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Work in Progress: Homework in the Digital Age: The Implementation, Effects, and Perception of Randomly Generated Custom Digital Assignments

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Abstract

This work-in-progress paper studies a particular method of creating and utilizing digital homework. Online homework systems are prevalent in many STEM fields. Such systems are valued for their ability to save time for faculty in preparing and grading homework assignments as well as for providing immediate feedback to the students. However, such systems also make it difficult to identify which students are actually working through the problems, and which students are obtaining their solutions illegitimately. In this work, a system was designed to randomly generate unique custom problems and track user activities as they attempted to solve the problem. The system generates a random pipe flow problem incorporating major and minor head losses for a junior level mechanical engineering fluid mechanics course. Assignment performance, exam performance, and user feedback were collected over three separate semesters for a total of 125 students. The effects on performance are currently inconclusive. On average, students reported a positive perception of the assignment. Additionally, the survey responses indicated that the students appreciated the ability to attempt a problem multiple times, receive immediate feedback on the correctness of their answer, and receive hints that allow them to check portions of their analysis.

Background

Homework is a crucial part of every student's education, especially in STEM disciplines. The statement that "the one who does the work does the learning," [1] can be clearly seen in action by any educator. However, in recent years more and more students are turning to copying and missing this crucial part of the learning process [2]. The growth of online homework "help" websites has made it easier and easier for students to attempt to shortcut this critical step in their learning process. In fact, many students don't even consider the use of such websites to complete their homework to be cheating. [3] There have been some attempts with online homework systems to use randomized variables and questions to mitigate this problem, but in most STEM subjects, the different values of the problem parameters all lead to the same underlying equation, and students only need to put the numbers from their problem statement into the proper equation.

One of the crucial educational objectives served by homework is providing students with formative feedback as they develop their understanding of new material. This feedback on their work is an important component of the learning process [4], though there is some disagreement on when that feedback is best delivered [5].

This work attempts to address the growing issue of students seeking to copy homework solutions while also providing immediate feedback regarding the correctness of their work. This is accomplished by using randomly generated homework problems. That is, problems for which the system to be analyzed is itself randomized, not just the particular values of various variables in given problem statement. These problems are presented in a digital environment that can not only provide feedback to the students on the correctness of their final solution but can also provide hints that a student can use to check various parts of their work. The topic that is addressed is the analysis of the flow of an incompressible fluid through a pipe or series of pipes. For this scenario, the governing equations are the energy equation for pipe flow with no pumps or turbines:

$$\frac{P_{in}}{\gamma}+\frac{v_{in}^2}{2g}+z_{in}=\frac{P_{out}}{\gamma}+\frac{v_{out}^2}{2g}+z_{out}+\sum_{i=1}^{n_{pipe}}\left(\left(f_i\frac{L_i}{D_i}+\sum_{j=i}^{n_{fit,i}}K_{L(i,j)}\right)\frac{v_i^2}{2g}\right)$$

and the continuity equation for an incompressible pipe flow:

$$v_iA_i=v_{in}A_{in}=v_{out}A_{out}$$

where 'i' is the index of any pipe in the system.

The program was developed in Excel with extensive use of visual basic for applications. Excel was selected due to its easy ability to record the problems each student was given, record the results of the students' answer submissions and hint requests, and easy transferability. With the program developed in VBA modules, the students can download the Excel document, generate their problems, check their solutions for each problem, and resubmit the same document after it recorded all of their interactions. An alternative approach would be to develop the program on a web-based platform, generating new problems server-side, and recording user interactions for the instructor to later assess.

Development

Due to the known limitations of previous implementations of digital homework assignments, it was desired that the problems generated be truly random, not only in the numbers used in the problem statement, but also in the system to be analyzed. Flow through a series of pipes lends itself to such randomization quite nicely. Furthermore, it is possible to specify the level of difficulty of a problem so that a student just beginning to learn to apply energy analysis to pipe flow won't receive a problem that is too challenging [6], [7].

A. Randomized parameters.

The first step was to explicitly identify what physical components a piping system can have and what boundary conditions must be known in order to uniquely identify the flow rate through the system. Once these are identified it would be possible to solve for the flow rate through the system. Specifically, if the entrance to the system, the piping components of the system, and the exit from the system are known, then the flow rate can be determined through application of the energy equation.

A piping system can have 3 basic types of entrances. The entrance to the system being analyzed can either be a point in a section of pipe, an open reservoir of fluid, or a pressurized tank of fluid. In the second and third cases, the type of transition into the first pipe must be specified. Thus, there are a total of $(1+2\cdot n)$ types of entrances that might be incorporated into any particular problem, where (n) is the number of types of transitions from a reservoir or tank that are considered. For the purpose, of this generator, reentrant, flush, and well-rounded transitions were considered, resulting in 7 unique types of entrances.

The components of a piping system are whatever pipes, fittings, pumps, and turbines are present. For the pipes, the diameter, length, and material of the pipes must be specified. For more complex problems, multiple different diameters of pipes might be incorporated. For the fittings, the number of different types must be specified. For the pumps and turbines, the head added or removed from the flow should be specified. The behavior of pumps and turbines is actually quite a bit more complicate than this, but this simplification was deemed acceptable for this problem type at this point in the students' education.

Finally, there are 4 types of possible exits that were considered. The exit could be into an open reservoir, into a pressurized tank, from the last pipe into the atmosphere, or through a nozzle into the atmosphere. In each case the elevation and pressure at the end must be known. For the exits in a reservoir or a tank, the final elevation is considered to be on the surface of the fluid.

B. Difficulty selection.

Before a system could be generated, different difficulty levels needed to be identified to ensure that a student new to the topic would receive a reasonable problem, and a more practiced student could be given a more challenging problem [6], [7]. There are several factors that affect the difficulty of these problems. First, problems with either an unknown flow rate or an unknown pipe diameter are the most difficult since they require an iterative approach to finding the Darcy friction factor, with having an unknown diameter being somewhat more difficult than an unknown flow rate. Second, the number of components a system has affects the difficulty of properly tracking and incorporating the effects of each component on the behavior of the whole system. Once these influences were established, 5 different difficulty levels were created, the characteristics of which are shown in Table 1 below.

Table 1: System characteristics for the various difficulty levels.

Difficulty Level	Number of Pipe Sizes	Number of Fitting Types Per Pipe	Possible Unknowns
1	1	0 – 1	Pressure Elevation
2	2	2 – 3	Pressure Elevation Pipe Length
3	3	2 – 3	Pressure Elevation Pipe Length
	1	1	Flow Rate
4	2	1 – 3	Flow Rate
	1	1	Pipe Diameter
5	2-3	2 – 4	Flow Rate Pipe Diameter

C. Problem generation.

With these parameters identified, the problem generation algorithms can proceed. The problem generation process begins by selecting the fluid, entrance type, and pipe material. The entrance location is considered to be the reference location for the system elevation, and the material limits the pipe sizes that can reasonably be considered.

Next, the pipe diameter(s) are randomly selected. The diameters are generated such that they are reasonable for the material selected and no two pipes (if there are more than one) are the same size. Once the pipe diameters have been selected, the pipe lengths are randomized to values reasonable for pipes of the given diameter. Then, for each section of pipe, the types and number of fittings present are randomly selected.

Finally, the exit from the system must be determined. Once the exit type is selected, the elevation of the exit must be chosen, and if the exit is pressurized, the exit pressure must be chosen. The exit elevation and pressure are carefully controlled to ensure that a non-physical problem is not generated.

Once the physical description of the system has been generated, the flow rate though the system can be solved using standard equations for fluid flow. The solution is inherently iterative in nature and is iterated until it reaches convergence of 10^{-8} with respect to the changes in the Darcy friction factor(s) of the pipe(s).

Finally, a problem statement is generated for the student detailing the fluid, entrance, pipes, fittings, and exit from the system. During the problem generation, whatever information is to be solved for by the student is excluded from the problem description.

D. Hints.

Once all of this has been created, a set of hints is generated based on what the student is solving for. Any hint that would allow the student to directly determine the requested value without solving the larger problem is disabled. The hints are set up such that a student can check portions of their work against the correct values, just as a tutor or instructor might do when helping them find errors in their work. The student can request a hint regarding the total head at the inlet, total head at the exit, head loss in each pipe, flow velocity in each pipe, total minor head loss coefficient in each pipe section, or the Darcy friction factors for each pipe section. Table 2 shows which types of hints are disabled for each problem type.

Table 2: Hint types that are disabled for various problem types.

Hint Type \ Solving For	Inlet pressure	Exit pressure or elevation	Length of first pipe	Flow rate	Diameter of first pipe
Inlet head	X			X*	X*
Exit head		X		X**	
Pipe head losses	X	X	X***	X	X***
Pipe velocities				X	X***
Minor loss coefficients					
Darcy friction factors					

* Only disabled if the inlet to the system is not a reservoir or tank.

** Only disabled if the exit from the system is not a reservoir or tank.

*** Not entirely disabled, but information for the first pipe will not be given.

Implementation

The digital problem generation was assigned as a part of the students' homework when studying pipe flow. The students used the problem generator to create 3 problems of varying difficulty levels, which they solved on paper and used the program to check their solution. If their solution was incorrect, they were expected to search for their errors and correct their work before submitting their homework.

The students were given surveys before and after they completed the assignment to investigate preconceptions they have regarding digital homework, how this assignment compares to previous experiences, and what features they disliked, appreciated, found to be useful, or would like to see included in the future. These surveys have multiple purposes. The primary purpose is to guide the development of future such digital homework assignments. Student perceptions are important in identifying aspects of the assignment that are more detrimental than beneficial so that they can be fixed or removed. Additionally, the surveys give some indication of whether the goal of developing a digital assignment that is superior to other systems the students have experienced in the past has been achieved.

Discussion

Thus far, the assignment has been given to 125 students over 4 semesters. Their performance was compared to that of 234 students who took the course with the same instructor but without the digital homework assignment in 5 prior semesters. The students' grades on the related exam problems were normalized based on their overall grade in the course to see how well students learned this particular topic as compared to how well they performed in the whole course. The results were promising, but inconclusive due to the presence of other possible contributing factors such as differences in the instruction and exam problems across semesters. Additionally, the performance of students was broken down by their final course grades to see if any difference were observed. The results are summarized in Table 3.

Table 3: Ratio of average grade on pipe flow exam problem to overall course grade.

	Normal Pipe Homework					Digital Pipe Homework			
Semester	1	2	3	4	5	6	7	8	9
Overall	93%	62%	95%	119%	107%	117%	122%	103%	125%
A	92%	76%	97%	107%	102%	105%	102%	97%	104%
B	98%	62%	96%	114%	99%	112%	112%	96%	110%
C	91%	61%	93%	124%	111%	115%	122%	103%	118%
D	83%	59%	91%	139%	141%	144%	124%	107%	143%
F	91%	43%	105%	135%	136%	159%	145%	111%	160%

As can be seen in the table above, students in every semester in which the digital assignment has been implemented have performed better, on average, on the pipe flow exam problems than on the course as a whole. However, in the last two semesters with normal written homework, higher performance on the pipe flow exam problem was also seen. This makes it uncertain whether the digital homework is having the desired effect of improving learning or if there are other effects affecting the scores. It is also noteworthy that the lower performing students had a showed a more pronounced difference between pipe flow analysis grades and grades received for the whole course. This may indicate that using such an approach could be a way of improving the understanding of struggling students.

The program was well received by students, as evidenced by survey responses and end-of-semester feedback received by the instructor. Of the students who responded to the follow-up survey, 50% rated the assignment as slightly or significantly better than other digital assignments, while 32% rated it as equivalent to other digital assignments. However, what was more surprising was what while only 17% expressed a preference for digital homework assignments in the pre-survey, in the post-survey 53% rated the digital homework assignment as more effective than traditional homework assignments and 35% rated it as equally effective. The aspects that the majority of students identified as the most useful were the ability to control the difficulty of the generated problems, the availability of multiple attempts, the availability of targeted hints, and the immediate feedback regarding the correctness of their solution. The most requested additional feature was the ability to get a detailed breakdown of the values given by the hints instead of just a number to compare their work to.

Conclusions

Although inclusive, it seems that the assignment may yield improved learning compared to traditional homework. More investigation will need to be done on this. The students were satisfied with the problem generator (as indicated by survey feedback) and offered valuable feedback regarding potential improvements. Additionally, the instructor was pleased that the assignment is much more robust than other digital homework randomizers in its ability to promote the engagement of each student with the problems by eliminating the easy methods of cheating.

Although a significantly larger amount of work is required to develop this sort of assignment, that work only needed to be done once. Unfortunately, the time required to develop it was not tracked, but it is expected that the experience of creating the tool will significantly reduce the time required to develop similar software in the future. After it is completed, this method effectively solves the problem of students being able to copy their homework solutions. This won’t deter those who are the most determined to cheat and thereby damage their own education, but it provides a solid deterrent to the easy methods of cheating.

Future Work

The feedback from the students identified several improvements that could be made to the implementation of the assignment. Most prominent was a desire for a few “free” hints and an incorrect answer submission without being penalized. Additionally, many expressed an appreciation for the simple hints that are currently given, but they also desired the ability to ask for a more detailed explanation of how a particular value was calculated if they got stuck.

Further development of the pipe flow problem generator is required to implement the possibility of including pumps or turbines in a piping system. Additionally, a program to generate problems for branching pipe flow instead of series pipe flow would be beneficial.

A study conducted with a simultaneous control group will be needed to conclusively quantify the effects, if any, on the learning outcomes of students using this sort of homework system. This may be done with this problem generator, or additional problem generators may be developed for this or another course to study the effects.

Using this methodology on various other topics and subjects is an obvious next step that is ongoing. Not all topics lend themselves well to this approach, but many engineering problems can be broken into component parts and randomly generated in a similar manner. Even for more complex topics, this method could be used to generate introductory problems to help students develop foundational skills before tackling more complex systems.

Finally, it would be beneficial to have the algorithms developed for deployment as a website. It would need to be set up with all calculations and logging to be performed server-side to ensure security. The algorithm is entirely based on random number generation, simple mathematical operations, conditional statements, and various types of loops, so the implementation should be relatively straightforward for someone familiar with web development and engineering computation.

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