Precise Personalized Learning Tool for STEM Word-Problems

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Abstract

This research-in-progress proposes the first high-precision personalized learning tool for STEM students learning how to solve complex word problems that involve mathematical models. Learning how to model and solve word problems is the overarching objective of most STEM majors, yet the difficulty in mastering this skill is a key reason why the average STEM retention rate is only 52%, despite tutors, TAs, and office hours. While there have been numerous research efforts in improving this low STEM retention rate, since the 1970s, all efforts to remedy the problem of personalized learning has been quite elusive. The most successful of those tools to date were called intelligent tutoring systems (ITS), which ultimately suffered from the course-authoring problem. That is, ITS did not allow instructors to choose which textbook, which topics, the sequence topics, nor the depth of topics to be covered in their course. To address this and similar problems, we have developed the first STEM word-problem solver, which is not tied to any particular textbook or schedule of topics. We have previously shown that the tool is able to derive all possible solutions to an arbitrary word problem from a particular subject. In this paper, we propose how our engine can be extended to scaffold personalized solution paths that are guided by the student. That is, instead of scaffolding just one of a multitude of solution paths (as is currently done when students receive homework solutions from their professor), our tool will guide the student along their very own chosen solution path, based on how the student has personally decided to attack the word problem, while guiding the student through path corrections along the way. That is, at each step along their chosen solution path, the tool shows all valid next steps, for which the student is able to choose their preferred next step. This way, students are able to construct their very own valid solution path that is based on how they personally think. Such a high-precision personalized scaffolding tool is expected to help students determine exactly where they went wrong or how to get unstuck by precisely pinpointing their mistakes. Such personalized help is not possible with other learning tools and not possible with premade hardcopy solutions.

Keywords: engineering education, personalized learning, problem-solving, modeling, word-problem solver, pathway, e-learning, scaffolding

I. Introduction

STEM attraction and retention are two areas that are expected to have a significant impact on increasing the number of professionals in science, technology, engineering, or mathematics (STEM)[1]. Currently, 93% of high school students do not go on to major in STEM. Of the 7% that do major in STEM, only an average of 52% of them complete the degree [2], which varies across majors and demographic groups[3]. A most common denominator in the low retention rate has to do with the difficulty in STEM; in particular, the co-called weed-out courses. A weed-out course is a very difficult course that must be successfully passed with a grade of C or better before continuing to upper-division courses. Such courses typically have the largest increase in the level of difficulty compared to their prerequisites. Without successfully completing the weed-out course, subsequent coursework would be much more difficult because subsequent courses rely on the problem-solving skills gained within the weed-out course. Weed-out courses are often so difficult that a grading curve is often necessary to shift an average grade of a D or a C- to a C, otherwise, too many students would not matriculate to upper-division courses.

Thermodynamics is a well-known weed-out course that is required by several engineering majors. This is because thermodynamics is the science of energy conversion and transmission, which is important for a variety of STEM disciplines. The National Council of Examiners for Engineering and Surveying reports the average exam scores of thermodynamics for an eleven-year period for the majors of mechanical, civil, and electrical engineering graduates[4,5]. The majority of passing rates fall between 40% to 65%, see **Figure 1**.

A common issue with other learning tools and solution handouts that they only present one solution path (the author's solution); however, we have found that there are usually a large number of valid solution paths and that different students can attack a problem in different ways. So unless the student's chosen solution path closely matches the author's solution, then there can be a significant disconnect between the author's solution and exactly where the student went wrong in their very own solution. To address the disconnect between the student's solution and the author's solution, we propose adding a personalized-scaffolding feature to our word-problem solver. This new feature will allow the user to input their very own solution path, one step at a time, as the tool checks and offers valid next steps. To make a student's solution path entry quick, only point and click operations are used (no typing).

In Section II we describe our prototype personalized learning tool. In Section III we propose our personalized-scaffolding feature. And we summarize in Section IV.

II. Word-problem solver

Compared to Mayer's cognitive principles of multimedia learning, our tool more comprehensively and directly addresses the large variety of word problems that students may encounter in homework, may find to practice with, or create themselves to better understand particular concepts and to improve their problem-solving skills[6]. We are addressing this challenge by developing the first word-problem solver (called Pathway).

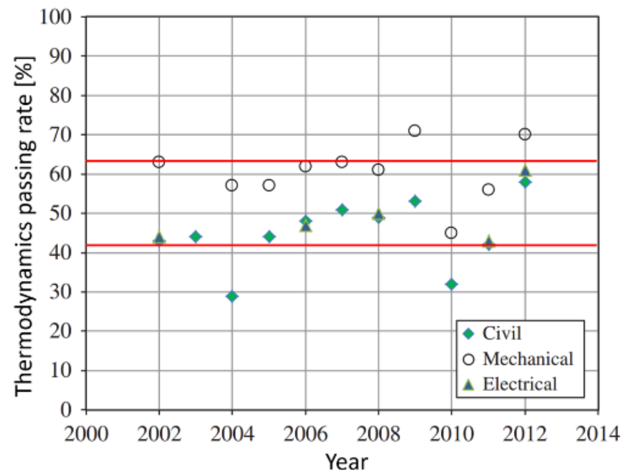

Figure 1: Average exam scores for degree-holding engineers taking a standard test on thermodynamics. The data is from the National Council of Examiners for Engineering and Surveying.

Common scaffolding approaches include the use of models, video demonstrations, hints, encouraging reflection and metacognition, and problem-solving strategies[7,8]. According to Bandura[9,10] "the ability to persist in the face of aversive experiences and obstacles is dependent on the strength of personal self-efficacy" and personal self-efficacy begets intrinsic motivation which leads to desirable student learning outcomes[9,10]. We hypothesize that Pathway's proposed *personalized-scaffolding* approach will enhance the strength of student's self-efficacy and intrinsic motivation which is especially needed when students get stuck or can't even get started on solving a problem. We plan to measure self-efficacy and intrinsic motivation through qualitative surveys. A measure of improvement in exam scores will be done by comparing prior exam scores to current scores, where the instructor does not return final exams back to students so that the same exam can be repeatedly used and compared. Several years of historical data for this comprehensive exam exists.

Pathway's interface for thermodynamics is shown in **Figure 2**, which consists of an input window and two output windows. Using only mouse-clicks or touch-clicks, users enter their word-problem specifications through Pathway's expandable menus. These input menus expand to all possible quantities and relations that can be given in a word problem. That is, the student is able to select the type of analysis (static, steady-state, cyclic, or transient); the type of substances (ideal to non-ideal types, liquid, solid, multi-phased, etc.); the number of states; the number and types of control volumes; the states variables at each input/output port between each control volume; and select the unknown they wish to solve for. The input method is meant to accommodate the specifications of every type of problem that book authors, instructors, or students might create.

Once a word problem has been specified by the student within the right window, Pathway then outputs a step-by-step solution path and modeling assumptions in its left windows. Pathway's solution path is always displayed in a systematic outline format, which begins by being seeded with the unknown quantity that is to be determined. Each equation line includes the quantity that is being solved for, a mathematical relation, and a short phrase describing the purpose of the relation. The subscripts on each equation quantity discern one quantity from another of the same type. The three-character subscripts identify the substance, port, and component for which the quantity is associated with. To help the user follow along, a tilde over each quantity in an equation identifies the quantity that is being solved for, and underline identifies which quantities are known in the equation, and a hat identifies which quantity should be substituted into the equation above it (see the lower-right window in **Figure 2**). That is, if all equations were substituted into each other, from the bottom to the top, the results would be a single equation consisting of a single unknown (identified by a tilde) and several other underlined known quantities. Last, the upper-left window displays the modeling assumptions that were applied to the problem. Assumptions are often absent in the solutions of beginning STEM students; however, assumptions are a critical aspect of a word-problem solution.

Pathway's solution path is logical and intuitive for learners, as they always begin with the quantity to be determined, no steps are skipped, and each step is explained. Conversely, if a student is asked to solve for, say, temperature, the textbook's solution often starts off with an equation that does not include temperature! Without experiential insight, most beginning students would not consider starting with an equation that does not include the temperature variable. Moreover, author solutions often skip steps and offer no explanations as to why particular equations are chosen. Author solutions can be so confusing that students often ask instructors to explain author solutions.

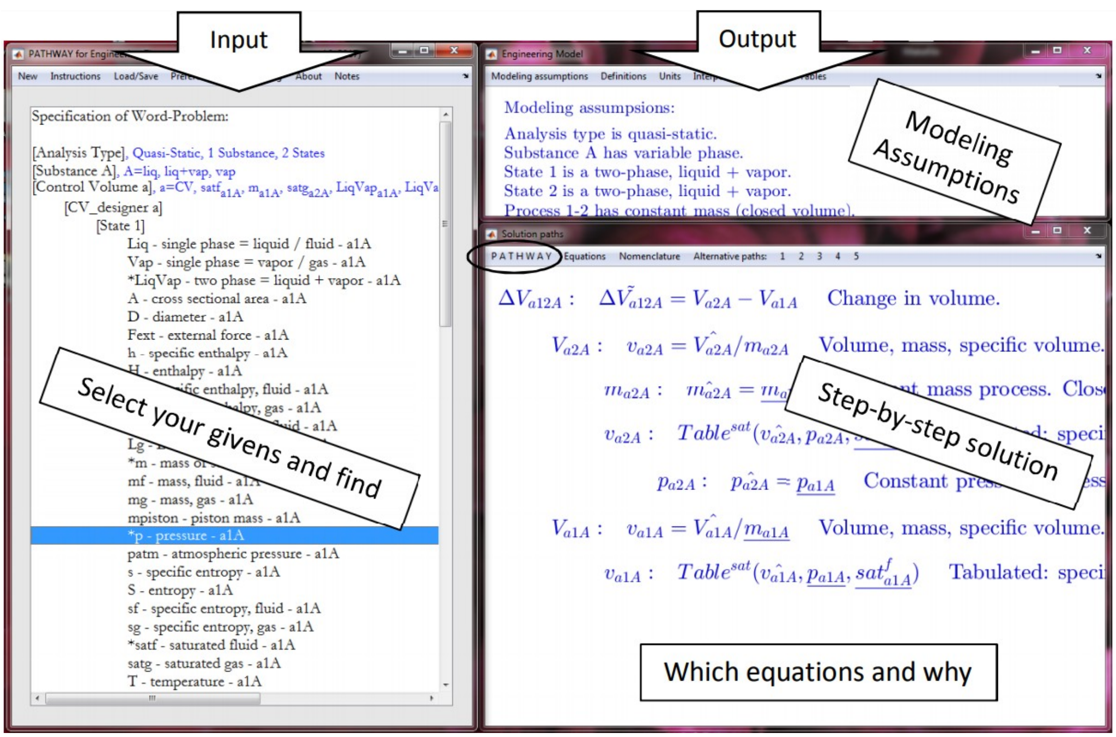

Figure 2: Pathway prototype. To get unstuck, a user inputs their word-problem specifications into the right window using the expandable menus. Then in the right windows, Pathway will output modeling assumptions and a step-by-step solution path.

III. Personalized scaffolder

Different students require different amounts of help. But just showing a student a correct solution path is not enough if that solution does not address the issue that the student had with their own solution path. We plan to develop the first ultra-precise personalized scaffolder with Pathway. The issue being solved is that when students solve word-problems, they either get stuck and learning stops, or they complete the problem without knowing if they did so correctly or incorrectly. Unlike learning the piano or sports, there is no immediate feedback in STEM for corrective action. Once the solutions are provided days later, the official solution often does not follow the same path as that of the student. One method we are exploring is to enable the student to enter the sequence of steps of their very own solution path, where the tool will constrain the student's steps to only valid choices along the way. This idea is depicted in **Figure 3**. The two columns in **Figure 3** (Left) show the student's incorrect solution steps and professor's correct solution steps. In STEM, there are many valid solution paths. For example, there can be four valid choices for Step 1; i.e., 1a, 1b, 1c, or 1d. The professor's solution path was different than the student's, where only Step 1a is the same in both paths. The student's Steps 4 through 7 are incorrect. Although the student's Steps 1 to 3 are valid, knowledge of the professor's solution path does not necessarily help the student determine how to correct the misconception in their own solution path at Step 4 and beyond. However, **Figure 3** (Right) depicts my proposed solution to this issue. At each step, Pathway will offer the student all possible next steps, which enables the student to choose their preferred valid step, one step at a time, which provides ultra-precise personalized scaffolding and it precisely identifies their prior error.

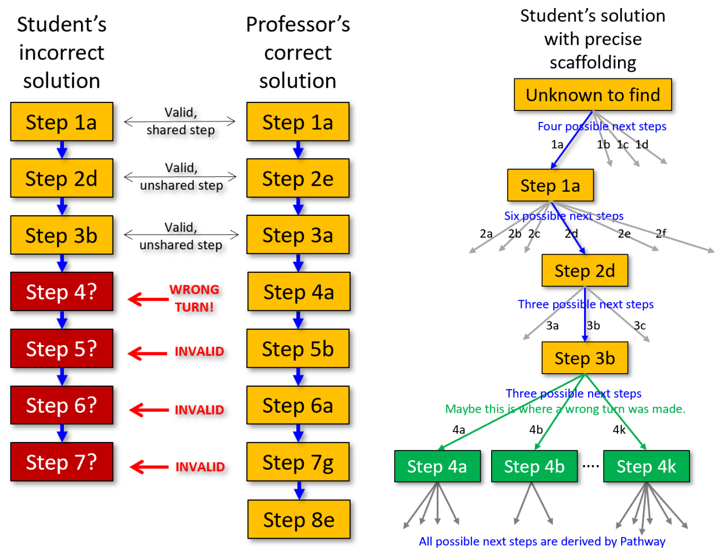

Figure 3: (Left) Different mathematical steps taken by the student and professor. (Right) How Pathway will pricely scaffold and correct the student's preferred solution steps.

To test and optimize our personalized scaffolder, we plan to get user feedback from students that will be enrolled in thermodynamics at Auburn University. In comparing students that use Pathway to those that do not, we will compare their study-times, amount of times they got stuck and ceased to progress, amount of times they did not master one lecture's concepts before preceding to the next lecture, ability to explore curiosities, amount of additional problems tried, necessity to attend office hours, exam scores, and level of frustration.

IV. Summary

An Achilles heel of prior intelligent tutoring systems since the 1970s has been the course-authoring problem. We are addressing the course-authoring issue with our STEM word-problem solver, which is the first that is able to derive solution paths of arbitrary engineering word problems, which should not be confused with mathematical equation solvers that already exist. Another problem with learning tools is their lack of personalization. However, we propose to address the personalization issue by adding our unique personalized-scaffolding algorithm to our word-problem solver. Our personalized scaffolder is expected to help develop students' problem-solving skills by enabling them to prescribe their very own guided solution path, which will enable the tool to precisely to pinpoint their student's area of weakness and making the appropriate solution path corrections. Additional benefits might include: reduced study time, optimized learning, elimination of downtime, ability to explore curiosities, unlimited practice, reduced frustration, and increased exam scores.

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