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An Infinitely Explorable Online Learning System for Civil Engineering

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Abstract

In this paper, we will present analysis of student interaction with a newly developed infinitely explorable online learning system. The Sigma Grading System (SGS), www.sigma-gs.com/SGS, provides students three dimensional infinitely explorable engineering problems in statics, fluids, mechanics of materials, and physics. The system is ideally suited for Civil Engineering where students are presented with full 3D bridge, building, and road problems. In addition, we will discuss tracking student understanding across multiple courses using this software. The system also allows students to obtain evaluation for intermediate steps or to test hypotheses. As students gain confidence in the system, they also transition from a guess / check pattern to a structured search of intermediate steps. Creating systems which are capable of interpreting student responses in the same way that an instructor does allows students to explore problems more deeply instead of simply following “recipes”.

Introduction

Over the past decade, there has been a rapid improvement in “smart” computer tutoring systems. Computer systems are ideally suited to aid students who have difficulty visualizing structures. By allowing interaction, students may change the view angle to discern the three dimensional nature of the problem. In addition, the software may be used to guide a student through the solution process.

While students have different learning styles, and professors often have different teaching styles, it is becoming increasingly clear that effective assessment and immediate student feedback can produce beneficial results in the classroom [1]. Computer systems are ideally suited for such immediate feedback. They can also be used to present interactive case-based problems [2]. Systems have emerged which are capable of analyzing student response and providing targeted feedback to students when their response is incorrect. Systems such as ARCHIMEDES [3], Statics Tutor [4], Shaping Structures: Statics [5], BEST Statics [6], M-Model [7] and many others have emerged to provide students with modern computational learning tools [8] [9]. However, as noted by St. Clair and Baker [10], there remains room for improvement. None of these software solutions provides both an online distribution mechanism and a flexible entry system capable of handling a variety of problem types and vector notation.

An informal discussion with students who were currently using online homework systems revealed that students disliked using these systems for several reasons. Students find it difficult to ask the professor questions regarding the online solution and methodology. There is no record of effort involved or of partial progress made in the solution of the problem. Determining the exact format expected by the software is difficult. An informal discussion with professors using the online software systems indicated that many professors found that scores for online homework did not correlated with student exam scores.

Learning sciences have shown that active engagement [12], integrated assessment [13], targeted feedback [14], and scaffolding [15] can be used to improve learning outcomes. The SGS system is designed to take advantage of these learning mechanisms.

Software description

The SGS system is designed as a homework or exam problem delivery system. A student logs into the system over the internet and is directed to an assignment. The student is presented with a problem statement, a three dimensional interactive figure, and an empty solution area. The student can then click on icons to add text, equations, or diagrams to the solution. Each time an equation or diagram is entered into the system, the student receives feedback on the correctness of the entry.

The SGS system allows students the ability to interact both graphically, and through equations with a problem. Students can explore the three dimensional figure presented along with the program to determine how parts are connected or to explore the three dimensional geometry, Figure 1. Clicking on the image allows the student to rotate the figure, zoom in, or select parts of the structure. Equation entry is accomplished using the toolbar shown in Figure 2. Clicking on these icons brings up an equation editor, a text editor, or a free body diagram editor. The system automatically grades problems and identifies student weakness.

The main advantage of this system is that it can evaluate any and all possible intermediate steps required to solve a problem. As a trivial example, if a problem asked a student “What is 2 + 3 +

4?”, a student might not know the answer right away but might enter “2 + 3 = 5”. The system would then identify this as a correct entry. Instead of being a system that presents content, it is a system that understands a subject and can provide immediate feedback regarding student hypotheses even when they are not anticipated by the instructor. In Figure 2, a student has entered an equation for the position vector $\vec{r}_{A/D}$, the unit vector $\hat{e}_{A/D}$, and the tension in the bar AD. These were not asked for in the problem, but the software can evaluate each statement and indicates to the student that the answer is correct by displaying a blue check box on the left margin. For a mathematics course, this means the system would understand the mathematical operators and relevant equations and operations. In statics, the system understands reaction, internal, and external forces and fields and other related topics. In other words, the system can interpret student responses in the context of a given subject. It can determine that a student is requesting a particular type of information such as the internal stress in a beam and compute this information on the fly. As such, this system provides an infinitely explorable learning environment or an environment where student interaction is not predetermined by the instructor but can consist of any relevant subject material which the system can recognize.

Teaching students to be creative problem solvers is difficult. In many engineering courses, students learn “recipes” which they apply over and over. When they are working on homework in the evening with their classmates, the instructor is not present and it may be easier to take a standard approach to a problem than to try something which might be wrong. This system provides students a 24 hour instructor which is capable of analyzing any potential solution or solution path. Students can form hypotheses and test them immediately at any time and from anywhere. This is a significant deviation for many of them. In fact, during preliminary studies at Merrimack College, students had to be taught to take advantage of the system. Students who take an incorrect approach focus on the final answer and often are reluctant to go back to earlier intermediate steps. This results from previous interaction with other online systems which can evaluate a final result but not an intermediate step. Students had to be encouraged to provide the entire solution through the SGS system. By doing this, they test intermediate steps as they progress through a problem and ensure that they understand the solution process and do not propagate algebra errors in their solution.

Figure 1:. The system allows for three dimensional fully interactive problems. This allows students to determine 1) how systems are connected, 2) the three dimensional relationship between objects, 3) explore the relative directions and geometry of the object.

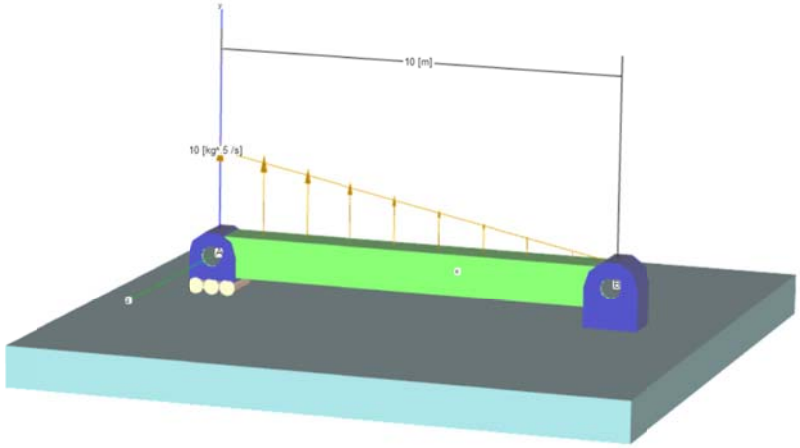
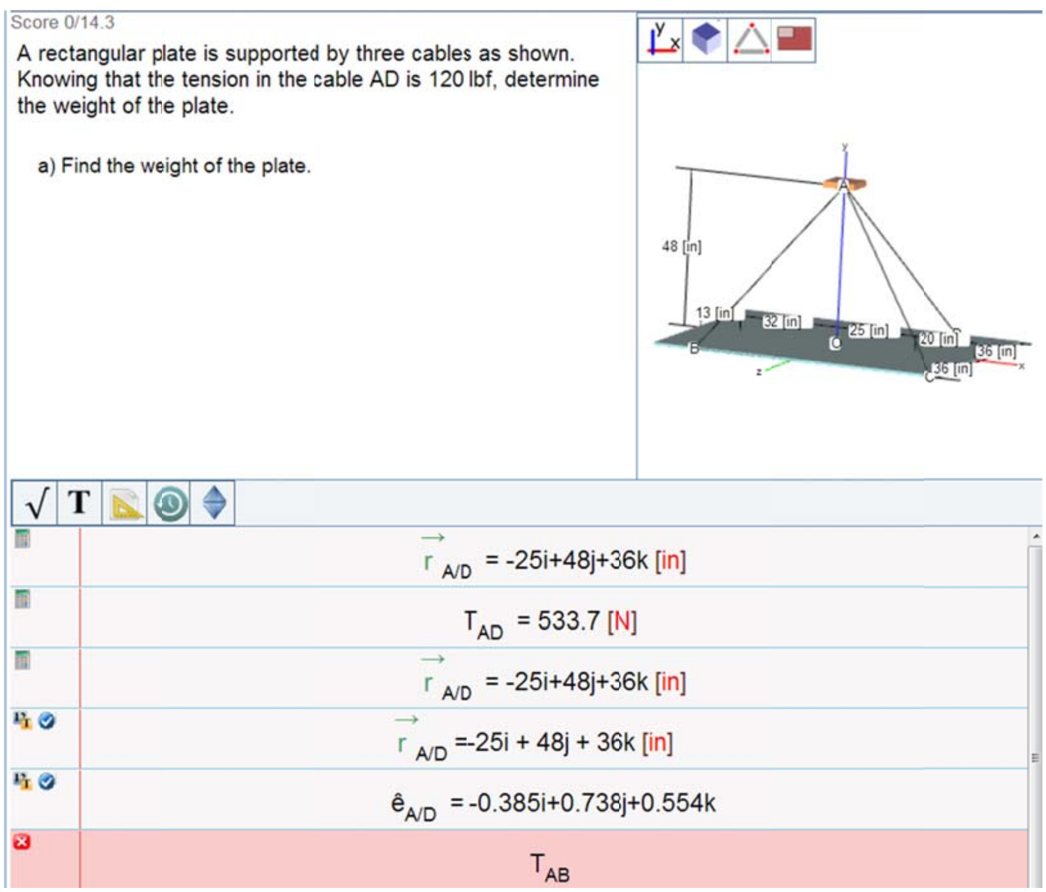


Figure 2: The system allows students to enter intermediate steps and obtain feedback. In addition, students use vector notation and notation common within engineering textbooks within the software.



Previous Studies

A previous study conducted at Merrimack College [11] showed that students using the SGS system performed better on coursework than those who did not. Two sections taught by the same instructor were split into a control and treatment group. The treatment group performed their homework online using SGS while the control group received identical homework except that it was completed on paper. Students were given identical midterms and finals and a direct comparison between the results showed that the treatment group performed about 1 grade level (10 points) better than the control group even when normalized for initial level of competency.

Methodology

This paper focuses on a study conducted in the Fall semester of the 2012-2013 academic year at Merrimack College. A group of Civil Engineering taking the introductory engineering statics were broken up into a control and treatment group. The treatment group used the SGS system and had 12 students while the control group submitted traditional written homework and had 7 students. Both groups were taught by the same instructor. Overall student performance was found to improve using the system [11]. In this study, the evolution of student responses in the treatment group was analyzed. The SGS system is capable of recording and characterizing each student response. A student response might consist of an equation, text statement, or a free body diagram. These responses were marked as 1) required for solution, 2) correct hypothesis, 3) program syntax problems, and 4) incorrect statements. The evolution of student responses was also monitored.

Figure 3 presents an example problem which was included in the analyzed homework sets. Students are asked to enter expressions for the sum of forces and to compute the values of particular forces. The figure on the right is interactive and students can click on it to rotate the object and look at it from different angles. They can then enter equations which answer the question. Various possible responses are shown in Table 1. Entries which contain syntax errors are isolated. It is difficult to interpret these because the parser cannot make sense of the equation. Therefore, they are left out of the analysis. Entries which can be read are evaluated and marked as correct or incorrect and are split into "required for solution" or "hypothesis" categories.

Figure 3: Sample problem from online learning environment.

Consider the forces acting on a particle shown in the figure.

a) Write down an expression for the sum of forces in the x direction.

b) Write down an expression for the sum of forces in the y direction.

c) Calculate the value of FA.

d) Calculate the value of FB.

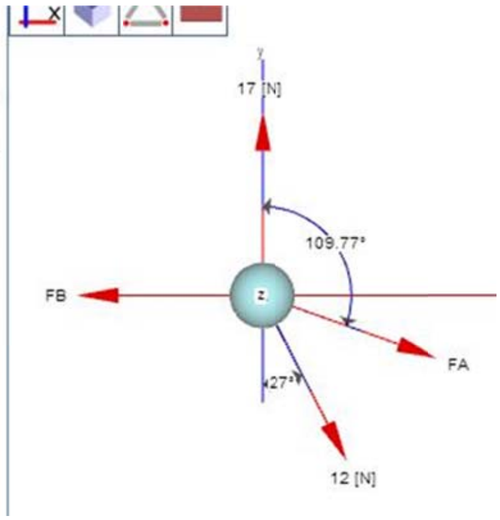


Table 1: Sample student entry in response to part a of the problem shown in Figure 3.

Student Entry	Category
$\Sigma F_x = FA_x + 12[N]\sin(27[deg]) - FB$	**Required for solution:** Part a asks specifically for this result.
$\sum F_x = FA_x$ + 12 [N sin(27 [deg]) – FB	**Program syntax error:** It is missing closing bracket after '12 [N'.
$sin(27\ [deg]) = 0.454$	**Correct hypothesis:** It is a correct statement which is not required for the problem.
$\sum F_x = FA + 5.448\ [N] - FB$	**Incorrect statement:** The student did not specify the x component of the force FA but instead suggested that the sum of forces in the x direction was equal to the magnitude of the force FA + 5.448 [N] – the magnitude of the force FB. **Required for solution: P**art a asks specifically for this result.

Results

The first homework was administered at the beginning of the period without encouraging students to take advantage of the hypothesis testing mechanisms in the software. Before beginning homework 2 students were encouraged to use the hypothesis testing mechanism and the mechanism was explained in great detail. Homework 3 was given at the end of the test period.

	Homework 1	Homework 2	Homework 3
Percent of total answers which contained program syntax errors	12%	41%	52%
Percent of non-syntax errors which were correct / incorrect statements	83%/17%	46%/54%	21%/79%
Percent of correct answers which were required for solution	93%	67%	53%
Percent of correct answers which were hypotheses	7%	33%	47%

Discussion

The results clearly indicate a trend toward more hypothesis testing as the class progressed. This is a product of both the encouragement of the instructor and the increasing complexity of the problems.

Homework 1 consisted of introductory problems which showed students how to enter data using the system. For example, students are asked to enter the result of simple algebraic equations. It is intended as an introduction to the software. This explains the relatively small number of syntax errors and the high percentage of correct scores. The relatively few hypotheses tested (less than 1 in 10 entries) came primarily from a single student who was investigating the usage of the program.

Homework 2 consisted of a set of questions asking students to find the components of vectors. For this homework set, students tested their angle calculations which led to increased numbers of hypotheses. One in three entries was an intermediate step or hypothesis and the hypothesis were more evenly distributed amongst the students. However, the hypotheses generally followed an incorrect answer or a syntax error. Therefore, students were not starting with intermediate steps. Instead, they would attempt to input the solution and if this was incorrect, they would then try an intermediate step.

Homework 3 asked students to make use of equilibrium equations. There were a large number of hypothesis tests which consisted of students checking geometry, lengths, angles, and testing the value of a vector component before forming equilibrium equations. However, the added complexity in the entry of equilibrium equations resulted in more syntax errors in homework 3. In addition, students were making errors and attempting to iteratively change the value. For example, a student entered the value of a force as 1.23 [N] and then immediately tried 1.24 [N], 1.25 [N], and 1.26 [N]. This guessing drove down the percent correct answers. Only 1 in 5 entries which did not contain a syntax error was a correct statement.

Conclusion

In previous studies, we have seen that use of an infinitely explorable online learning environment significantly improves learning outcomes. In this study, we have focused on measuring changes in the character of student responses. In the previous studies, the improvement in student performance occurs almost immediately which we hypothesize is due to the software's strict adherence to engineering notation with immediate feedback on inconsistencies and errors. In this study, we have found that students using an explorable environment learn to take advantage of this facility. We have seen significant increases in hypothesis testing by each of the students in the study. While the problems presented to students consisted of introductory statics problems, we expect that student learning of more complex material will benefit greatly by giving students the ability to test intermediate step. In addition, by not constraining student methodology, they may attempt to solve a problem using any method they would like while still receiving feedback.

We are focusing our current efforts on reducing the number of student entries with syntax errors. This requires a redesign of the equation interface. Giving students flexibility in the entry of equations has led to unacceptable numbers of syntax errors. These syntax errors serve to discourage students from making more use of the system. We hope to reduce the numbers of syntax errors by incorporating syntax highlighting which will draw attention to syntax errors as the student enters an equation.

In addition, students approached the system attempting simply to enter answers. Requiring them to enter solutions would encourage them to test additional intermediate steps. In the future, we will inform students that their grades will be modified based on the completeness of the solution and that a correct answer will not suffice.

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