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Randomization of problems in online assessments for various courses in mechanical engineering

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Abstract

In continuation to previous work on development of online exams for both in-person and online courses, more examples of online questions plus analysis of grades for various courses in mechanical engineering will be presented. Previously, questions were developed for which the numerical values can be randomized for different students. In addition to such questions, questions in which the problem can be randomized between students will be presented. The questions developed for this purpose must of similar difficulty and solution approach to keep it fair among students. Further analysis on grades between online and in-person exams will be presented to investigate the effectiveness of online exams, particularly those which are not proctored.

The inspiration for this work started during and continued after the covid pandemic; initially on how to conduct online exams and then due to relatively a greater number of students being sick on the exam day or being in quarantine. This is particularly problematic during the final exams, in which there is limited time for makeup exams. In most cases, taking a makeup exam in the following semester to clear an incomplete grade mostly negatively affects the student's letter grade. Several other benefits of this approach also came to light after the execution of exams. For example, students are able to take the exam at their best time and lengthier exams may be given for the courses that require it. Since the study is conducted at a regional teaching campus of a major state university, many students are working adults with full time jobs and in certain cases, full time families. This approach has also helped those students to stay on the course for their academic journey.

Introduction

In this study, the previous framework developed for online exams in Blackboard [1] will be further advanced to make the online exams more randomized. In the previous work, detailed examples were provided for three courses in mechanical engineering (Dynamics of machines, Machine design, Vibrations) and one general engineering course (Software tools). In those examples, numerical values were randomized among students i.e., each student was given a different numerical value that made it impossible to submit a standard solution or even simply copying another student's work. The results were encouraging in discouraging academic dishonesty while still providing several benefits for both the instructor and the students. For the instructor, the grading time was reduced, longer exams could be administered, and no need to prepare makeup exams. For the students, the flexibility to take an exam at their best time, taking a break between several problems of the same exam and avoiding missing an exam (and in the case of the final exam, an incomplete grade) were some of the foreseen benefits. However, there were some surprise benefits that the instructor learned from the students' perspectives. For example, students with families were not only happy but performed better with the added flexibility of the exam. Some international students and domestic students not within driving distances were able to avail better/cheaper flights while being able to take the exam (and holidays) at their family homes etc.

In the present study, methods will be presented on randomizing not only the numerical values but also the problems. The most important point to remember is that the different problems which will be randomized among students should be of the similar difficulty to keep it fair among students. Examples will be given for different courses in mechanical engineering.

Development of Questions in Blackboard

Development of exam questions was presented in detail in a previous study [1]. Blackboard can generate several types of questions. A quick review of the two types of questions previously used will be presented here: Calculated Formula and File Response. *Calculated Formula* question allows to use a range of numerical values for declared variables and generates a set of possible solution such that each student will get a problem with different numerical values. To generate a question of this type, the instructor needs to provide a statement with embedded variables' declaration and then provide a formula to calculate the answer using the declared variables. The formula can be a simple one or as complicated as needed, and it may or may not use all declared variables (i.e. superfluous data is allowed) along with constant values. It also allows to generate as many data sets with different numerical values as desired based on the number of students. The *Calculated Formula* questions are automatically graded by Blackboard based on a given range (numeric or percentage) with a manual override by the instructor, if needed. *File Response* question allows the student to upload a file with the solution, in response to a prompt, to be graded by the instructor later. These two question types are used in combination to develop exam problems.

In addition, to randomize not only the numerical values but also the problems, the concept of *Question Set* will be utilized in Blackboard. A *Question Set* allows the instructor to pick more than one problem to create a set from which a certain number of problems will be randomly put in the exam for each student. For example, there could be two problems in one set and only one problem will be given to a student. If there are three problems, then either one or two problems can be given to randomize (three out of three problems can be given but the system will obviously not able to randomize). The degree of randomization increases with the bigger difference in the number of problems in a *Question Set* and the number of problems to be given in the exam. A *Question Set* requires a pool of problems to be generated before setting it up. The pool of problems must be of similar difficulty to keep it fair among students.

For each course in mechanical engineering presented here, first examples of problems that can be put in a *Question Set* will be presented and then the mechanics of developing and delivering *Question Sets* will be presented.

An Example Question from Dynamics of Machines

Figure 1a represents a problem from dynamics of machines course as developed in the Blackboard. The problem shows a four-bar mechanism with given dimensions, and the angular velocity of the crank. The solution includes drawing a scaled position diagram and a scaled velocity polygon. This is the *Calculated Formula* question.

1. **Calculated Formula: 2a: For the four-bar linkage, assume that...** Points: 1

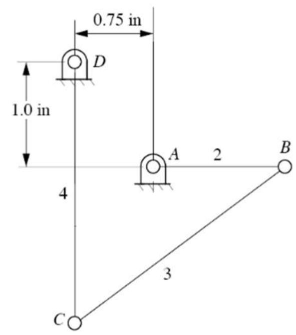
Question	For the four-bar linkage, assume that link 2 is horizontal and rotating with ω_2 = [omega] rad/s ccw. *AB* = 1.25 in, *BC* = [bc] in, *CD* = 2.5 in.  Determine the magnitude of the v_B in in/s^2.
Answer Formula	omega*1.25
Precision	Decimal
Answer Range +/-	± 0.3
Number of Answer Sets	30

Fig 1a: Problem as developed in Blackboard (instructor view) – Dynamics of Machines

Figure 1b represents the alternate problem to the problem shown in Fig. 1a. The problem shows a crank-slider (still a four-link) mechanism with given dimensions, and the angular velocity of the crank. The solution includes drawing a scaled position diagram and a scaled velocity polygon. This is also a *Calculated Formula* question.

2. **Calculated Formula: 2aA: For the slider-crank linkage, assume ...** Points: 1

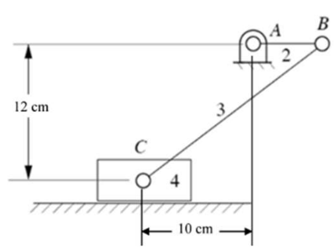
Question	For the slider-crank linkage, assume that link 2 is rotating with ω_2 = [omega] rad/s ccw. *AB* = 6 cm, *BC* = [bc] cm.  Determine the magnitude of the v_B in cm/s^2.
Answer Formula	omega*6
Precision	Decimal
Answer Range +/-	± 0.3
Number of Answer Sets	30

Fig 1b: Alternate problem as developed in Blackboard (instructor view) – Dynamics of Machines

Figure 1c shows the second part to both problems given in Figs. 1a & 1b. Please note that careful consideration is required to be able to use the same second part for two different problems (a four-bar mechanism and crank-slider mechanism here).

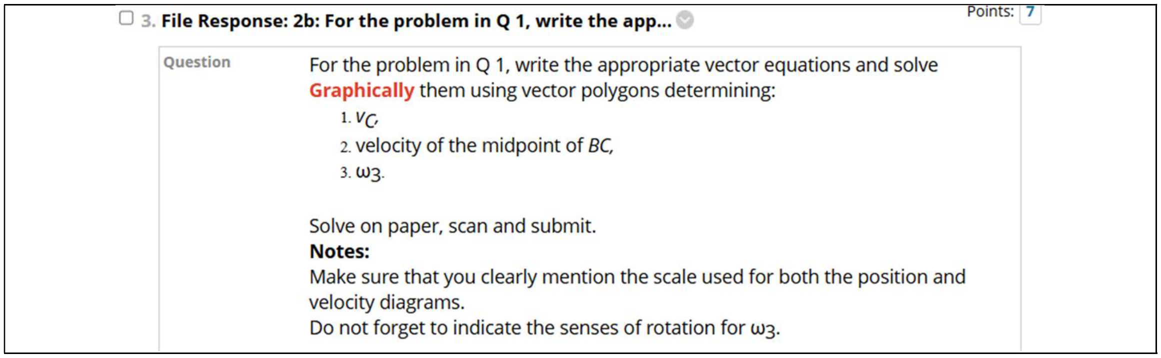


Fig 1c: Second part for both problems given in Figs. 1a & 1b as developed in Blackboard (instructor view) – Dynamics of Machines

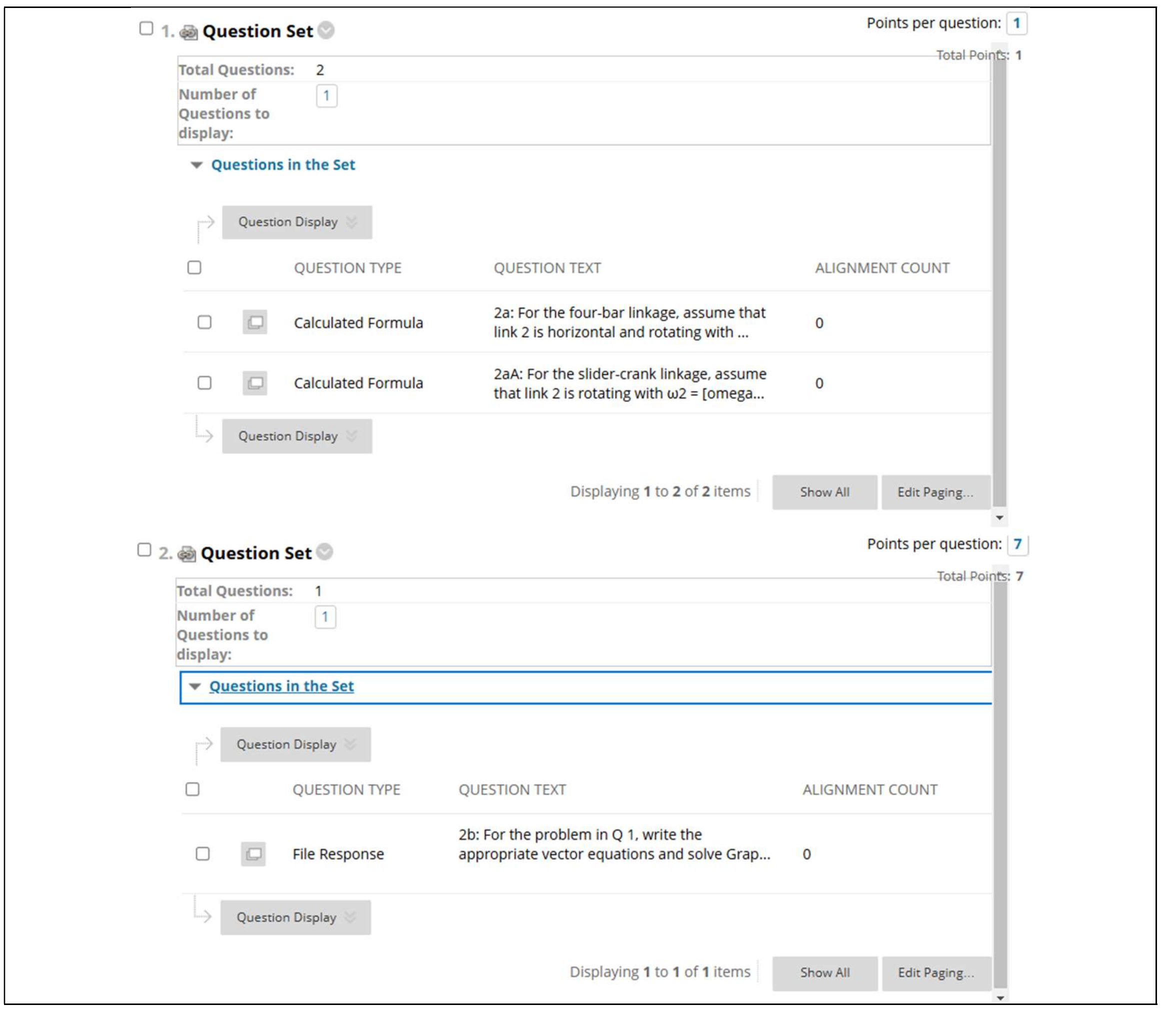


Fig 1d: Question Set based on the problems given in Figs. 1a, 1b & 1c as developed in Blackboard (instructor view) – Dynamics of Machines

Figure 1d shows the *Question Set* as developed in Blackboard. There are two question sets: Q 1 has two problems out of which one will be delivered to a student and Q 2 has only one problem that will be delivered to every student. One might ask why not put two problems in Q 2 too, one for each of the alternate problems (given in Fig. 1a & 1b)? The answer lies in the way Blackboard works. If there are two problems in question set 2 one for each problem in question set 1, then those may (or will) be mismatched as there is no control over which problem(s) are given from the set. It is quite possible that all students may get the same problem in question set 1.

In terms of selecting similar problems so that the exams are fair for all students, it is not necessary to select entirely different geometry of the problem. For example, if there are two forces acting on a mechanism and let's say one is known, and the other is unknown then the two can be switched with each to create a similar problem. An example is given in Fig. 2a through 2c.

1. Calculated Formula: 6a: For the mechanism shown, block 2 is s... Points:

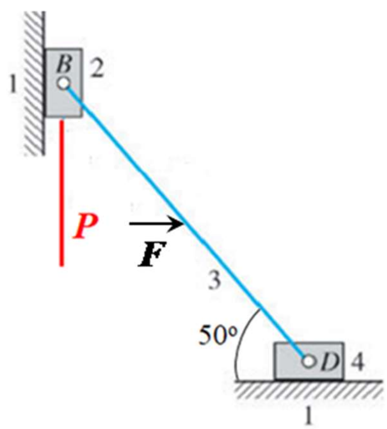
Question

For the mechanism shown, block 2 is sliding up with a constant velocity. A horizontal force ***F*** of magnitude [F] N is applied to the midpoint of [l]-cm long link 3.

Determine the vertical force ***P*** required to produce this motion.

The answer should be in N.

Solve, scan and submit your solution with the second question.



Solve GRAPHICALLY. Both the position diagram and force polygon(s) must be on the same page, otherwise it will not be graded.

Answer Formula	0.5*F*tan(50/57.3)
Precision	Decimal
Answer Range +/-	± 0.5
Number of Answer Sets	25

Fig 2a: Problem as developed in Blackboard (instructor view) – Dynamics of Machines

☐ 2. **Calculated Formula: 6aA: For the mechanism shown, block 2 is s...** Points: 2

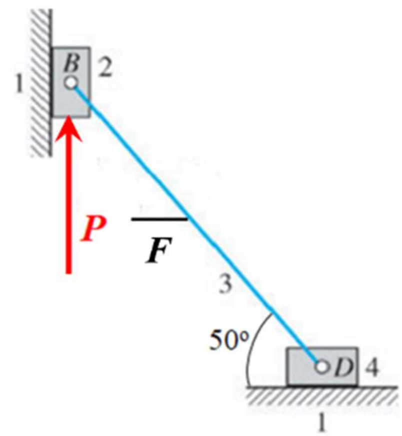
Question	For the mechanism shown, block 2 is sliding up with a constant velocity. A vertical force ***P*** of magnitude [P] N is applied to block 2. Determine the horizontal force ***F*** applied to the midpoint of [l]-cm long link 3 and required to produce this motion. The answer should be in N. Solve, scan and submit your solution with the second question.  **Solve GRAPHICALLY. Both the position diagram and force polygon(s) must be on the same page, otherwise it will not be graded.**
Answer Formula	2*P/tan(50/57.3)
Precision	Decimal
Answer Range +/-	± 0.5
Number of Answer	25

Fig 2b: Alternate problem as developed in Blackboard (instructor view) – Dynamics of Machines

☐ 3. **File Response: 6b: For the problem in Q 1: Determine the...** Points:

Question	For the problem in Q 1: Determine the normal reactions of the surface 1 on block 2 and block 4.

Fig 2c: Second part for both problems given in Figs. 2a & 2b as developed in Blackboard (instructor view) – Dynamics of Machines

An Example Question from Vibrations

Figure 3a represents a problem from vibrations course as developed in the Blackboard environment. In this case, the first problem is a file response problem without any numerical values.

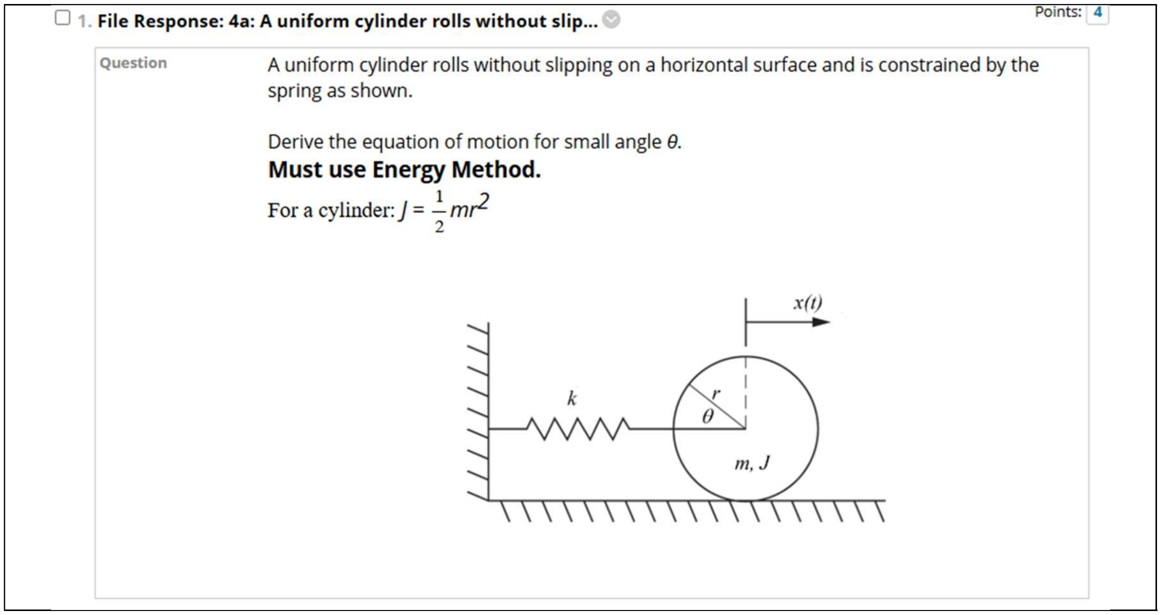


Fig 3a: Problem as developed in Blackboard (instructor view) – Vibrations

Figure 3b represents the alternate problem to the problem shown in Fig. 3a. The problem shows a similar problem to the one in Fig. 3a. The solution for both problems will contain the same number of steps.

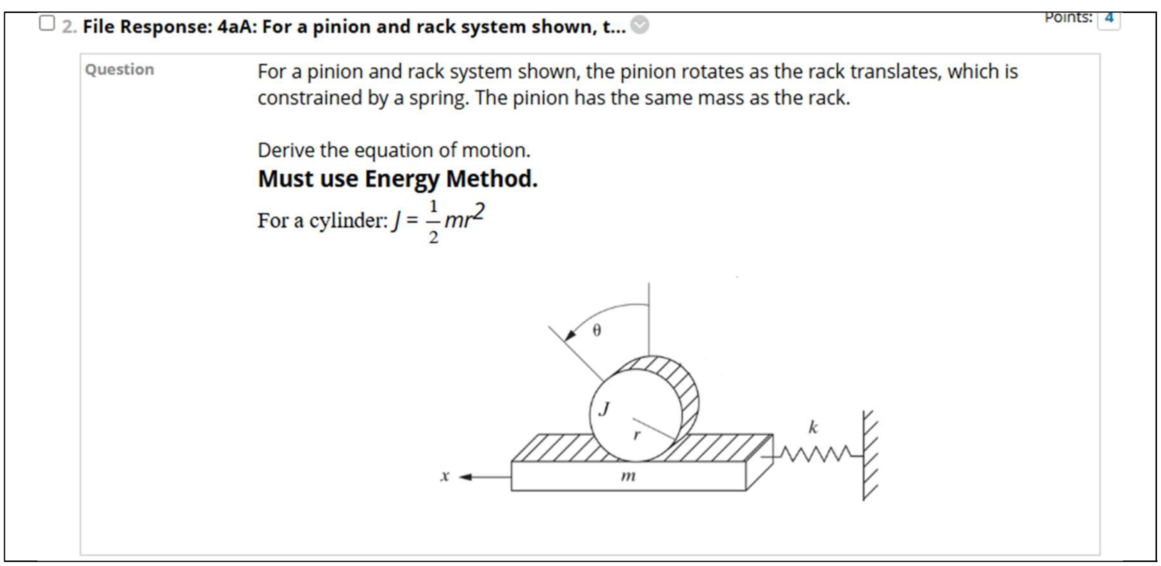


Fig 3b: Alternate problem as developed in Blackboard (instructor view) – Vibrations

Figure 3c shows the second part to both problems given in Figs. 3a & 3b. In this case, the calculated formula question is used here to give different numerical values to students.

☐ 3. **Calculated Formula: 4b: For the problem given in Q 1, if k = ...** Points: 1

Question	For the problem given in Q 1, if k = [k] lb/ft and the weight of the cylinder is [w] lbs, determine the natural frequency of the system. ***Enter your calculated answer for natural frequency in the units of Hz.***
Answer Formula	$\left(\sqrt{\frac{2*k*32.2}{3*w}}\right)/(2*\pi)$
Precision	Decimal
Answer Range +/-	± 0.05
Number of Answer Sets	25

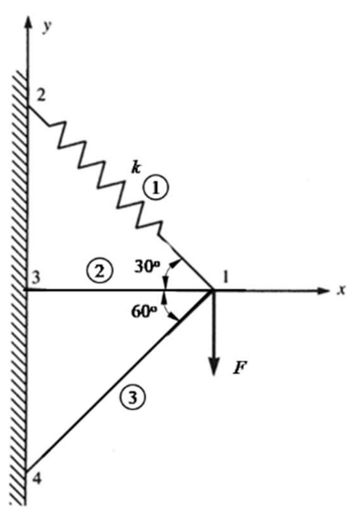
Fig 3c: Second part for both problems given in Figs. 1a & 1b as developed in Blackboard (instructor view) – Vibrations

An Example Question from Finite Element Analysis

Figure 4a represents a problem from Finite Element Analysis (FEA) course as developed in the Blackboard environment. This is a calculated formula problem with given values and the value of the applied force is a variable.

☐ 1. **Calculated Formula: 3a: For the structure shown, F = [f] lb. ...** Points: 1

Question	For the structure shown, F = [f] lb. Note that the material properties are as follows: Element 1 k = 10000 lb/in Elements 2: A = 10 in^2, E = 10^6 psi, L = 100 in Element 3: A = 10 in^2, E = 2x10^6 psi, L = 200 in



	Determine the horizontal displacement of node 1 (in mills i.e. milli inches).
Answer Formula	1000*38970*f/8750089100
Precision	Decimal
Answer Range +/-	± 0.01
Number of Answer	15

Fig 4a: Problem as developed in Blackboard (instructor view) – FEA

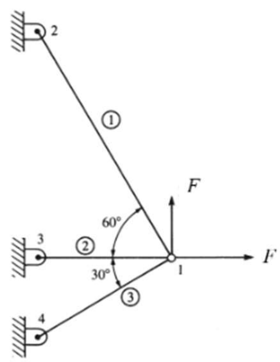
Figure 4b represents the alternate problem to the problem shown in Fig. 4a. The problem shows a similar problem to the one in Fig. 4a with only one added short step (calculating the stiffness of element 1).

2. **Calculated Formula: 3a: For the structure shown, F = [f] lb. ...** Points: 1

Question

For the structure shown, F = [f] lb.

Note that the material properties are as follows:
Element 1: A = 10 in^2, E = $2x10^6$ psi, L = 200 in
Element 2: A = 10 in^2, E = 10^6 psi, L = 100 in
Element 3: A = 11.5 in^2, E = 10^6 psi, L = 115 in



Determine the horizontal displacement of node 1 (in mills i.e. milli inches).

Answer Formula	1000*(1−0)*f/200000
Precision	Decimal
Answer Range +/-	± 0.01
Number of Answer Sets	15

Fig 4b: Alternate problem as developed in Blackboard (instructor view) – FEA

Figure 4c shows the second part to both problems given in Figs. 4a & 4b. Again, this part should be carefully crafted to match both the original and alternate problems.

3. **File Response: 3b: Submit the complete solution for Q 1:...** Points: 9

Question

Submit the complete solution for Q 1:
a. the elemental stiffness matrices,
b. the vertical displacement at node 1, and
c. the stress in the elements 2 & 3.

Fig 4c: Second part for both problems given in Figs. 4a & 4b as developed in Blackboard (instructor view) – FEA

Mechanics of Delivering the Tests

Since *Question Set* requires a pool of questions available, the best way is to develop a pool of questions and organize it in some way. The pool questions may be organized as per chapters (or topics) in the course, or as per exam number, or even part numbers within exams. The smaller the pool size will help in better managing it in Blackboard i.e., when it is the time to pick problems for one question set. One can build tests to sort and organize pool questions; these tests will never be administered directly. Instead, the question sets based on these pools will be administered. In this respect, it is important to note that if any change or correction is needed for any problem, it must be made in the pool directly; questions sets are simply a holding place. Rest of the procedure is the same as outlined in the previous study [1]. It is important to carefully and correctly control all these options to discourage academic dishonesty [2,4]. It is also important to clearly communicate the requirements of the exam with students; a detailed set of instructions, even before the exam is available, displayed on the exam webpage is good idea.

Lessons Learned

Randomization of problems in addition to randomization of numerical values for each student is achieved in this study, which is considered an important aspect to discourage academic dishonesty [3,4]. All examples presented in this study are based on two problems in each question set and one of the problems is given in the exam, that is a 50% probability of getting one or the other problem. If the number of available problems is more than two, the probability of two students getting the same problem will reduce. It is understood that it will take considerable time and effort to develop larger pools of problems. However, such pools can be used indefinitely, which can provide some help during preparation and grading of exams for faculty while still being able to administer effective exams. At the same time, it is important to note that the grading time may increase as not all students will be getting the same problem.

To investigate the effectiveness of the online exams and to check for any dishonest behavior, three examples will be presented here:

1) An exam of Dynamics of Machines from three different semesters (Fall 2019, Fall 2023, Fall 2024; the class size varied from 17 to 19 students): in-person exam, online exam with only the numerical values randomized and online exam with both problems and numerical values randomized,
2) A quiz from Finite Element Analysis lecture (hand-written solution) from two different semesters: in-person and online,
3) A quiz from Finite Element Analysis lab (software generated solution) from two different semesters: in-person and online.

Please note that the exam or quiz content in these examples were the same and obviously students being tested were different.

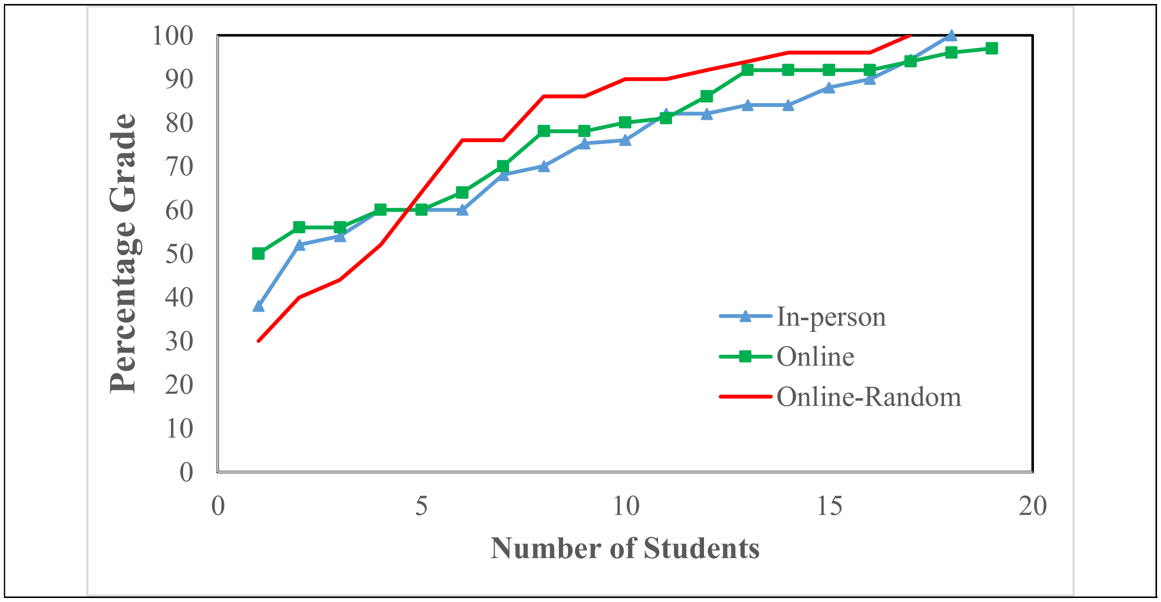


Fig 5: Analysis of grades for an exam from three different semesters – Dynamics of Machines

Figure 5 presents results for dynamics of machine course, and it shows the percentage points of students in the second major exam after arranging in an ascending order. Considering in-person exam as the most 'honest' exam, it clearly shows that the difference between the three cases is within statistical accuracy especially since not the same students were being tested. Table 1 shows the average grade and standard deviation for the three semesters. The average grade almost remains the same for the three semesters and the standard deviation too for the first two cases. Adding randomized problems setup increases the standard deviation.

Table 1: Average grade and standard deviation for an exam – Dynamics of Machines

	Average grade (out of 25)	**Standard deviation**
In-person	18.3	4.2
Online	19.4	3.9
Online with problem randomization	19.2	5.6

Table 2 represents the average grade and standard deviation for a quiz from FEA lecture, which are both very close to each other. It shows that the students' grades were not artificially inflated due to academic dishonesty.

Table 2: Average grade and standard deviation for a quiz – FEA Lecture

	Average grade (out of 10)	**Standard deviation**
In-person	8	1.9
Online	6.8	2.0

Table 3 represents the average grade and standard deviation for a quiz from FEA lab, which shows a surprise reduction in the average grade for the online exam in addition to an increase in the standard deviation as compared to the in-person quiz. One possible explanation is that the in-person quiz was taken right after a regular lab (and during the lab hours). Although the lab that was completed before starting the quiz was not on the same topic (e.g. beam or bar analysis) but the students were already warmed up.

Table 3: Average grade and standard deviation for a quiz – FEA Lab

	Average grade (out of 10)	**Standard deviation**
In-person	9.2	1.0
Online	6.4	4.4

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