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Student Problem Solving on Textbook and YouTube Problems Pertaining to Vapor-Liquid Equilibrium

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Abstract

Faculty often utilize homework problems to help students practice problem solving. Recently, with textbook solution manuals being freely available online, students are prone to copying/cheating, which can severely limit improvements in problem solving. One hypothesis is that YouTube problems could serve as alternatives to textbook problems to significantly reduce cheating and promote better problem solving. YouTube problems are student-written problems that were inspired by events in a video publicly available online. While our previous studies have showcased positive attitudes related to engineering, high engagement, and rigor of YouTube problems, the current study examines a subset of problems related to one major course topic, namely vapor-liquid equilibrium (VLE). The cohorts included engineering students from a public university who were assigned homework problems as part of a Material and Energy Balance (MEB) course. Two constructs were explored: problem solving and perception of problem difficulty. The study adopted an established and validated rubric to quantify performance in relevant stages of problem solving, including problem identification, representation, organization, calculation, solution completion, and solution accuracy. While problem solving can be influenced by perception of problem difficulty, the widely used NASA Task Load Index (TLX) was adopted to measure the problem rigor. This compared textbook and YouTube problems with respect to overall problem-solving ability as well as within each stage of problem solving. Furthermore, paper investigated whether disparities exist in students' perceptions when solving VLE problems. Students displayed at least 7% higher problem solving abilities when solving YouTube problems compared to when a Textbook problem was completed. Finally, problem solving and perception of problem difficulty negatively correlated with a stronger correlation for the Textbook problem compared to YouTube problems.

Keywords: problem solving, rigor, visuals, problem-based learning

Introduction

Online teaching has increased due to institutional responses to the COVID-19 pandemic [1]. Concerns over student engagement and faithful completion of assigned coursework have been exacerbated due to the online availability of solution manuals to standard textbook problems [2]. Student access to solution manuals, on sites such as Chegg and Course Hero, has caused significant harm in the expected development of student problem-solving ability [3]. In fact, many students do not consider copying homework from a solution manual as a form of cheating [4].

Instructors have explored multiple strategies to improve the authentic learning experience of students [1, 5]. One promising strategy has been the use of a YouTube pedagogy. Students use videos that are accessible in the public domain to create novel problems that explain engineering concepts. In this manner, YouTube pedagogy provides useful solutions to the engagement challenges experienced by instructors. Additionally, YouTube pedagogy has generated an archive of new problems that can significantly mitigate the issue of the solution manual dilemma.

Besides the issue of academic integrity, YouTube pedagogy has led to improvement in student conceptual understanding and engagement. In addition to improved engagement in classroom, advancement in YouTube pedagogy led to the adoption of a student-centric environment in teaching where students employ numerous learning levels in Bloom's taxonomy through creating homework problems from videos and solving problems [6]. Over the years, student-written problems formed by reverse engineering a video to apply course concepts have been archived and are referred to as YouTube problems. Examples of YouTube problems are detailed in a number of publications [7-9].

YouTube problems fall under a category of contextual problems that possess the potential of improving learning outcomes [10, 11]. Previous studies have incorporated YouTube problems as substitutes for textbook problems and recorded improved problem-solving skills and learning attitudes with solving YouTube problems [12, 13]. YouTube problems are qualitatively similar in content with textbook problems and could be administered as in class, homework, quiz, or exam problems. However, this study is limited to deployment of YouTube problems as homework.

Material and Energy Balance (MEB) is an introductory course for chemical engineers. Students learn material balance calculations coupled with stoichiometry. MEB courses typically begin with stoichiometry followed by material balance for reacting systems with recycles and systems for vapor-liquid equilibrium (VLE). While course design contain multiple topics and homework problems [13], this study takes a specific approach by examining students' experience when solving YouTube problems pertaining to a major course topic related to VLE. This study compares homework problems within VLE using two major constructs: problem solving and perception of problem difficulty.

The study adopted an established and validated rubric called PROCESS to quantify performance in relevant stages of problem solving [13-15]. Problem solving can also be influenced by perception of problem difficulty, so the widely used NASA Task Load Index was adopted to measure the problem rigor. This paper will compare textbook and YouTube problems with respect to problem-solving ability and at each stage of problem solving. Furthermore, we will investigate whether disparities exist in students' perceptions when solving VLE problems.

Methods

Problems considered in the current study represent part of homework sets completed by students in a MEB course. We considered three problems from the VLE topic — one Textbook homework (traditional homework problem) and two YouTube problems (see S.1 for problem statements).

The intervention constituted of a group of 182 students (40% females) across two academic years from a large public university. The distributions for highest mathematics courses completed by group and demographic information were recorded to be similar across two cohorts (Table 1). As a result of similarity between cohorts, both cohorts were combined for analysis.

Table 1. Comparison of participants across two academic years. Cohort 1 and 2 represent participants in 2018 and 2019 academic years respectively, while combined is an aggregate of both cohorts.

	Math Course	Cohort 1	Cohort 2	Combined
Cohort information	Total	90	92	182
	Female %	42	38	40
% By highest math course	Calculus 1	68	65	66
	Calculus 2	12	17	15
	Calculus 3	12	11	12
	Differential Equation +	7	7	7

Quantifying Problem-Solving Ability using PROCESS

Students' problem-solving skills were measured using a modified PROCESS rubric with 6-stages: Problem definition, representing the problem, organizing information, calculations, solution completion and accuracy (see S.2 for PROCESS rubric). PROCESS was modified to assess the problem-solving process for solved handwritten homework problems, which differs from its original use where participant solutions were collected on tablets with custom software [16, 17]. The tool was modified to suit MEB problems [13]. Each item in the revised PROCESS consists of four scaling levels ranging from 0 to 3 with zero being the minimum attainable score. To ease in communicating the findings, aggregated PROCESS scores were rescaled from 0 to 100, with 100 representing a perfect score.

While implementation of YouTube pedagogy involved a large group ~90 students in each year (Table1), ~30 students' work from each cohort were selected to be scored using the PROCESS instrument for ease in assessment. Prior to scoring with the modified PROCESS, identifiers regarding student or group identity were removed. Participants' names were replaced with a project-assigned ID number to maintain privacy and to mask group membership from raters. All students' solutions were scored using the PROCESS rubric after the semester. Thus, PROCESS scores did not reflect or influence students' course grades.

In the present analysis, four different raters used the PROCESS tool to assess problem solving to eliminate possible rater bias. Raters' assessments were analyzed to determine how consistently raters measured problem-solving ability. Traditional statistical (intraclass correlation coefficient, ICC) and item response measures (rater severity from the Rasch many facets model) of inter-rater reliability were computed for the four raters, as previously described [18]. The many-facet Rasch measurement model provided a correction for any differences in rater severity in assessing PROCESS scores, such that the scores were free from any rater bias/leniency [19]. A previous paper detailed the process of establishing inter-rater reliability for multiple raters using the PROCESS rubric[15]. Consequently, the intraclass correlation coefficient (ICC) reported that the scores from the four raters were highly reliable. The average measure ICC was 0.92 with a 95% confidence interval from 0.90 to 0.93 (F (262, 786) = 11.8, $p < 0.001$).

Assessing Problem Difficulty with the NASA TLX

In the case of problem solving, researchers must know how difficult the problem is in order to make a valid assessment of performance, i.e., comparing performance across problems, problem types, and participants. NASA TLX (Task Load Index) provides an appropriate gauge of problem difficulty [20]. For over three decades, NASA TLX has measured workload by assessing six constructs: three measuring demand put on the participant by the task, and three measuring stress added by the participant as a result of interacting with the task. The three measures of task demand are mental demand, physical demand, and temporal demand, while stress measures include effort, performance, and frustration. The original NASA TLX measured workload in two stages consisting of participants' ratings of each subscale and a pairwise comparison of each subscale [20-25]. For ease of administration, NASA TLX could utilize participants' rating in exclusion of the pairwise comparison of subscales, which is often referred to as Raw TLX [26].

The current study utilized only the participants' TLX ratings to measure the rigor of problems (Table 4). Previous work showed that seven categories or more frequently exceeds the discriminative capacity of the respondent [27]. For each participant, responses to the 6 TLX questions were analyzed by aggregating TLX ratings rescaled to an aggregate score that ranges from 0 to 100. More demanding tasks earn higher scores. Difficulty of a problem was assessed by averaging participants TLX scores for each problem.

Results and Discussion

Problem-Solving Ability with PROCESS

Across 60 randomly selected participants whose works were assessed using PROCESS rubric, only 50 students completed all three problems considered for analysis. PROCESS scores earned by these 50 students in each problem were compared in pairs. Throughout this paper, YT1 and YT2 represented YouTube problems while TB is the Textbook problem. Two tailored t-tests compared problems, and significance was considered when $p < 0.05$.

Table 2. Comparing PROCESS scores for 50 students solving VLE problems.

	Problem pair	Mean ± SD	*p*
Pair 1	TB	71 ± 13	0.004*
	YT1	79 ± 11	
Pair 2	TB	71 ± 13	0.06
	YT2	76 ± 13	
Pair 3	YT1	79 ± 11	0.2
	YT2	76 ± 13	

* Denote statistically significant differences between compared pairs.

Problem solving displayed for each YouTube problem compared to Textbook problem such that students gained higher PROCESS scores when solving YouTube problems (Table 2). However, the differences between PROCESS scores in YouTube problem versus Textbook problem differed in varying degrees. First, PROCESS scores earned for YT1 were 8 points higher than scores for TB, and differences were statistically significant ($p = 0.004$). Next, ~7% higher PROCESS scores were measured for YT2 than TB, which was just outside being statistically significant ($p = 0.06$). Finally, PROCESS scores from both YouTube problems (YT1 and YT2) were similar ($p = 0.2$). Overall, problem solving displayed for YouTube problems were measured to either be statistically higher or higher and statistically similar to Textbook problems. Increases in problem solving recorded for YouTube problems could be as a result of the real world nature of problems, which been reported in other studies to increase learning outcomes [10, 11]. In addition to contextual nature of YouTube problems, the visual aspects which in turn enhance learning attitudes and help students understand better may also be contributing factor to better problem solving [9, 12, 13, 28].

Table 3. Ranking for categories in PROCESS for 3 VLE problems.

Ranking from most to least difficult	Categories	Nominal order of PROCESS
1	Solution Accuracy	6
2	Calculation	4
3	Organization	3
4	Solution Completion	5
5	Problem Identification	1
6	Representation	2

The order of severity of stages in the PROCESS were similar across all YouTube and Textbook problems related to VLE. Solution accuracy identified as the most difficult item within PROCESS (Table 3). Solution accuracy measures the final outcome of problem solving and is not surprising to be most severe as low scores might be compounding from missing or incorrect steps identified with earlier stages of problem solving, such as Organization and Calculations components.

Problem Difficulty with NASA TLX

NASA TLX surveys collected for all students taking MEB across two cohorts were screened and only responses from students who completed NASA TLX for all three VLE problems were analyzed. Out of 182 students, 73 students completed NASA TLX rating for all three VLE problems considered in this paper.

Table 4. Comparing NASA TLX of VLE problems rated by 73 students.

	Problem pair	Mean ± SD	*p*
Pair 1	TB YT1	45 ± 11 40 ± 16	0.003*
Pair 2	TB YT2	45 ± 11 49 ± 16	0.02*
Pair 3	YT1 YT2	40 ± 16 49 ± 16	<0.001*

*Denote statistically significant differences between compared pairs

Students reported different rigor for three problems considered (YT1, TB and YT2). While YT1 was reported to be the least rigorous, YT2 was considered most difficult. Though differences in rating between YT1/TB pair and YT2/TB pair were ~ 10%, differences within each pair were measured to be statistically significant. Though all problems considered fall into the same topic, findings show that students' perception of problem difficulty are not only associated with problem topic or problem type but could be influenced by individual problem. Additional comparison revealed a statistically significant difference ($p < 0.001$) between the two YouTube problems (YT1 and YT2).

Table 5. Significance ranking in NASA TLX across three VLE problems.

	Rank	Categories
Most significant	1	Effort
	2	Mental
	3	Frustration
	4	Physical
	5	Temporal
Least significant	6	Performance

The order of significance of each item in the NASA TLX were same across all YouTube and Textbook problems about VLE (Table 5). In addition, item analysis identified mental demand, effort, and frustration as the most significant factors to problem difficulty across all three VLE problems. Mental demand and perceived effort appearing as the most significant categories indicated that solving VLE problems tasked students more mentally than any other load. And as expected, physical and temporal demand were among the least significant categories since for completing tasks, less physical exertion was required, and sufficient time – about 1 week was allotted for each homework.

Correlation between Problem Difficulty and Problem solving

NASA TLX and PROCESS scores for all students taking MEB across two cohorts were matched and only students whose work were assessed with PROCESS and had completed the NASA TLX were analyzed. The number of students who had both NASA TLX and PROCESS scores for Textbook problem and YouTube problems were 26 and 46 respectively (Table 6).

Table 6. NASA TLX - PROCESS correlations across various VLE problems

Problems	Pearson coefficient (r)	Slope	N	*p*
TB	-0.5	-0.6	26	0.01*
YT1	-0.03	-0.03	46	0.8
YT2	-0.2	-0.3	46	0.1

*Denote statistically significant correlations

Correlating NASA-TLX with PROCESS provided some relationship between problem solving ability and perception of problem difficulty. NASA TLX - PROCESS correlations (Table 6) for Textbook problem, TB yielded a significant Pearson coefficient ($p = 0.01$) that translates to a moderate negative correlation ($r = -0.5$). However, NASA TLX -PROCESS correlation for YT1 and YT2 (Table 6) resulted in weaker negative correlations ($r= -0.03$ and -0.2). Overall, findings reveal a significant negative correlation between problem solving ability and students' perception of problem difficulty for textbook problems which aligns with a previous study perceived level of difficulty correlated with lower performance [29]. Contrary to findings for textbook problems, irrespective of difficulty perception, students still demonstrated higher problem solving ability in YouTube problems than in Textbook problems.

Conclusion

Homework-style, YouTube-inspired problems have been implemented in an undergraduate MEB course. YouTube problems were utilized as alternative Textbook homework problems covering vapor-liquid equilibrium concepts. Research questions were directed towards evaluating students' perception of problem difficulty and problem solving on three VLE problems — one from Textbook and two from archive containing student written YouTube problems.

An established problem-solving rubric was implemented. Problem solving displayed when 50 students solve YouTube problems were measured to either be statistically higher or equal to those showcased for Textbook problems. Item analysis within PROCESS identified solution accuracy stage as the most difficult item. This finding is not surprising since solution accuracy measures the final outcome of problem solving and low scores might be compounding from missing or incorrect steps identified with earlier stages of problem solving.

NASA TLX quantified difficulty of the problems across six constructs. Overall ratings by 73 participants who completed NASA TLX for all three problems found ~10% difference in rigor between YouTube and Textbook problems. All pairwise comparisons yielded statistically significant differences in difficulty. The Textbook problem considered was perceived to be more difficult than one YouTube problem and less challenging than another YouTube problem. Similar to previous work, item analysis identified mental demand, effort, and frustration as the most significant factors to problem difficulty in solving MEB problems. In addition, a negative correlation was measured between problem solving ability and perception of problem difficulty.

YouTube problems written by students could easily be adaptable in other disciplines either as part of classroom activity or as replacements for traditional course problems. Replacing textbook problems with YouTube problems may help instructors tackle the issue of solution manual dilemma. Further iteration will compare problem solving in other topics that make up MEB course.

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Supporting Information

Exercise 5.5.1: Benzene-aniline flash. About

A liquid mixture containing 20.7 wt% aniline (C_6H_7N) and the balance benzene (C_6H_6) enters a flash tank. The tank is maintained at 1.25 bar gauge pressure and 125 °C. The flow rate of the entering stream is 42.0 mol/hr.

(a) Draw and label a process flow diagram. Clearly number each stream and indicate the components in each stream.

Solution

(b) Determine the molar flow rates (mol/hr) of the vapor and liquid streams exiting the flash tank. Also, calculate the mole fractions for all of the streams.

Solution

(c) If the pressure of the flash tank decreases by 33%, will the benzene composition in the liquid stream exiting the flash tank increase, decrease, or stay the same?

Solution

(a)

Video title: Artificial Trees That Absorb CO2 - Hot Planet Preview - BBC One
http://www.eng.utoledo.edu/~mliberat/ArtificialTreeMEB2019.html

1. An artificial tree prototype is being built to absorb carbon dioxide (CO2) out of the air to produce a cleaner atmosphere. This is achieved by running air through a column that has a special plastic packing. The prototype absorber is being first tested with a stream of oxygen (O2) and carbon dioxide gas. The inlet stream of gas is composed of 1.5 mole percent carbon dioxide and the balance oxygen. The inlet gas stream flows at 225 mol/h and is in vapor-liquid equilibrium at the bottom of the absorption column. The liquid inlet stream is pure water (H2O) and absorbs the carbon dioxide gas. The exit gas stream is set to have 0.4 mole percent remaining and the balance oxygen gas. The absorber operates at 28°C and 45600 mmHg. Antoine coefficients for CO2 at 28oC; A=7.58828, B=861.820, C=271.883

(a) Draw and label a process flow diagram.

(b) Find the mole fractions of each component in the liquid stream exiting from the absorber.

(c) Find the component molar flowrate (mol/h) of the streams exiting from the absorber.

(d) The pressure of the system is found to be lower than originally thought. How would the molar flow rate of inlet water change? (Increase, Decrease, Stay the same)

(b)

Video title: Ethanol Production Process
http://www.eng.utoledo.edu/~mliberat/ethanolMEB2019.html

3. A liquid stream containing 22 mol% water, 45 mol% ethanol, and balance solids is fed into a distillation column. The distillation column produces a gas and liquid stream. The liquid stream contains 37.5 mol% ethanol, and the balance water and solids. The flow rate of the gas stream is 75% the flow rate of the liquid stream. The gas stream flows at 135 mol/s and contains only ethanol and water. The gas stream is condensed and the new liquid is then fed to an evaporator working at 5670 mmHg and 152°C. The evaporator produces a liquid and gas stream in VLE.

(a) Draw and label a process flow diagram.

(b) Find the mole fractions and component molar flowrate (mol/s) in the streams exiting the distillation column.

(c) Find the mole fractions and component molar flowrate (mol/s) in the streams exiting the evaporator.

(d) If the pressure is reduced by 10% what happens to the mole fraction of ethanol in the vapor stream? Increase, decrease, or stay the same

(c)

S. 1: Assigned problem statements that covered VLE concepts for homework practice. (a) A typical Textbook problem (TB), (b) and (c) Student written YouTube problems (YT1 and YT2) respectively.

Table S.2. Modified PROCESS rubric for problem solving using handwritten solutions.

Problem Solving Process/ Category	Explicit Tasks Performed	Level of Completion				
		Missing 0 points	Inadequate 1 points	Adequate 2 points	Accurate 3 points	Error
Identify Problem and System Constraints	Identified unknown	Did not explicitly identify or define the problem/system	Completed few problem/system definition tasks with many errors	Completed most problem/system definition tasks with few errors	Clearly and correctly identified and defined the problem/system	Identified Incorrect unknown
						Identified fewer unknown than required
Represent the Problem	Drew a flow diagram	No representation drawn, no relationships indicated	Drew a representation or related variables, but not both	Drew a representation and related most variables with some errors	Drew a representation with all streams and process units and indicated variable relationships correctly	Too many/ fewer streams than required
						Wrong location of process unit
	Labeled the flow diagram					Wrong location of stream/process unit
Organize Knowledge	Identified known values	Did not explicitly organize information about the problem	Completed few information organization tasks	Completed most information organization tasks	Fully organized information needed to solve the problem	Solved using wrong values of known values
	Identified equations (atomic or component mass/mole balance equations)					Missing term in balances
	Identified extra equations example, Conversion, percentage excess,recycle ratio					Missing term in extra equations
	Identified other useful equations example, antoine, raoult's law equations					Wrote Incorrect formula
Calculation (Allocate Resources)	Manipulated/ solved equations	No work shown	Partially documented execution tasks (Work showed some evidence of relevant tasks)	well documented execution tasks but with few ommisions	Fully documented execution tasks (Work showed evidence of relevant tasks)	Calculation error from extra equation
	coverted to the required units(optional)					Did not simplify equations correctly
						Calculation error from balance
Final Solution Completion	Provided answers to the problem statement	All answers are missing	Explicitly evaluated some of the solution or evaluated incorrect unknown	Explicitly evaluated most of the solution	Evaluated all the solutions required	
Final Solution Accuracy	Correct/incorrect values for answers to all parts of the problem.	Missing Answer	Provides mostly incorrect answers or no units to all parts of the multiparts problem answer	Provides mostly correct answers and units to all parts of the multiparts problem	Provides correct answers and units to all parts of the multiparts problem	presents wrong answers
	Correct units for answers to all parts of the problem.					wrong units
TOTAL SCORE						