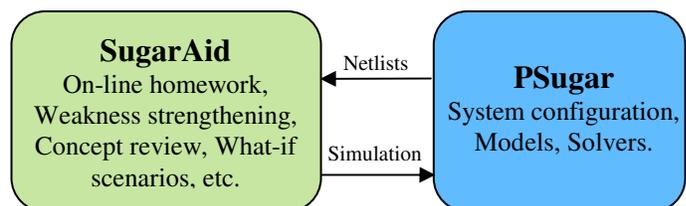
SugarAid is written in MATLAB [10]. Its exercises can be pre-defined questions or interactive simulations. It uses a multi-disciplinary simulation engine called PSugar [11], which can design, model and simulate systems of various disciplines like electrical, mechanical, thermal, etc. This simulation engine uses extremely versatile netlist text syntax to configure components of multidisciplinary systems. Netlists are text files

that describe the connectivity between different components in a given system. They gained popularity from their use with SPICE (Simulation Program with Integrated Circuit Emphasis) [12]. Examples of systems that can be simulated with this engine are system-level electric circuits, thermodynamic systems, and electro-mechanical systems, fluidics, etc. The powerful netlist syntax used in SugarAid has the following MATLAB cell array format

$$p = [ model_j \quad \{nodes_j\} \quad \{parameters_j\}; \dots ];$$

where  $model_j$  defines the type of parameterized lumped component (e.g. text, resistor, flexure, turbine, etc.),  $nodes_j$  lists the node name(s) associated with the component that is used to position and connect to other components of the system, and the  $parameters_j$  field specifies particular modeling parameters of the component (e.g. the resistance of a resistor element, values for text questions, function calls, etc.). The same syntax is used to define additional features of the tool like allotted time for each question, concepts involved in a particular question etc. This generalized syntax facilitates the addition of new features to the tool.

All the elements of a question are stored in a netlist using the above syntax. The major elements include question description, answer, detailed solution, circuit or an illustration (if required), allotted time, and list of concepts involved. This netlist may be created using a text editor or a mouse-driven graphical user interface (GUI), which greatly simplifies its creation. Through this 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.



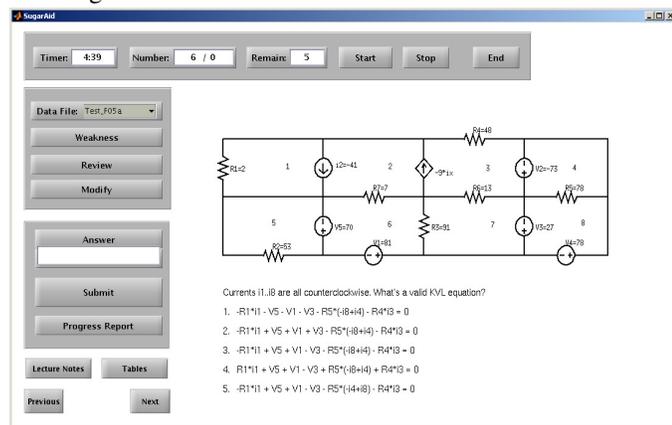
**Figure 1. SugarAid PSugar connectivity.** SugarAid provides on-line homework exercises through nanoHUB.org. It includes various features like weakness strengthening, concept review, and an option to modify exercises by exploring what-if scenarios. PSugar is used to simulate the what-if scenarios and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

## III. USAGE

This section briefly describes how SugarAid was most often used by students, and some of its key features such as *Progress*, *Weakness*, *Review*, *Modify*, *Notes*, and *Tables*.

The screen shot of SugarAid is shown in Figure 2. A student may typically use 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 count down. 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 are 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.



**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.

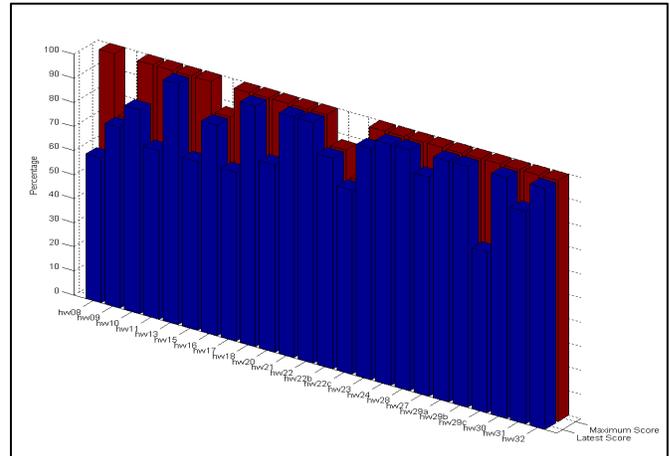
### Homework scoring method

After each in-class lecture, the corresponding homework exercises are uploaded into SugarAid which can be instantly accessed by students. SugarAid uses the following 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. Explanations of particular features follow.

### Weakness

The weakness mode 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 mode 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 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

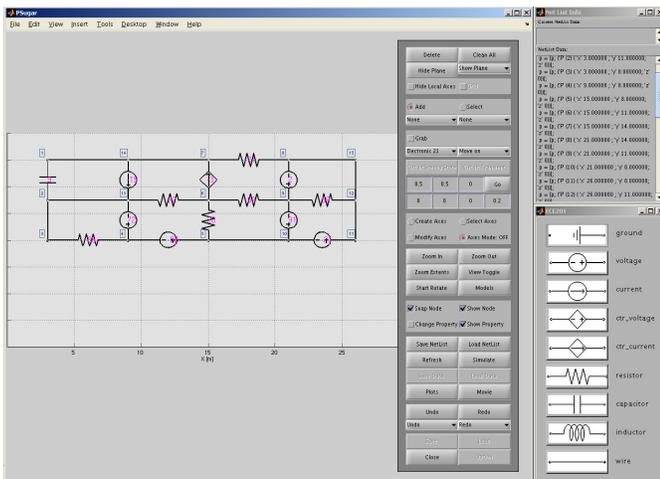
Because of the programmable framework of SugarAid, it is able to store and measure ABET outcomes, concepts, and difficulty level of each exercise. For example, a measurable ABET outcome is *Ability to apply Norton's theorem*. The review section of SugarAid lists all available concepts, and allows students to select problem sets based on concept and difficulty for a more focused study. The more difficult problems may comprise multiple concepts. In this case, such exercises appear under multiple concepts headings. The review mode is not graded or timed.

### Modify

The modify mode is rather interesting. It allows students to experiment by modifying one or more components of an exercise to examine how the solution varies. This is in stark contrast to hardcopy textbook exercises with answers or solutions that cannot be modified for such explorations by students.

For instance, activating the modify mode in SugarAid changes the screen shown in Figure 2 to the editable configuration mode shown in Figure 4. As seen by comparing the figures, the left-most resistor in Figure 2 has been replaced with a capacitor in Figure 4. Figure 4 shows control menus that may be used modify exercises. The student may also choose to create an entirely different circuit configuration from scratch. The simulated results show voltages and current flow. These simple operations do not require extensive training and can usually be quickly performed with a few mouse clicks.

The modify mode is provided so that students are not limited to the problems provided in the homework sets. Using this feature, students can immediately find personal answers to questions that may arise at any time after class or after office hours, instead of waiting to meet with their instructors or teaching assistants on a particular day and time. The mode is also intended to help students develop their intuition, creativity, problem-solving skills, and to a deeper understanding by allowing them to design and test what-if scenarios. More studies are needed to validate these intentions.



**Figure 4. Modify mode.** Students may modify regularly-assigned homework exercise (or make up exercises from scratch) to explore what-if scenarios by clicking the modify button. The homework exercise and control menus appear. In this figure, the left-most resistor has been changed to a capacitor (compare with Figure 2). Menu items are also available for common thermodynamic system components. Upon modification, a solution can be 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, Figure 5 shows 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 in-class exam. Lecture notes may also be made available in SugarAid; however, whenever lecture notes are accessed during an exercise, the timer and exercise reset whereby changing the numerical values of the exercise.

**Figure 5. Data tables.** Data tables such as phase diagrams, periodic table of elements, conversion tables, etc. are sometimes required to solve exercises. SugarAid is able to display such tables. Numerous data tables were provided by the publishing company John Wiley and Sons Inc.

IV. METHODS

This study was designed to compare students’ performance on exams after using SugarAid 0.2 versus using a traditional method of doing homework based on: 1) consulting with classmates, teaching assistant, or professor during limited windows of opportunity, 2) turning in a hardcopy of the homework for grading, and 3) waiting several days for feedback about the effort. This study also identifies students’ perceptions towards their use of SugarAid and their perceived impact on their learning. The participants of this study were the students from a Thermodynamics course offered in the department of Mechanical Engineering, Purdue University in the spring semester of 2010. There were about 600 students divided into five course sections. Each section had about 120 students, and each section was instructed by a different research professor with different teaching style and rapport with students. One of the five sections used SugarAid, the experimental group (~120 students). The other four sections did not use SugarAid, the control group (~480 students). The class for the SugarAid group met at 12:30pm, and the control group sections met at 8:30 am, 10:30 am, 1:30 pm, and 3:30 pm. Each class met for 50 minutes, 3 days per week on Monday, Wednesday, and Friday. All 5 sections followed the same course syllabus (covering the same topics), used the same textbook, and offered the same exams. On examination days, all sections (~600 students) got together in a large auditorium to take identical written exams. Each student was separated by an empty seat. The examinations were proctored by 5 professors and 5 teaching assistants to address various issues and to discourage cheating. There were 3 midterm exams and 1 final exam. The average midterm exam scores of the sections were collected and sent to all professors for comparison purposes after each exam. However, each section applied separate grading curves when it came to assigning student letter grades at the end of the semester.

For the section that used SugarAid, all usage data were recorded (i.e. every type and time of button click). While some of this data is analyzed in the present study, other data is

expected to be analyzed in the future by us or others to explore correlations that have yet to be considered.

To identify students' perceptions towards their use of SugarAid, data were collected through an online survey instrument. Survey questions were adapted from [13]. Questions were selected to identify students' perceptions of SugarAid and the way it was used as part of their course. In particular, the survey instrument focused on identifying students' perceptions of: a) SugarAid as supporting the goals of the course and the relevance to their areas of interest, b) their perceived increased learning with SugarAid, c) SugarAid as a tool that helped them in their learning process, and d) SugarAid as being easy and intuitive to use. The survey data was coded on a scale from four to one as follows: 4 = strongly agree, 3 = agree, 2 = disagree, and 1 = strongly disagree. Our interpretation of students' responses was that perceptions were: a) positive if responses were scored three and over, b) negative if responses were scored two and under, and c) inconclusive if responses were scored between two and three points. The survey instrument also included three open-ended questions that gave students an opportunity to provide unconstrained comments.

The survey was anonymous and voluntary. Students were free to respond to any of the questions and they could stop responding to the survey at any time. About 30% of the SugarAid group responded to the survey request. And of the open ended questions, 96 responses were obtained.

Two levels of analyses were conducted on the survey data. The first level of analysis consisted of a quantitative analysis where descriptive statistics were used to identify overall students' perceptions of SugarAid. The second level of analysis involved a qualitative analysis of students' responses to open-ended questions which was done to provide additional insight into the students' perceptions of their experiences with SugarAid. One of the open-ended questions asked what could be done to make SugarAid more useful for students' learning in their courses. Another question asked students how SugarAid might have helped them in their learning, and the last question on the survey asked for students' general comments. Grounded theory approaches [14] were used to analyze the qualitative data where theoretical explanations were derived inductively from students' responses.

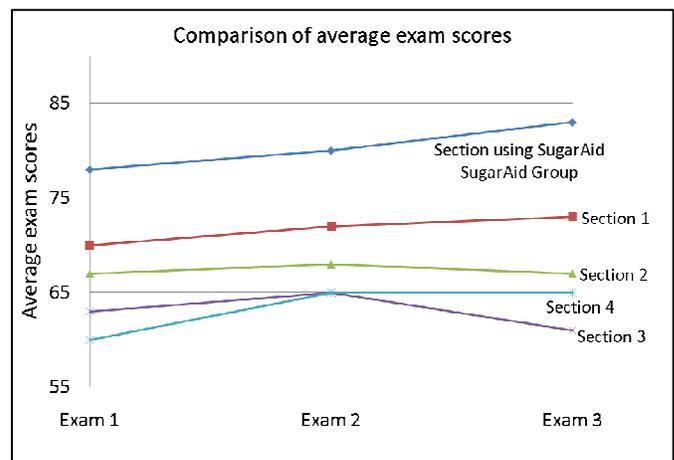
## V. RESULTS

In this section the outcomes of the analyses related to SugarAid's usage and evaluation are presented. First, a comparison of in-class written exam scores between the experimental and control groups are given. Second, the correlation between SugarAid scores and final exam scores are presented. Third, SugarAid's frequency of use during the day is described. Last, students' open-ended perceptions of using SugarAid are reported.

### Exam performance

The average scores of the three midterm exams for each course section are plotted in Figure 6. The average scores for midterm exams 1, 2, and 3 of the four course sections comprising the control group were 65.0%, 67.5%, and 66.5%, which is an overall average of 66.3%. The standard deviations of each of these exam scores were 3.8%, 2.9%, and 4.3% respectively. The average standard deviation (noise in the data) is 3.7 percentage points. The corresponding scores of the SugarAid group were 78.0%, 80.0%, and 83.0%, which is an overall average of 80.3%. That is, the average midterm exam score of the SugarAid group is 14.0 percentage points higher than the control group that did not use SugarAid. As previously mentioned, SugarAid is considered as the most significant difference between the five course sections. Less significance differences in exam performance (such as the research professor's teaching style, time of day that the course is offered, variability among the student population, etc.) is considered as the 3.7 percentage points of noise in the data. With respect to these differences, since the 14.0 point improvement over the control group is well above the average (and maximal) standard deviations of 3.7 (and 4.3) points, it suggests that the use of SugarAid is the cause of improved student performance on exams. This is important because timed exams are the most critically significant measure of a student's mastery of concepts and ability to identify, formulate, and solve engineering problems.

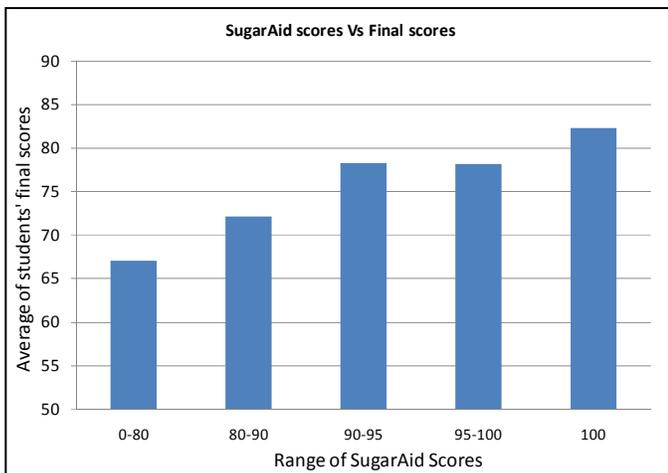
A comparison of the final exam scores between sections is not included in our present analysis because not all section professors responded to a request for their section's final exam score after the end of the semester, during the instructional break.



**Figure 6. Exam scores of the experimental and control groups.** Comparison of scores between the course section that used SugarAid (experimental group) and the four other sections that did not use SugarAid (control group). Students that used SugarAid scored on average 14.0 points higher than other sections on the three midterm exams, which well beyond statistical noise of 3.7 points.

*Correlation between final exam and SugarAid scores*

A comparison between students' performance in SugarAid and performance on the final exam is presented in Figure 7. It suggests that students who scored more than 90% in SugarAid 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. Recall that in SugarAid, students are able to repeat timed exercises and their scores are determined by the highest score achieved on each exercise. This suggests that students who achieved a high SugarAid score had a corresponding high final exam score through more practice than students that did not repeat the time exercises until they got them right. It is well-known that students that do well on traditional homework do not always do well on exams. However, SugarAid's repeatable and time-sensitive exercises appear to make a difference in exams scores. Results suggest that there is a positive correlation between students' SugarAid scores and final exam scores (see Figure 8, correlation value = 0.43). Further study is planned in this area to study difference in exam scores between students that achieve high SugarAid scores but require different amounts of practice in SugarAid.



**Figure 7. Final exam vs. SugarAid scores.** This data suggests that students who took the most advantage of SugarAid's features (> 90%) performed better on their final exam by an average of 10 percentage points than students in the experimental group that not fully exploit SugarAid's features.

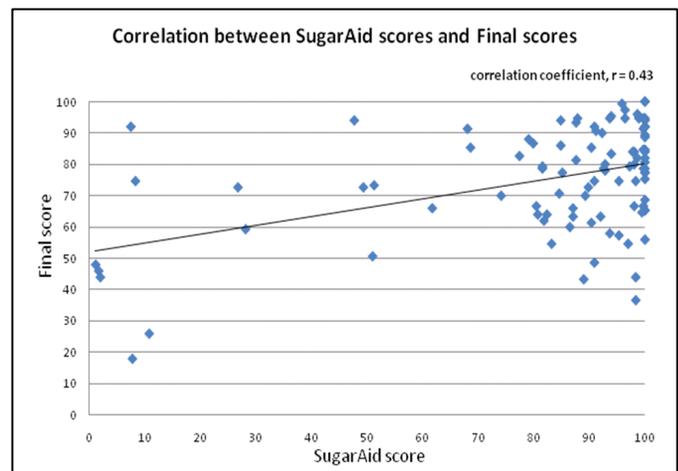
*Frequency of use during the day*

Frequency of SugarAid use during the day is plotted in Figure 9. It can be seen that most of the students preferred working at later hours of the day. This is important because during such times the professor and teaching assistants are not available for help. A correlation between the exam scores and help room usage was not performed in this study.

*Students' perceptions of SugarAid*

A voluntary exit survey was given to the experimental group. Options for the ranked questions were: 4 = strongly agree, 3 = agree, 2 = disagree, and 1 = strongly disagree. In considering students' perceptions of SugarAid it was identified that students had a positive experience using the tool, with a mean score of M = 3.3, standard deviation 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). Students agreed that the SugarAid homework was highly relevant to their areas of interest (M=3.1, SD=0.6) and that SugarAid properly guided them in formulating and solving the exercises (M=3.0, SD=0.6). Students reported that they were able to comprehend the concepts better by using SugarAid compared to lectures and readings alone (M=3.3, SD=0.7), that they did not have trouble completing any of the SugarAid assignments (M=3.3, SD=0.6). They reported that they were able to apply concepts learned in class to solve the SugarAid assignments (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). Students reported that by using SugarAid they decreased the time they spent in the help room (M=3.5, SD=0.6) and they felt that SugarAid helped them significantly decrease their study time (M=3.2, SD=0.8) with compared to their classmates in other sections. Students agreed that operating SugarAid is easy and intuitive (M=3.3, SD=0.5), and they strongly agreed that SugarAid helped them to do better on the exams (M=3.7, SD=0.5). Students expected their performance in the class was going to be very good due to SugarAid (M=3.6, SD=0.5), and students leaned toward disagreeing that there were too few problems on SugarAid (M=2.1, SD=0.7). Last, students were undecided that they experienced more exercises than was required for respective lessons (M=2.8, SD=0.9).

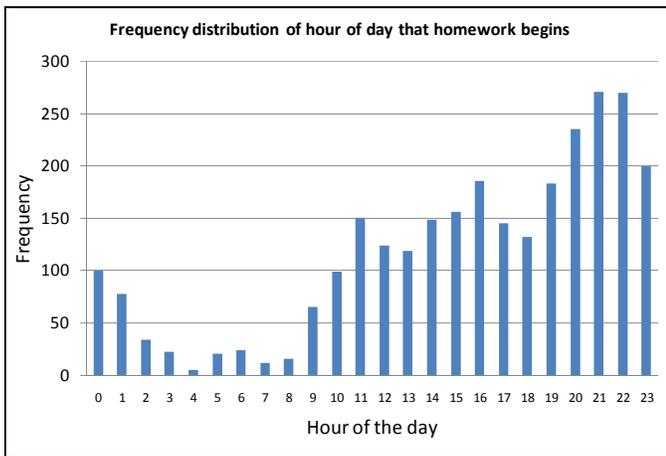


**Figure 8. Correlation between the scores of SugarAid and the final.**

*Open-ended perceptions using SugarAid*

Three major themes were identified from students' responses to the open ended questions. Of the total responses, 28% described how they perceive SugarAid, 42% described what was particularly useful for learning, and 30% provided suggestions on how to make SugarAid more useful.

*How did students perceive SugarAid?* Overall, the students liked using SugarAid. 42% decided to mention that they found SugarAid to be very helpful in enhancing their learning



**Figure 9. Frequency of use during the day.** This frequency distribution of the hour of the day when student begin SugarAid reveals that most students preferred working in the late hours of the day. This is when professors and teaching assistants are not available. Since course met at 12:30-1:20pm Monday, Wednesday, and Friday, the appearance of students using SugarAid during such time slots are most likely due the other days of the week, including weekends.

and in applying their critical thinking skills. And 21% chose to mention that SugarAid helped them perform better on the tests. A couple typical quotes that exemplify their perceptions of SugarAid are as follows:

*"I like SugarAid a lot; I think it was infinitely more helpful than the traditional book problems."*

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

*What students found useful about SugarAid?* Students found many aspects of SugarAid as useful for their learning. 55% of the students decided to mention that a most beneficial characteristic of SugarAid was the feedback it provided to them in the form of a count-down timer, solutions, progress reports, review, etc. 28% decided to mention that the different variety of problems. 14% chose to site SugarAid's ability to repeatedly practice problem-solving skills. 3% chose to state that the visuals were very useful for them. A couple of quotes that exemplify what students found useful about SugarAid are as follows:

*"I really liked the part where if you get it wrong, then it shows you how to do it and [it gives you] the correct answer, because sometimes I would just have a unit mistake and therefore my answer was off by a factor of 100 or something, and with the answer I would be able to know that. I also liked the part that showed how to do it as well as for the times where I started the problem going in a wrong direction. I also really liked the review problems put up before exams."*

*"It helped me understand where I was doing a problem wrong and what concept I didn't completely understand."*

*What suggestions students made for making SugarAid more helpful?* 52% of the suggestions were related to improvement of feedback. For example, students mentioned they would like to have different levels of feedback where they are first given a hint, and if they keep struggling with the same question then more detailed feedback would be given. Along the same line, 10% chose to suggest that the scoring method could be aligned with the different levels of feedback. 19% chose to mention that they wanted a much greater variety of problems to solve. And 19% chose to suggest improving the overall internet connectivity and glitches in SugarAid version 0.2.

## VI. DISCUSSION

Classical research in instructional technology has emphasized that the choice of a specific media for delivering instruction does not directly influence the students' learning benefits [15]. Such research has also emphasized that what has produced differences in students' learning could be attributed to the method of instruction and not the media [15]. However, today's technological advances have allowed not only the merging of method and media [16], but also have provided affordances that support instructional strategies that without technology would not be possible [17]. These instructional strategies can take the form of immediate feedback, frequent and more varied practice, and descriptive and dynamic visual representations. Utilizing the capabilities of a particular medium together with appropriate methods may influence learners' representation and processing of information resulting in more or different learning [18].

Through these instructional strategies, the results of SugarAid suggest that it has provided students with the ability to monitor their own learning and progress through the learning materials at their own pace. It also provided students with a personalized drill and practice environment that allowed them to tests their own learning and designs. Similarly, the visual and dynamic representations of SugarAid may result in the students' mental representations of the concepts being learned. Therefore, SugarAid can be suggested as an effective and engaging learning tool for engineering education.

However, validating which aspects of exam performances are attributable to which features of SugarAid is will require more study. For instance, what aspects of in-class exam performance are directly affected by SugarAid's time-sensitive exercises, solutions, review mode, weakness mode, the variety of problems, etc.? Moreover, there are numerous uncertain or unknown personal parameters which contribute to the noise in the data that we may find correlations to. For instance, variations of grade point averages, discipline levels, type of background course preparation, present course load, extracurricular activities, socioeconomic backgrounds, study groups, emotional stability, the time of the day when their class is offered, the instructor's teaching style, etc. In this study it was assumed that such uncertainties are represented within the reported standard deviation of the 4 course sections of the control group, which averaged 3.7 points. During a previous offering of the course prior to the existence of SugarAid, the instructor of the control group had experienced

test scores that were within a couple of percentage points of other course sections; i.e. it is most likely safe to rule out the teaching style of the instructor of the experimental group as the cause of the 14 point improvement in exam scores. Since the exam performance of the SugarAid group is 3.8 (14/3.7) standard deviations away from that of the experimental group, it is regarded as a preliminary proof-of-concept of a successful application of SugarAid 0.2.

## VII. SUGAR AID IMPROVEMENT PLANS

Based on the abovementioned SugarAid results and feedback from students, several improvements are planned for SugarAid in the areas of the weakness mode, review mode, reports to the instructor, and adaptive difficulty levels.

To improve the weakness algorithm, one way is to aid the student using a step-by-step solution to pinpoint deficiencies in shallow-knowledge (concepts and definitions) and deep-knowledge (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 mode 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; some may have good short-term memory but do not know when or how much they should review areas that they have shown a weakness in. An improved algorithm with optimal review features is currently being investigated.

One suggestion from the students is to allow the option to view solutions even if their answer is correct. Currently, if the answer is correct SugarAid moves on to the next exercise without displaying the solution to the previous exercise. This leaves students to wonder if there was a more efficient solution to the exercise. For this feature a *Verify* button (adjacent to the *Submit* button) can be implemented that both submits the answer and shows a solution.

In order to more clearly identify questions that were attempted incorrectly by a large number of students, such concepts or question types can be red flagged to be identified by the instructor. This can be done by providing a predefined relative tolerance value in SugarAid, and if the percentage that a question is answered incorrectly exceeds this value, then SugarAid can automatically red flag the question type and its concepts. A SugarAid interface will be developed that can display all these red flagged questions. In addition, instructors can also use this interface to monitor the overall performance of the class by examining various metrics like individual homework scores, trends in performance, etc. With this information, a better understanding about what concepts the

students as a whole find difficult can be gained immediately. Steps can then be taken to help students in such areas within SugarAid, or steps can be taken by the instructor during the next lecture to better-explain the proper application of the concept.

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.

More emphasis will be placed on providing better review capabilities. The current review mode allows students to select the concept of their interest and provides all questions that utilize the selected concept. 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.

Emphasis will also be given to further reduce the amount of time students spend using SugarAid while maintaining improved exam scores.

With every new course that uses SugarAid, the tool new features may be added that are unique to that instructor or course. For example, SugarAid is currently used by the Linear Circuit Analysis course at Purdue University, which requires the symbolic computation of Laplace transforms, Inverse Laplace Transforms, partial fractions, etc., which were features not required during the Thermodynamics course.

Last, suggestions from students will continue to be regularly implemented. For example, when a student proposes a SugarAid feature in class that most others would like to see implemented as well, then the new feature is usually implemented immediately or in a matter of days.

## VIII. CONCLUSION

This paper presented an online learning tool called SugarAid version 0.2 that assists in engineering education. The tool was used across electrical and mechanical engineering disciplines, in the courses of Linear Circuit Analysis and Thermodynamics. The tool has several unique features that appear to help students do better on exams than traditional homework. The improvement in exam performance is by over a letter grade (nearly a letter grand and a half). The features include online accessibility, timed exercises, immediate feedback with detailed solutions, lecture notes, data tables, weakness and review modes, and a modeling and simulation interface to explore what-if scenarios. A survey on students’ perceptions of SugarAid suggested that students found this tool helpful for exam preparation. Students were also interested in using this tool in their other courses as an alternative to traditional homework exercises.

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