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Strategies for Using Online Practice Problems

Jess Everett
Rowan University

Kaitlin Mallouk
Rowan University

Joseph Stanzione
Rowan University

Jenahvive Morgan
Michigan State University

Strategies for using on-line practice problems

Dr. Jess W. Everett, Rowan University

Jess W. Everett has worked in four distinct areas: waste management operations research, contaminated site assessment and remediation, education innovation, and sustainable engineering. He has employed a wide variety of techniques, including computer modeling, laboratory experiments, field testing, and surveys. His current research focuses on energy conservation, alternative energy generation, engineering learning communities, and hybrid courses (courses with classroom and on-line aspects).

Ms. Kaitlin Engle Mallouk, Rowan University

Kaitlin Mallouk is an Instructor of Mechanical Engineering at Rowan University. Kaitlin has a BS in Chemical Engineering from Cornell University and an MS in Environmental Engineering in Civil Engineering from the University of Illinois. She is completing her PhD in Environmental Engineering with a focus on Air Quality Engineering at the University of Illinois.

Prof. Joseph Francis Stanzione III, Rowan University

Prof. Stanzione currently teaches Polymer Processing and Freshman and Sophomore Engineering Clinics. His teaching interests include thermodynamics; separations; reaction engineering; polymer science and engineering; green/sustainable chemistry and engineering; and bio-based materials. His research interests include the utilization of lignin as an alternative renewable chemicals feedstock; lignin-based plastics; green chemistry and engineering for the development of next-generation lignocellulosic biorefineries; and bio-based polymers and composites. His work has been published in Green Chemistry; ChemSusChem; ACS Sustainable Chemistry & Engineering; ACS Applied Materials & Interfaces; the Journal of Applied Polymer Science; and the Journal of Non-Crystalline Solids. He is currently collaborating with scientists at Drexel University, the University of Delaware, and the Army Research Labs. While at the University of Delaware, he completed the Higher Education Teaching Certification program, a program that is offered by the Center for Teaching & Assessment of Learning, and participated in the Chemical & Biomolecular Engineering's Teaching Fellowship program.

Dr. Jenahvive K Morgan, Rowan University

Strategies for using online practice problems

Abstract

PathFinder is an active website coded in html, asp.net, c#, JavaScript, xml, and MathML. The website assembles ebooks on the fly from an xml database. The ebooks have randomly selected and generated exercises that are automatically graded. Instantaneous feedback is provided to both students and teachers regarding performance on online exercises.

PathFinder is used to deliver an ebook to a first year introductory engineering course at Rowan University, Glassboro, NJ, USA. In Fall 2013, 12 sections of 20 – 25 students each used the Pathfinder ebook. Because PathFinder provides online practice problems that students can work before completing scored problems, this large implementation of the PathFinder ebook provides an opportunity to investigate the effectiveness of online practice problems. Practice problems can be "Similar" or "Related" to the student's scored problem.

Four sets of four problems each were used to investigate four scenarios. Scenarios were randomly applied such that each student was exposed to all four, but on different problem sets. In all scenarios the fourth problem had no practice problem, so it could be used as a test of the effectiveness of the practice problems provided for the first three problems. In the first scenario, no practice problems were provided. In the second, three similar practice problems were provided. In the third, three related practice problems were provided. In the fourth, the first problem had a similar, the second a related, and the third no practice problem.

Over 50 % of the students attempted at least one practice problem. Completing practice problems was associated with better scores on associated scored problems. The four scenarios did not result in different performance on their fourth problems, the ones without practice options. It appears that the first three scored problems provided sufficient skill acquisition. In essence, the first three scored problems were "practice" for the fourth.

Introduction

The PathFinder website was used to deliver an ebook to a first year introductory engineering course at Rowan University, Glassboro, NJ, USA. In the Fall 2013 semester, 12 sections of 20 – 25 students each used the Pathfinder ebook. A significant portion of a student's grade was based on their performance on 150 online scored problems. Practice problems were provided for many of the scored problems. This created an opportunity to investigate the effectiveness of online practice problems.

PathFinder provides online practice problems that students can work before completing scored problems. Practice problems can be "Similar" or "Related" to the student's scored problem. A similar practice problem is identical to the scored problem (same problem statement), but the given input values are different. A related practice problem is different from the scored problem, both in input values and problem statement, but requires the same skill set to solve.

Four sets of four problems each were used to investigate four practice scenarios. Scenarios were randomly applied such that each student was exposed to all four scenarios, but on different problem sets. In all scenarios the fourth problem had no practice problem, so it could be used as a test of effectiveness. In the "None" scenario, no practice problems were provided. In the "Similar" scenario, three similar practice problems were provided. In the "Related" scenario,

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three related practice problems were provided. In the "Mixed" scenario, the first problem had a similar, the second a related, and the third no practice problem.

The effectiveness of types of practice problems (Similar and Related) and the scenarios (None, Similar, Related, and Mixed) was evaluated using (1) student scores on problems, (2) survey questions completed by students after finishing each series of four questions, and (3) a survey administered to the students at the end of the semester.

The goal of this research was to better understand the role of online practice problems. This was done by exploring three questions. (1) Will students complete online practice problems? (2) Why do students complete (or not complete) online practice problems? (3) Do online practice problems help students to correctly complete online scored problems?

Background

Online homework has been used in various forms in college STEM classrooms for at least two decades. Studies have shown engagement with online homework to be either neutrally,[1,2] or positively correlated with course success,[3,4,5,6,7] particularly when compared to ungraded traditional homework.[8] Additionally, student and instructor attitudes towards online homework tend to be positive.[5,6,9,10] Online homework has several distinct advantages over traditional homework, such as providing students with real-time feedback,[4,5,7] the option to redo problems for partial credit,[5,6] and significant time savings for instructors.[5,6,9] Many of these advantages adhere to the Seven Principles for Good Practice in Undergraduate Education.[11] In particular, online homework encourages active learning, gives prompt feedback, and emphasizes time on task.

Online homework is not without shortcomings. A commonly cited disadvantage of online homework is that it does not allow for commenting on students' problem-solving process.[1] This downside is of particular concern when considering that studies have shown that, in the quest for higher grades, students tend to learn concepts by rote rather than pursuing a deep understanding of the topic.[10,12] However, previous research has shown that a majority of students using online homework in a general chemistry class made an attempt to learn from mistakes made on the homework and more than 90 % of students worked problems with pencil and paper before answering online.[6] Another study of online homework in a freshman chemistry class showed that students found the opportunity to practice concepts beneficial and those same students did not believe their passing quiz scores were due to pattern recognition.[10]

Within the PathFinder system, students have several options for gaining a more in-depth understanding of the topic while pursuing the correct answer to the scored homework questions. They can investigate the relevant topic within the ebook and they can attempt different types of practice problems before attempting the graded questions. Thus, by providing students with ample opportunities to practice, PathFinder system was designed such that students gain a deeper understanding of course material while minimizing repetition purely for the sake of achieving a high grade.

Course Description

The course described here is Freshman Engineering Clinic I, an introduction to engineering course taken by all freshmen engineering students at Rowan University. There were twelve sections of 20 – 25 students each in Fall 2013. The course is interdisciplinary, with chemical, civil and environmental, electrical and computer, and mechanical engineering majors in each

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section. The course met twice a week during the 15 week semester: a 50 minute "lecture" and a 160 minute laboratory session. The purpose of the course was three-fold: (a) help students make a good transition to college; (b) introduce students to engineering; and (c) prepare students for the engineering curriculum by teaching them basic skills.

The online portion of the course was implemented using PathFinder, an active website created at the University using html, asp.net, c#, JavaScript, and pathML, a PathFinder specific markup language. Content consists of images, html, xml, and mathML. Equations coded in mathML are used both for display and solving exercises.

The website assembles ebooks on the fly using pathML to access content as needed. Content is stored modularly, so a given variable, equation, article, etc. is stored once but can be called up to form a part of any ebook chapter. Updates are applied in one location and automatically appear wherever and whenever the associated material is incorporated into the online content. PathFinder ebooks have randomly selected and generated exercises that are automatically graded. The website provides instantaneous feedback to both students and professors regarding performance on online exercises.

The learning sequence supported by PathFinder is:

- Prepare for class;
- Demonstrate preparedness by completing BEFORE exercises;
- Attend class and participate in active learning activities; and
- Demonstrate skill acquisition by completing AFTER exercises.

Thus, PathFinder supports the flipped classroom. PathFinder ebooks incorporate online exercises to achieve the second and fourth steps. BEFORE-exercises motivate students to read chapters before class. AFTER-exercises provide students an opportunity to demonstrate what they have learned after materials are covered in class. Both types of exercises constitute a significant portion of a student's grade. Students access PathFinder through a dashboard that provides links to chapters and problems, and displays due dates and results (for each chapter: total score, percent score on completed problems, and number of problems completed) More general information on PathFinder is given elsewhere.[13,14]

Students are assigned exercises from banks, so they typically get different problems. Calculation problems have the input values randomly assigned, so even if two students get a common problem, the given information will be different. In the hybrid flipped course described here, students completed nine BEFORE, one for each chapter, and five AFTER online problem sets. Each problem set contains multiple problems. Depending on the course, offline homework can be assigned to provide students with more open-ended problem-solving experience. In the course studied here, the amount of offline homework varied between instructors.

PathFinder ebooks include multiple choice and calculation exercises. The ebook described here contained 757 exercises in 150 banks. BEFORE exercises were grouped into 86 banks. AFTER exercises were grouped into 64 banks. Each bank was used to select one problem for a given student; thus, each student completed 150 online questions over the course of the semester.

PathFinder can assign multiple choice or calculation problems. All of the problems included in this study are calculation AFTER exercises. An example is shown in Figure 1. Calculation problems can have multiple parts. As shown in the Figure, the student is on their first attempt of the first part of the problem, which has two parts total. This particular problem came from a bank

of 9, each randomly assigned to students in a given section. The given information (X_1 to X_5) was randomly varied for each student, so students assigned the same problem got different given information. PathFinder uses the same MathML used to display equation 1 in the Figure to determine the answer to part 2.

| PathFinder | Manage | Plan | Read | Work | Team | Help |

■ Sig Fig Terms
⊟ AFTER
　■ Rounding 1
　■ Rounding 2
　■ Rounding 3
　■ Significant Figures 1
　■ Significant Figures 2
　■ Significant Figures 3
　■ Significant Figures 4
　■ Significant Figures 5
　■ Significant Figures 6
　■ Significant Figures + 1
　■ Significant Figures + 2
　■ Significant Figures + 3
　■ Significant Figures + 4
　■ SF + Eval 1
　■ SF + Eval 2
　■ SF + Eval 3
　■ Significant Figures */ 1
　■ Significant Figures */ 2
　■ Significant Figures */ 3
　■ Significant Figures */ 4
　■ SF */ Eval 1
　■ SF */ Eval 2
　■ SF */ Eval 3
　■ Significant Figures */+ 1
　■ Significant Figures */+ 2
　■ Significant Figures */+ 3
　■ Significant Figures */+ 4
　■ SF */+ Eval 1
　■ SF */+ Eval 2

Exercise: Significant Figures */+- 3

Solve equations with correct significant figures

Given

The following values and an equation are given.

X_1 = 4.9 (units not given)

X_2 = 0.04 (units not given)

X_3 = 0.25 (units not given)

X_4 = 0.0067 (units not given)

X_5 = 0.2 (units not given)

$$Y_1 = \left(X_1 - X_2\right) + \frac{X_3 \cdot X_4}{X_5} \quad \text{(Eq. 1)} \ \boxplus$$

This exercise is the third in a series of four on significant figures and calculation problems with addition, subtraction, multiplication, and division.

Please do the four problems in order.

Question(s)

1. How many significant digits should be used to report the answer to equation 1? Count only the ones of which you can be certain.

[   ] (unitless) (Answer Length = 1)

| Score My Answer | Practice | Investigate |

2. Give the answer to equation 1 with the proper significant figures. Your answer must be exactly correct.

Attempt 1/3 of Part 1/2 for 5 points. Points (So Far/Possible/Total): 0/10/10 points.

Figure 1: PathFinder EBook Calculation Exercise

Each exercise is assigned a maximum score, which is equally divided between the parts. If the problem shown in Figure 1 was assigned 10 points, each part would have a maximum possible score of $10/2 = 5$. Maximum points are awarded for parts completed correctly the first time. Reduced points are obtained upon subsequent correct attempts. If the problem was assigned 8 and 6 points for second and third attempts, a student would obtain $10/2 + 6/2 = 8$ points upon completing the first part on a first attempt and the second part on the third. AFTER exercise scores count towards a student's grade.

The "Practice" button shown in Figure 1 can be used to access a similar or related exercise that the student can complete for practice; their score on the practice exercise is not recorded. Both practice and scored problems are taken from the same exercise bank.

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Methods

Sixteen AFTER calculation exercises were selected for this study. Table A1 in the Appendix is used to describe the four sets of four exercises. Set A contains four problems on using significant figures in equations with addition and subtraction only. Set B contains four problems on using significant figures in equations with multiplication and subtraction only. Set C contains four problems on using significant figures in equations using addition, subtraction, multiplication, and division. Set D contains four problems on maintaining unit consistency in equations.

AFTER exercises were used for this study because they are calculation based. The BEFORE exercises for this course are multiple choice, of a type that do not work well with practice problems. Any calculation problems could have been chosen, significant figures and unit consistency were simply reasonable choices.

The sixteen exercises contain 35 parts. With 256 students using PathFinder, a total of 8,960 parts could be completed. One sample problem from each bank is included in the Appendix, after Table A1. Practice exercises were selected from the same banks.

The 16 exercises were used to investigate four scenarios for providing practice problems through four sets of four exercises. In each scenario the fourth problem had no practice problem, so it could be used as a test of the effectiveness of the scenario. In the "None" scenario, no practice problems were provided. This provided a control group. In the "Similar" scenario, three similar practice problems were provided for the first three exercises. In the "Related" scenario, three related practice problems were provided for the first three exercises. In the "Mixed" scenario, the first problem had a similar, the second a related, and the third no practice problem. The "Mixed" scenario needed four problems. This necessitated using four problems in the other scenarios.

Scenarios were applied such that each student was exposed to each scenario once. There are 24 ways to apply the four scenarios to four exercise sets, 4x3x2x1 = 24. Treatment one assigned sets A, B, C, and D to "None", "Similar", "Related" and "Mixed", respectively. See Table A2 in the Appendix for descriptions of all 24 treatments. Students were randomly assigned to a treatment; thus, each treatment was applied to approximately 1/24 of the students.

Each student ended up with 11 practice problems with 23 or 25 parts, depending on how the scenarios were applied to their sets. With 256 students using PathFinder, a total of 6,144 practice problem parts could have been completed by the students.

For the sake of this study, student performance was estimated for each part. Performance is *not* the grade assigned by PathFinder (described in the previous section). If a correct answer was not obtained, but at least one attempt was made, the student obtained 1 performance point. Three incorrect attempts were awarded 2 points (the student would be able to see the solution to the part). A correct attempt after two incorrect attempts was awarded 3 points. Similarly, a correct attempt after one incorrect attempt was awarded 4 points. Finally, a correct attempt on the first try was awarded 5 points. It was in the student's interest to avoid incorrect attempts due to the grade penalty associated with incorrect answers.

After students completed each exercise set they could complete 3 survey questions on PathFinder. The response rate was 88 % (224 of 256). The questions and possible answers are given in Table A3 in the Appendix.

A second survey of 12 questions was administered via SurveyMonkey® during the last two weeks of the semester. The response rate was 58 % (150 of 256 students). Two questions obtained results pertinent to this study (Table A4 in the Appendix). Student responses were anonymous.

Results and Discussion

Do Students Practice?

The 256 students using Pathfinder attempted only 723 practice exercise parts out of a possible 6144 associated with the four exercise sets. This is only 12 % of the possible parts. However, over 50 % of the students (136 of 256) completed at least one part of a practice exercise.

Students could attempt each part up to three times. After three attempts (successful or not) PathFinder displays the solution of a part. Students attempted practice parts as shown in Figure 2.
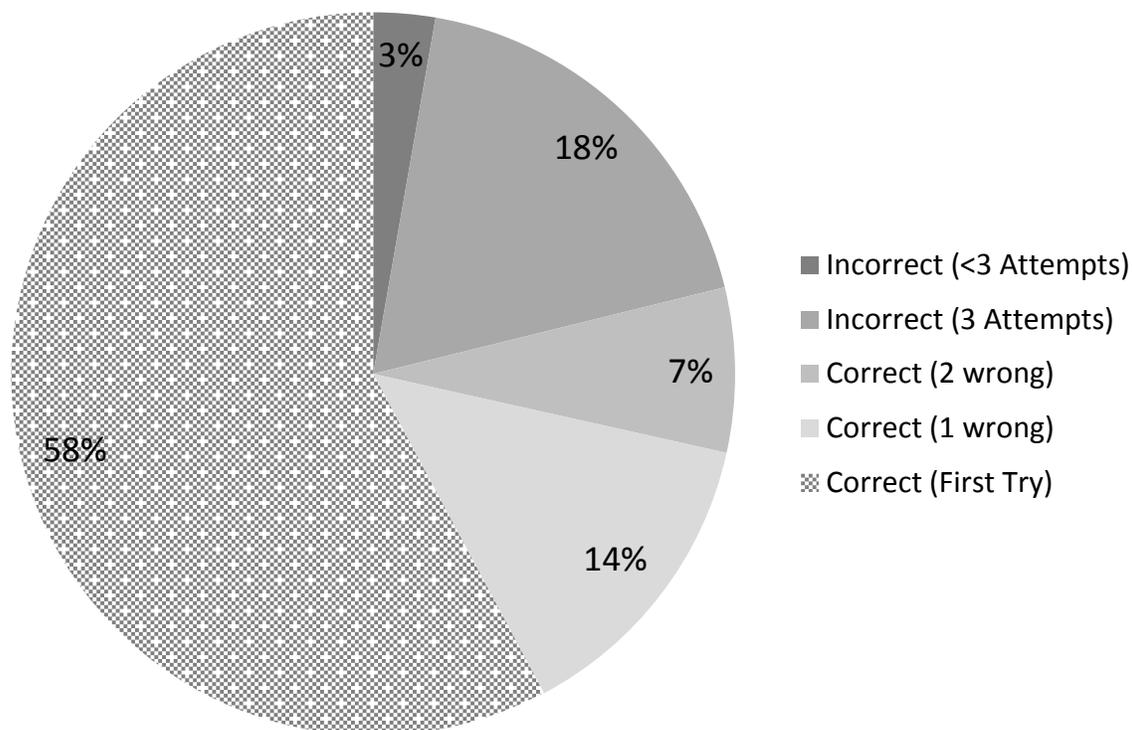

Figure 2: Outcomes on Practice Problem Parts

Students can employ two basic strategies regarding practice problems. From a pedagogical viewpoint, the best strategy is to make a sincere attempt to correctly solve each part. At least 79 % of the attempts were of this nature, i.e., 79 % of the part attempts ended in a correct answer. The second strategy is to quickly enter three incorrect values in order to see the solution. No more than 18 % of the attempts fell into this category. Some of the parts attempted incorrectly three times could represent three sincere attempts to complete the problem; others could have started with one or two sincere attempts. Only 3 % of the parts attempted at least once were abandoned before seeing the solution.

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The student responses to the first question given in Table A4 are pertinent to the results in Figure 2. Students were asked in the second survey to estimate the percent of PRACTICE exercises parts they completed in each of three ways. The results are given in Table 1. The percentages do not add to 100 as each is an average of the student responses. The self-reported strategies are consistent with the interpretation given above of the events recorded by PathFinder.

Table 1: Practice Part Solution Effort

Effort Used to Complete Parts	Parts (%)
Made a strong effort to solve the step	60
Made a quick attempt to solve the step	31
Entered any number 3 times to see the solution to the step	15

Why do Students Practice (or Not)?

The authors hypothesize a number of reasons a student might not complete a practice part:

   i.   They do not know that practice exercises exist or how to access them;
  ii.   They prefer other sources of information;
 iii.   They believe they do not need to complete the practice part to score well on the associated scored AFTER part.
 iv.   They do not believe that completing a practice part will improve their performance on the associated scored AFTER part; and
  v.   They are unwilling or unable to spend extra time completing practice exercises.

This study did not obtain information that could be used to investigate reasons v. The other Reasons are discussed further below.

Reason i does not appear to have been important. In response to the first PathFinder survey question (Table A3) less than 5 % of the students indicated they did not know practice problems were available. Students were informed about and strongly encouraged to use practice problems. Practice problems were described in an introduction to the PathFinder system on the first day of class and a short chapter on the PathFinder system included in their ebook. They were shown a chart from the previous year's class that demonstrated the positive effect of completing practice problems. Each section's instructor was asked to further encourage students to complete practice problems. Finally, when completing any scored exercise with an associated practice exercise, a button clearly labeled "Practice" appeared next to the Submit button (Figure 1).

The student responses to the second question given in Table A4 are pertinent to reason ii. Students were asked how they obtained the information needed to complete the AFTER exercises. The results are given in Table 2. The percentages do not add to 100 as each is an average of the results reported by all students. The most common information source was equations in the ebook. Practice problems were the second most common information source, but ebook examples, high school experience, and class notes were important as well. Students could have also engaged in cooperative learning, in which case the information source would be other students; however, this was not a given as an answer choice.

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Table 2: Information Sources used to solve AFTER Problems

Information Source	Exercises Completed Using source (%)
Used equations in ebook	32
Used practice problems in ebook	21
Used examples in ebook	18
Used information I knew from High School	16
Used information in my class notes	12
Looked up information on Internet	6
Used Excel help guide (or similar)	3

Reasons iii and iv may be important, given the relatively simple nature of the problems in the "introduction to engineering" course used for this study. Students may have believed they could obtain a good score without practicing or that practicing would not help. Either reason is consistent with the relatively high number of students that avoided practice problems all together and the low number of practice parts completed by the 136 students that did practice.

Does Practice Help Students do well on Scored Problems?

It is reasonable to assume that a student who performs well on a practice part will perform well on the related AFTER exercise part. Table 3 is used to describe linear equations obtained from regressing student AFTER problem part performance on the related practice problem part performance. Only data pairs with a 1 or higher practice part performance score were considered. All of the coefficients (intercept and slope) were statistically different from zero (p-Value = 0.000, not shown in Table 3).

Table 3: Linear Regressions of AFTER Part Performance on Practice Part Performance

Practice Part	Data Points	Intercept	Slope	R^2	F	p-value
Similar	417	3.6	0.25	0.15	74	0.000
Related	306	2.4	0.44	0.22	83	0.000
All	723	3.1	0.33	0.17	145	0.000

While the R^2 values are low, each linear relationship is statistically significant. It appears that a student's performance on a PathFinder practice part is related to their performance on the related AFTER part. The slope associated with "Related" practice parts is higher than the slope obtained for "Similar" practice parts. Perhaps mastering a slightly different problem strengthens a student's skills.

The major intent of this study was to compare four scenarios for providing practice problems online: None, Similar, Related, and Mixed. In each scenario the fourth problem had no practice problem, so it could be used as a test of the effectiveness of the scenario. In the "None" scenario, no practice problems were provided. This provided a control group. In the "Similar" scenario, three similar practice problems were provided for the first three exercises. In the "Related"

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scenario, three related practice problems were provided for the first three exercises. In the "Mixed" scenario, the first problem had a similar, the second a related, and the third no practice problem.

Table 4 is used to present the results of the scenario evaluation. Only the 136 practicing students were evaluated. The mean performance given in Table 4 is solely based on the two parts of the fourth AFTER exercise in each set. These exercises were completed last, after 3 AFTER exercises and any practice parts. No students were able to access practice parts for the fourth AFTER exercises. The best outcome desired from each practice scenario is higher performance on the fourth problem. As presented in Table 4, no practice scenarios resulted in a statistically significant increase in performance over the None scenario. It seems unlikely that practice does not, in some way, improve student performance on subsequent (non-practiced) exercises. Perhaps low levels of practice and relatively easy AFTER problems resulted in little benefits from the various scenarios. Also likely, the three previous AFTER exercises completed in each set served as sufficient "practice" for the fourth exercises, obscuring any positive effect of the practice problems.

Table 4: Fourth Exercise Performance by Scenario (T-Test, variances assumed equal)

Scenario	Number of Data Points	Mean Performance	p-Value*
None	136	8.2	NA
Similar	136	8.04	0.59
Related	136	7.87	0.27
Mix	136	8.2	0.90

*p-Value is for T-Test of comparison with None scenario

After each set, students could respond to three questions about their experience. Table 5 is used to present the results. The possible answers are given in the Appendix. Only practicing students are included in the results for the first question. Results range from 3.0 to 4.2 (neutral to somewhat helpful). Students found the practice problems most helpful for set C (significant figures with equations including addition/subtraction/multiplication/division). This was probably the most complicated set of problems, so this result is reasonable. The lowest score was for set B (significant figures and equations with multiplication/division). Since this was probably the easiest set, this too is a reasonable result. On average, 66 (50 %) of the non-practicing students selected the answer "I knew practice problems were available, but did not use them." A high of 88 (67 %) selected this answer for set B.

Mean results for the second question ranged from 3.0 to 3.8 (neutral to somewhat helpful). The lowest score was obtained for Set D; perhaps this set could be improved. Mean results for the third question ranged from 3.0 to 3.6 (reasonable to somewhat long). The highest value was obtained for set D, indicating that students feel this set is too long.

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Table 5: Student Appraisal of sets (AFTER and Practice exercises)

Question	Set			
	A	**B**	**C**	**D**
Did PRACTICE PROBLEMS help you complete the _____ problems?	3.8	3.0	4.2	3.5
Did the problems (practice OR counted towards your grade) help you master the use of _____?	3.8	3.7	3.6	3.0
Did the problems (practice OR counted towards your grade) take an appropriate amount of time, given the results (i.e., mastery of the material)?	3.0	3.0	3.2	3.6

The SurveyMonkey questionnaire asked students to suggest ways to improve PathFinder. The comments shown here illustrate student opinion, but should not be taken to be representative of all students. A number of comments focused on practice problems. Some students want more practice problems. Student comments included:

- "More practice problems. They really helped me to understand the problem but not every problem had one. If I was confused I couldn't refer to a practice problem to help me out."
- "Practice Problems for every question."
- "I suggest several practice problems on every single equation problem instead of just one, PLEASE. I would have much more confidence in stuff like that had I had more than one practice problem. In my opinion this is one of the most pertinent ways PathFinder could be improved."
- "Also if it was possible to get more than one practice problem that would be very good. A number of times I would select the practice problem and it would give me a problem that was too dissimilar to the one I needed to do for credit and it didn't really help me practice for the credit problem."

Earlier versions of PathFinder let students practice on all of the problems in a given bank. One downside to this is that students could always find a similar practice problem, thus losing any benefit of only working related practice problems. This problem can be avoided by simply excluding a student's AFTER exercise from his or her practice problems, but students could easily cooperate to find similar practice problems. As banks are filled with more problems, it will become possible to give students 2 or 3 practice problems from each bank without making it too easy to collaborate in this way.

Some students want practice problems to include explanations. Student comments included:

- "Some of the problems can have multiple answers which is confusing. Also some questions are confusing and the practice problems don't help because they don't explain how you got to the answer."
- "The practice problems could include the information on how and why the problems were solved in the manner they were."

This is something that can be added to PathFinder.

One student objected to other students quickly entering three incorrect values in order to see a practice solution:

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- "Personally, I would remove the feature that allowed students to enter a wrong answer three times in the practice section. Many students took advantage of that, and neglected to put an effort in actually solving the problem. However, to make up for removing this feature, include some example, step-by-step solutions in the chapters. Students learn fast by seeing a run-through for a sample problem before tackling a problem on their own. This would definitely improve PathFinder as a whole."

As shown in Figure 3 and Table 1, fewer than 18 % of the practice parts were attempted in this way. The student's comment regarding the need for examples in the ebook is surprising, given that numerous examples were included.

Conclusions

This research was used to investigate three questions. (1) Will students complete online practice problems? (2) Why do students complete (or not complete) online practice problems? (3) Does practice result in higher performance on scored problems? The introduction to engineering course studied here used the PathFinder website to provide students access to an ebook and online exercises. The online problems studied here were completed after materials were covered in class. These problems are called AFTER problems in PathFinder.

The 256 students using Pathfinder attempted only 723 practice exercise parts out of a possible 6144 associated with the sixteen AFTER problems, only 12 % of the possible parts. However, over 50 % of the students (136 of 256) completed at least one part of a practice exercise. At least 79 % of the parts attempted were completed successfully, indicating that most students seriously attempted practice problems. Fewer than 18 % of the practice problem parts were completed by quickly submitting three wrong answers to view the solution.

The relatively low percent of students completing practice problems is not a result of lack of information. Fewer than 5 % of the students reported that they did not know practice problems were available. Completing practice problems is just one strategy for doing well on scored AFTER problems. In addition to practice problems, students indicated they used equations and examples from the ebook as well as information from their course notes and even high school. This, along with the relatively low difficulty of the online problems, may have led to the relatively low level of practice problem completion.

Completing a practice problem part was associated with better scores on associated AFTER problem parts. Related practice problem parts appear to result in higher performance on the scored problems, compared to similar practice problem parts.

The four scenarios each ended with a fourth problem without any associated practice parts. Amongst practicing students, the scenarios resulted in no difference in performance on the fourth problem. The None scenario resulted in no worse performance than the similar, related, or mixed scenarios. It appears that completing the first three problems provided more than sufficient skills to complete each fourth exercise. Where a series of related scored problems are assigned, the positive effect of practice problems may be obscured.

The main conclusion of this report is that online voluntary un-scored practice can positively affect student performance on similar and related scored problems. Related practice problems have a greater positive effect than similar ones. Where three scored problems in a common area are assigned, the effect of voluntary un-scored practice is not enough to improve performance on a fourth scored problem, for which no practice is provided, regardless of how practice is

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provided. Given the voluntary nature of the practice problems studied here, and the ease with which they can be provided with systems such as PathFinder, their use is recommended, especially related practice problems. Future work can focus on more difficult problems. Students can be directly asked why they do or do not use practice problems.

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Appendix

Table A1: Exercises included in Study

Exercise Set	Exercise	Parts	Bank Size
A. Significant Figures: Addition/Subtraction	1	4	11
	2	2	9
	3	2	12
	4	2	10
B. Significant Figures: Multiplication/Subtraction	1	4	10
	2	2	12
	3	2	12
	4	2	12
C. Significant Figures: Addition/Subtraction/Multiplication/Subtraction	1	2	8
	2	2	9
	3	2	9
	4	2	9
D. Unit Consistency	1	2	12
	2	1	6
	3	2	9
	4	2	9
Totals	*16*	*35*	*159*

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Example Problems

Set A – Exercise 1: Significant Figures +- 1

Solve equations with correct significant figures

Given

The following values and two equations are given.

$X_1 = 725$ (units not given)

$X_2 = 0.13321$ (units not given)

$$Y_1 = X_1 + X_2 \qquad \text{(Eq. 1)}$$
$$Y_1 = X_1 - X_2 \qquad \text{(Eq. 2)}$$

Question(s)

1. How many significant digits should be used to report the answer to equation 1? Count only the ones of which you can be certain.

2. Give the answer to equation 1 with the proper significant figures. Your answer must be exactly correct.

3. How many significant digits should be used to report the answer to equation 2? Count only the ones of which you can be certain.

4. Give the answer to equation 2 with the proper significant figures. Your answer must be exactly correct.

Set A – Exercise 2: Significant Figures +- 2

Solve equation with correct significant figures

Given

The following values and an equation are given.

$X_1 = 0.06$ (units not given)

$X_2 = 7.0412$ (units not given)

$X_3 = 2.24$ (units not given)

$$Y_1 = X_1 + (X_2 - X_3) \qquad \text{(Eq. 1)}$$

Question(s)

1. How many significant digits should be used to report the answer to equation 1? Count only the ones of which you can be certain.

2. Give the answer to equation 1 with the proper significant figures. Your answer must be exactly correct.

Set A – Exercise 3: Significant Figures +- 3

Solve equation with correct significant figures

Given

The following values and an equation are given.

$X_1 = 26.65$ (units not given)

$X_2 = 1.498$ (units not given)

$X_3 = 490.3$ (units not given)

$X_4 = 0.74207$ (units not given)

$$Y_1 = (X_1 + X_2) - (X_3 + X_4) \qquad \text{(Eq. 1)}$$

Question(s)

1. How many significant digits should be used to report the answer to equation 1? Count only the ones of which you can be certain.

Answer: N = 4 (unitless)

2. Give the answer to equation 1 with the proper significant figures. Your answer must be exactly correct.

Set A – Exercise 4: Significant Figures +- 4
Solve equation with correct significant figures

Given

The following values and an equation are given.

$X_1 = 4.0E3$ (units not given)

$X_2 = 6E1$ (units not given)

$X_3 = 19.21$ (units not given)

$X_4 = 2.9627$ (units not given)

$X_5 = 0.66294$ (units not given)

$$Y_1 = (X_1 + X_2 + X_3) - (X_4 + X_5) \qquad \text{(Eq. 1)}$$

Question(s)

1. How many significant digits should be used to report the answer to equation 1? Count only the ones of which you can be certain.

2. Give the answer to equation 1 with the proper significant figures. Your answer must be exactly correct

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*Set B – Exercise 1: Significant Figures */*

Solve equations with correct significant figures

Given

  The following values and two equations are given.

  $X_1 = 6.5$ (units not given)

  $X_2 = 54.684$ (units not given)

  $Y_1 = X_1 \cdot X_2$ (Eq. 1)

  $Y_1 = \dfrac{X_1}{X_2}$ (Eq. 2)

Question(s)

1. How many significant digits should be used to report the answer to equation 1? Count only the ones of which you can be certain.

2. Give the answer to equation 1 with the proper significant figures. Your answer must be exactly correct.

3. How many significant digits should be used to report the answer to equation 2? Count only the ones of which you can be certain.

4. Give the answer to equation 2 with the proper significant figures. Your answer must be exactly correct.

*Set B – Exercise 2: Significant Figures */ 2*

Solve equations with correct significant figures

Given

  The following values and an equation are given.

  $X_1 = 2$ (units not given)

  $X_2 = 69.442$ (units not given)

  $X_3 = 5.1E2$ (units not given)

  $Y_1 = \dfrac{X_1 \cdot X_2}{X_3}$ (Eq. 1)

Question(s)

1. How many significant digits should be used to report the answer to equation 1? Count only the ones of which you can be certain.

2. Give the answer to equation 1 with the proper significant figures. Your answer must be exactly correct.

*Set B – Exercise 3: Significant Figures */ 3*

Solve equations with correct significant figures

Given

The following values and an equation are given.

$X_1 = 0.664$ (units not given)

$X_2 = 2.3955$ (units not given)

$X_3 = 11.92$ (units not given)

$X_4 = 0.050$ (units not given)

$$Y_1 = \frac{X_1 \cdot X_2}{X_3 \cdot X_4} \quad \text{(Eq. 1)}$$

Question(s)

1. How many significant digits should be used to report the answer to equation 1? Count only the ones of which you can be certain.

2. Give the answer to equation 1 with the proper significant figures. Your answer must be exactly correct.

*Set B – Exercise 4: Significant Figures */ 4*

Solve equations with correct significant figures

Given

The following values and an equation are given.

$X_1 = 0.440$ (units not given)

$X_2 = 1.705$ (units not given)

$X_3 = 35$ (units not given)

$X_4 = 0.0262$ (units not given)

$X_5 = 696.83$ (units not given)

$$Y_1 = \frac{X_1 \cdot X_2 \cdot X_3}{X_4 \cdot X_5} \quad \text{(Eq. 1)}$$

Question(s)

1. How many significant digits should be used to report the answer to equation 1? Count only the ones of which you can be certain.

2. Give the answer to equation 1 with the proper significant figures. Your answer must be exactly correct.

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*Set C – Exercise 1: Significant Figures */+- 1*

Solve equations with correct significant figures

Given

   The following values and an equation are given.

   $X_1 = 0.04$ (units not given)

   $X_2 = 33.2$ (units not given)

   $X_3 = 113.4$ (units not given)

   $Y_1 = \frac{X_1 + X_2}{X_3}$ (Eq. 1)

Question(s)

1. How many significant digits should be used to report the answer to equation 1? Count only the ones of which you can be certain.

2. Give the answer to equation 1 with the proper significant figures. Your answer must be exactly correct.

*Set C – Exercise 2: Significant Figures */+- 2*

Solve equations with correct significant figures

Given

   The following values and an equation are given.

   $X_1 = 24$ (units not given)

   $X_2 = 0.023$ (units not given)

   $X_3 = 0.585$ (units not given)

   $X_4 = 0.0071$ (units not given)

   $Y_1 = \frac{X_1 + X_2}{X_3 + X_4}$ (Eq. 1)

Question(s)

1. How many significant digits should be used to report the answer to equation 1? Count only the ones of which you can be certain.

2. Give the answer to equation 1 with the proper significant figures. Your answer must be exactly correct.

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Set C – Exercise 3: Significant Figures */+- 3

Solve equations with correct significant figures

Given

   The following values and an equation are given.

   $X_1 = 10.6$ (units not given)

   $X_2 = 0.0513$ (units not given)

   $X_3 = 0.186$ (units not given)

   $X_4 = 0.00717$ (units not given)

   $X_5 = 0.0049$ (units not given)

   $$Y_1 = \frac{X_1 + X_2}{X_3 - X_4} X_5 \qquad \text{(Eq. 1)}$$

Question(s)

1. How many significant digits should be used to report the answer to equation 1? Count only the ones of which you can be certain.

2. Give the answer to equation 1 with the proper significant figures. Your answer must be exactly correct.

Set C – Exercise 4: Significant Figures */+- 4

Solve equations with correct significant figures

Given

   The following values and an equation are given.

   $X_1 = 2.7395$ (units not given)

   $X_2 = 0.6$ (units not given)

   $X_3 = 0.738$ (units not given)

   $X_4 = 0.0010$ (units not given)

   $X_5 = 0.0381$ (units not given)

   $$Y_1 = \frac{X_1 + X_2}{X_3 - X_4} X_5 \qquad \text{(Eq. 1)}$$

Question(s)

1. How many significant digits should be used to report the answer to equation 1? Count only the ones of which you can be certain.

2. Give the answer to equation 1 with the proper significant figures. Your answer must be exactly correct.

Set D – Exercise 1: Unit Consistency 1

Determine the volume of a sphere in cubic feet, given the radius (X) in inches. Your answer must be exactly correct, both in value and number of significant digits.

Given

   The units of X are inches:

   X = 124 (Units as given in problem)

Question(s)

1. How many significant digits should your answer have?

2. Determine the volume in feet cubed.

Set D – Exercise 2: Unit Consistency 2

Use the linear equation below to calculate Y in newtons. The units of X, m and b are W, N/(ft lbf/s) and lbf, respectively.

Given

   $Y = m \cdot X + b$ (Eq. 1)

   X = 22.4 (Units as given in problem)

   m = 4.23 (Units as given in problem)

   b = 0.548 (Units as given in problem)

Question(s)

1. Calcuate Y. Use all available digits and report answer using the number of significant figures specified.

Set D – Exercise 3: Unit Consistency 3

Estimate the maximum force a beam can take in tension without failing. Your answer must be exactly correct, both in value and number of significant digits.

Given

The formula used to estimate the force is $F_m = U_{TS} \cdot A$ (Eq. 1)

The ultamite tensile strength of the beam is given in MPa

UTS = 30.4 (Units as given in problem)

The area of the beam is given in inches squared

A = 8.5 (Units as given in problem)

Question(s)

1. How many significant digits should your answer have?

Answer: N = 2 (unitless)

2. Calculate the maximum force in Newtons.

Set D – Exercise 4: Unit Consistency 4

Estimate the force that can buckle a column (by compression). Your answer must be exactly correct, both in value and number of significant digits.

Given

The formula used to estimate the force is $F_B = \dfrac{E \cdot I \cdot \pi^2}{L^2}$ (Eq. 1)

The Young's Modulus of the beam is given in GPa

E = 197 (Units as given in problem)

The area moment of inertia is given in inches quadrupled (that IS correct, inches to the fourth power)

I = 2420 in4

The area of the beam is given in inches squared

A = 67.7 (Units as given in problem)

The length of the beam is given in inches

L = 132 (Units as given in problem)

Question(s)

1. How many significant digits should your answer have?

Answer: N = 3 (unitless)

2. Calculate the buckling force in Newtons.

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Table A2: Practice Problem Treatments

Treatment	A. Significant Figures: (+ & -)			B. Significant Figures (* & /)			C. Significant Figures: (+, -, * & /)			D. Unit Consistency		
1	None	None	None	Sim.	Sim.	Sim.	Rel.	Rel.	Rel.	Sim.	Rel.	None
2	None	None	None	Sim.	Sim.	Sim.	Sim.	Rel.	None	Rel.	Rel.	Rel.
3	None	None	None	Rel.	Rel.	Rel.	Sim.	Sim.	Sim.	Sim.	Rel.	None
4	None	None	None	Rel.	Rel.	Rel.	Sim.	Rel.	None	Sim.	Sim.	Sim.
5	None	None	None	Sim.	Rel.	None	Sim.	Sim.	Sim.	Rel.	Rel.	Rel.
6	None	None	None	Sim.	Rel.	None	Rel.	Rel.	Rel.	Sim.	Sim.	Sim.
7	Sim.	Sim.	Sim.	None	None	None	Rel.	Rel.	Rel.	Sim.	Rel.	None
8	Sim.	Sim.	Sim.	None	None	None	Sim.	Rel.	None	Rel.	Rel.	Rel.
9	Sim.	Sim.	Sim.	Rel.	Rel.	Rel.	None	None	None	Sim.	Rel.	None
10	Sim.	Sim.	Sim.	Rel.	Rel.	Rel.	Sim.	Rel.	None	None	None	None
11	Sim.	Sim.	Sim.	Sim.	Rel.	None	None	None	None	Rel.	Rel.	Rel.
12	Sim.	Sim.	Sim.	Sim.	Rel.	None	Rel.	Rel.	Rel.	None	None	None
13	Rel.	Rel.	Rel.	None	None	None	Sim.	Sim.	Sim.	Sim.	Rel.	None
14	Rel.	Rel.	Rel.	None	None	None	Sim.	Rel.	None	Sim.	Sim.	Sim.
15	Rel.	Rel.	Rel.	Sim.	Sim.	Sim.	None	None	None	Sim.	Rel.	None
16	Rel.	Rel.	Rel.	Sim.	Sim.	Sim.	Sim.	Rel.	None	None	None	None
17	Rel.	Rel.	Rel.	Sim.	Rel.	None	None	None	None	Sim.	Sim.	Sim.
18	Rel.	Rel.	Rel.	Sim.	Rel.	None	Sim.	Sim.	Sim.	None	None	None
19	Sim.	Rel.	None	None	None	None	Sim.	Sim.	Sim.	Rel.	Rel.	Rel.
20	Sim.	Rel.	None	None	None	None	Rel.	Rel.	Rel.	Sim.	Sim.	Sim.
21	Sim.	Rel.	None	Sim.	Sim.	Sim.	None	None	None	Rel.	Rel.	Rel.
22	Sim.	Rel.	None	Sim.	Sim.	Sim.	Rel.	Rel.	Rel.	None	None	None
23	Sim.	Rel.	None	Rel.	Rel.	Rel.	None	None	None	Sim.	Sim.	Sim.
24	Sim.	Rel.	None	Rel.	Rel.	Rel.	Sim.	Sim.	Sim.	None	None	None

Sim. = Similar; Rel. = Related; all fourth exercises are "None"

Table A3: PathFinder Survey Questions

Questions	Multiple Choice Answers (Points)
Did PRACTICE PROBLEMS help you complete the _____ problems?	A. My exercises did not have practice problems (NA) B. I did not know practice problems were available (NA) C. I knew practice problems were available, but did not use them(NA) D. I used them and found them extremely helpful (5) E. I used them and found them somewhat helpful (4) F. I used them and found they neither helped or hurt (3) G. I used them and found them somewhat unhelpful (2) H. I used them and found them extremely unhelpful (1)
Did the problems (practice OR counted towards your grade) help you master the use of _____?	A. The problems were extremely helpful (5) B. The problems were somewhat helpful (4) C. The problems neither helped or hurt (3) D. The problems were somewhat unhelpful (2) E. The problems were extremely unhelpful (1) F. I have not completed the problems (0)
Did the problems (practice OR counted towards your grade) take an appropriate amount of time, given the results (i.e., mastery of the material)?	A. The length of time was extremely long (5) B. The length of time was somewhat long (4) C. The length of time was reasonable (3) D. The length of time was somewhat short (2) E. The length of time was extremely short (1) F. I have not completed the problems (0)

Table A4: SurveyMonkey® Questions

Questions	Answers
Estimate the percent of PRACTICE problem steps you completed each way described below (Numbers must add up to 100 %, but do not include the % sign).	__ Made a strong effort to solve the step __ Made a quick attempt to solve the step __ Entered any number 3 times to see the solution to the step
How did you obtain the information needed to complete AFTER Problems? Estimate the percent of problem steps completed each way (numbers must add up to 100 %, but do not include the % sign).	__ Used equations in ebook __ Used examples in ebook __ Used practice problems in ebook __ Used information in my class notes __ Looked up information on Internet __ Used Excel help guide (or similar) __ Used information I knew from High School