

PrairieLearn:

A flexible platform for writing
randomized, auto-grading questions

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What is PrairieLearn?

- Flexible web platform for randomized question generation and auto-grading



- Open-source project used by hundreds of faculty



- Similar to WeBWork, LON-CAPA, WebAssign but more flexible and extensible

“Add numbers” question generator

question.html

server.py

```
1 import random
2
3 def generate(data):
4
5     # Sample two random integers between 5 and 10 (inclusive)
6     a = random.randint(5, 10)
7     b = random.randint(5, 10)
8
9     # Put these two integers into data['params']
10    data['params']['a'] = a
11    data['params']['b'] = b
12
13    # Compute the sum of these two integers
14    c = a + b
15
16    # Put the sum into data['correct_answers']
17    data['correct_answers']['c'] = c
```

```
1 <pl_question_panel>
2   <p> Consider two numbers $a = {{params.a}}$ and $b = {{params.b}}$.
3   <p> What is the sum $c = a + b$?
4 </pl_question_panel>
5
6 <pl_number_input answers_name="c" comparison="sigfig" digits="3" label="$c=$"/>
```

Question 5: Add two numbers

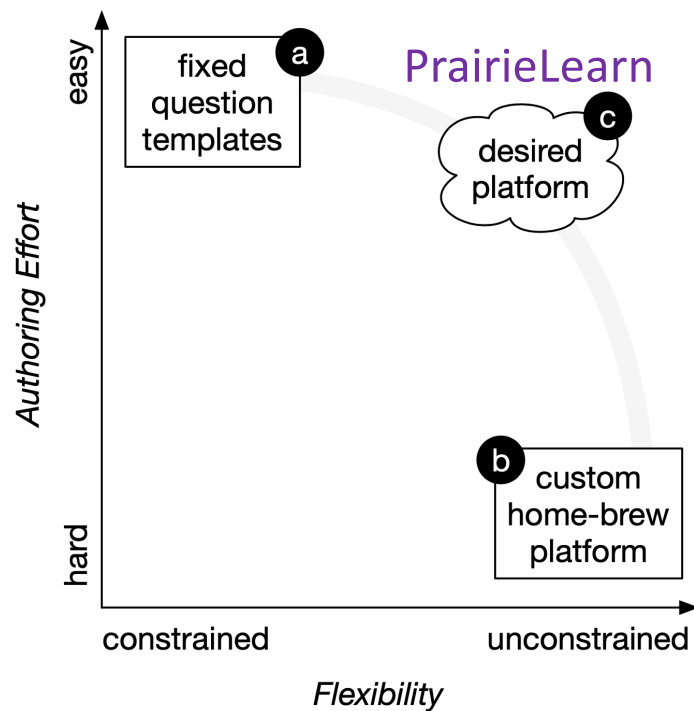
Consider two numbers $a = 9$ and $b = 8$.

What is the sum $c = a + b$?

$c =$?

Student view

Make easy things easy, hard things possible



Learning principles:

- Scaffolded practice
- Immediate feedback
- Frequent testing
- Help from human instructors

Rich set of question components

The image displays a question editor interface with several components:

- Understanding motion from a position-time graph:** A graph of position x (m) versus time. The graph shows a curve starting at point A (0, -2), passing through B (2, 0), C (3, 3), D (5, 2), and E (7, 5). Below the graph is a multiple choice question: "1. Select all regions where the object's velocity is primarily positive." with options (a) D-E, (b) A-B, (c) C-D, (d) E-F, and (e) B-C. A purple arrow labeled "Multiple choice" points to these options.
- Differentiate a polynomial function of one variable:** A symbolic differentiation problem. The text asks to "Find the derivative of $-9x^2 + 9x - 4$ with respect to x ". The answer field contains $\frac{df(x)}{dx} = -18*x+9$. A purple arrow labeled "Symbolic" points to the answer field.
- Multiply two matrices:** A matrix multiplication problem. It provides two matrices A and B and asks for their product. The matrices are displayed in a code editor. A purple arrow labeled "Matrix" points to the matrix input area.
- FBD:** A free-body diagram showing a horizontal beam supported by two vertical green lines. A series of downward arrows represent a distributed load. A pink curved arrow indicates a clockwise moment at the right end. A purple arrow labeled "Drawing" points to the diagram.

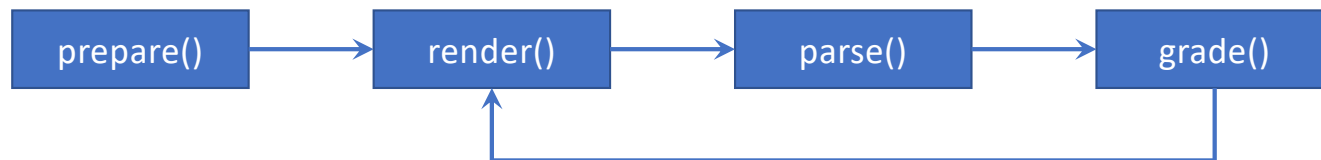
Easily add new custom elements that anyone can use

Elements: a flexible extension mechanism

```
1 <pl_question_panel>
2   <p> Consider two numbers $a = {{params.a}}$ and $b = {{params.b}}$.
3   <p> What is the sum $c = a + b$?
4 </pl_question_panel>
5
6 <pl_number_input answers_name="c" comparison="sigfig" digits="3" label="$c=$"/>
```



PrairieLearn *element*: A reusable package of HTML, Python, and JavaScript



Share between questions and courses

Symbolic element

question.html

server.py

```
import sympy, random

def generate(data):

    x = sympy.symbols('x')
    a = random.randint(1,10)
    b = random.randint(1,10)
    c = random.randint(1,10)

    f = a*x**2 + b*x + c
    df = sympy.diff(f, x)

    data["params"]["f"] = sympy.latex(f)
    data["correct_answers"]["df"] = str(df)
```

Symbolic math
in Python

Student view

```
<pl-question-panel>
  <p> Find the derivative of  $f(x) = \{\{params.f\}\}$  with respect to  $x$ .</p>
</pl-question-panel>

 $\frac{df(x)}{dx}$  = <pl-symbolic-input answers-name="df" variables="x"></pl-symbolic-input>
```

Demo: Randomized symbolic calculations

Find the derivative of $f(x) = 8x^2 + 7x + 6$ with respect to x .

$\frac{df(x)}{dx} = 7 + 2 \cdot 8 \cdot x$ 100%

Save & Grade Save only New variant

Correct answer

$\frac{df(x)}{dx} = 16x + 7$

Symbolic comparison for grading

Matrix elements

Student view

question.html

```
<pl-question-panel>
  <p> Suppose  $A$  is the following matrix:  $A =$  <pl-matrix-latex params-name="A" digits=
  <p> In code this is: <pl-variable-output digits="2"><variable params_name="A">A</variab
  <p> What is the matrix  $B = AA^T$ ? </p>
</pl-question-panel>

<pl-matrix-component-input answers-name="B" label="$B = $" comparison="sigfig" digits="2">
```

server.py

```
import numpy as np
import prairielearn as pl

def generate(data):
    A = np.random.rand(2, 2)
    A = np.round(A, 2)

    B = A @ A.T

    data["params"]["A"] = pl.to_json(A)
    data["correct_answers"]["B"] = pl.to_json(B)
```

Many input
and output
formats

Matrix input and output

Suppose A is the following matrix:

$$A = \begin{bmatrix} 0.42 & 0.020 \\ 0.17 & 0.070 \end{bmatrix}$$

In code this is:

Matlab **Mathematica** Python R

```
A = [0.42 0.02; 0.17 0.07];
```

copy this text

What is the matrix $B = AA^T$?

B =

 ⓘ

Save & Grade Save only New variant

Diagrams and 3D objects

Built using existing open-source web libraries

Demo: Drawing sketch

Sketch the function $y(x)$ given below.

$$y(x) = \begin{cases} 2x - x^2/4, & 0 \leq x < 4 \\ 12 - 6x + x^2/2, & 4 < x < 8 \\ -8 + x/2, & 8 \leq x \leq 16 \end{cases}$$

Graded objects:

Help buttons (not graded):

(The expected tolerance is 1/2 square grid for position and 10 degrees for angle.)

Save & Grade Save only New variant

Element pl-threejs: Display 3D objects and input transformations

Translate the body by 1 unit along the x axis and rotate the body by 45 degrees about the y axis with respect to the space frame.

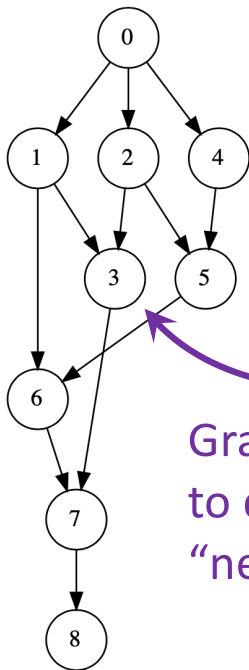
reset translate object rotate object \curvearrowright x \curvearrowright y \curvearrowright z \curvearrowright

body objects visible space objects visible frames visible shadows visible

Save & Grade Save only New variant

Proof blocks

Scaffolded practice for proof writing



Graded by matching to directed graph of "needed by" relations

Isomorphism Preserves Bipartite

Drag and drop **ALL** of the blocks below to create a proof of the following statement.

If graphs G and H are isomorphic and G is bipartite, then H is bipartite.

Drag from here:

7 One of u and v is in $L(H)$, and the other is in $R(H)$.

4 Let $\langle u - v \rangle$ be an edge in H . (If instead there are no edges in H , then H is trivially bipartite and we are done.)

6 One of $f(u)$ and $f(v)$ is in $L(G)$, and the other is in $R(G)$.

5 $\langle f(u) - f(v) \rangle$ is an edge in G

8 H is bipartite. (end of proof)

2 Let $L(G)$ and $R(G)$ be a partitioning of G 's vertices such that each edge of G has one endpoint in each set.

Construct your solution here:

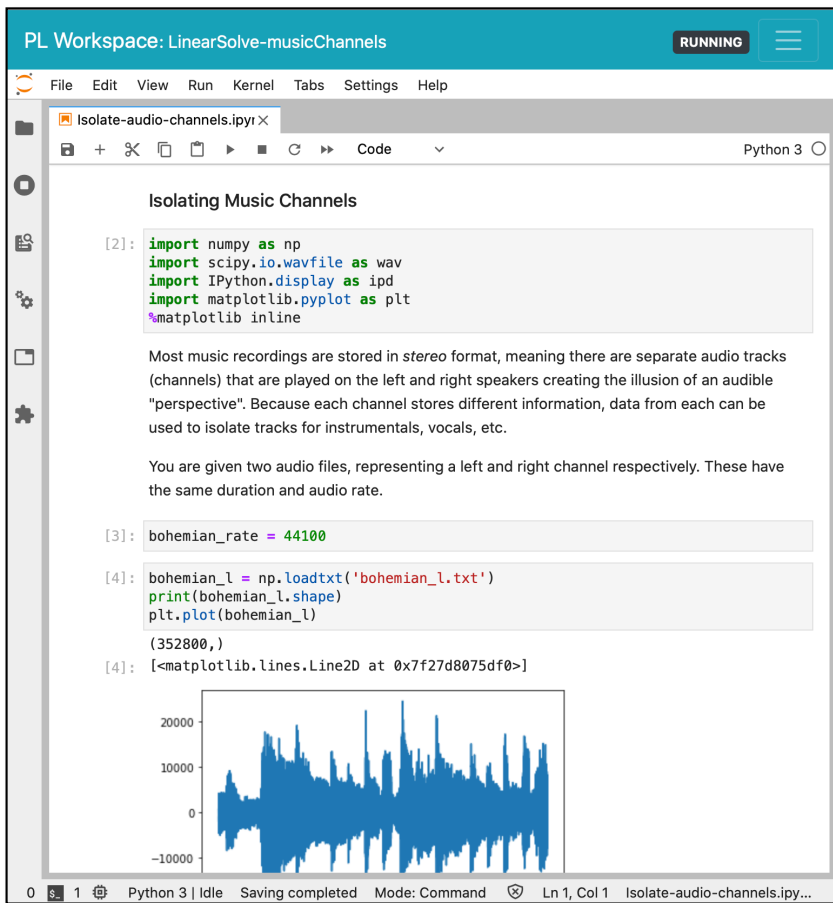
0 Assume G and H are isomorphic graphs and G is bipartite.

1 Let f be an isomorphism $V(H) \rightarrow V(G)$

3 Define $L(H) = \{v | f(v) \in L(G)\}$ and $R(H) = \{v | f(v) \in R(G)\}$

Save & Grade
Save only
New variant

Workspaces and containerized grading



PL Workspace: LinearSolve-musicChannels RUNNING

File Edit View Run Kernel Tabs Settings Help

Isolate-audio-channels.ipynx Python 3

Isolating Music Channels

```
[2]: import numpy as np
import scipy.io.wavfile as wav
import IPython.display as ipd
import matplotlib.pyplot as plt
%matplotlib inline
```

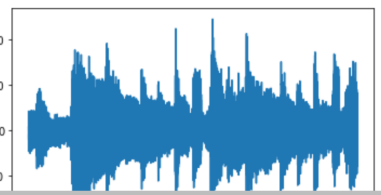
Most music recordings are stored in stereo format, meaning there are separate audio tracks (channels) that are played on the left and right speakers creating the illusion of an audible "perspective". Because each channel stores different information, data from each can be used to isolate tracks for instrumentals, vocals, etc.

You are given two audio files, representing a left and right channel respectively. These have the same duration and audio rate.

```
[3]: bohemian_rate = 44100
```

```
[4]: bohemian_l = np.loadtxt('bohemian_l.txt')
print(bohemian_l.shape)
plt.plot(bohemian_l)
```

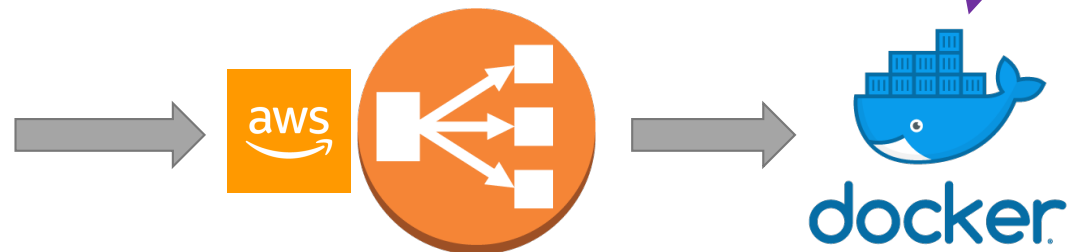
```
[4]: [<matplotlib.lines.Line2D at 0x7f27d8075df0>]
```



0 1 Python 3 Idle Saving completed Mode: Command Ln 1, Col 1 Isolate-audio-channels.ipynx...

Workspaces run inside PrairieLearn for Jupyter Notebooks, VS Code, R Studio, and more

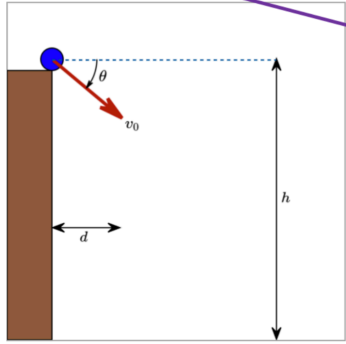
Safely auto-graded at scale in course-specific containers



Advanced randomization

Randomized multiple-choice question with dynamic drawing

A cannon ball with mass $m = 3 \text{ kg}$ is fired downward from a cliff at a height $h = 12.672 \text{ m}$, at an angle $\theta = 40^\circ$ with respect to the horizontal, and an initial velocity $v_0 = 21 \text{ m/s}$, as illustrated in the figure below.



This image is generated dynamically using the provided angle.

The problem statement is selected at random (either given t find d , or given d find t)

Suppose the ball hits the ground after $t = 0.74 \text{ s}$. What is the distance from the base of the cliff that the ball hits the ground? Assume the acceleration due to gravity is $g = 9.8 \text{ m/s}^2$.

- (a) $d = 14.588 \text{ m}$
- (b) $d = 11.904 \text{ m}$
- (c) $d = 15.54 \text{ m}$
- (d) $d = 2.683 \text{ m}$
- (e) $d = 9.989 \text{ m}$

The correct answer and the distractors are computed based on the given parameters.

Save & Grade Save only New variant

Python can generate HTML to change anything about the question

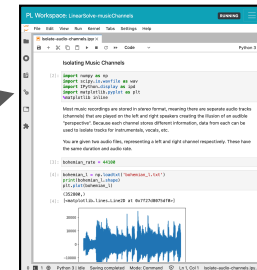
Write questions once, use everywhere

Computerized question pool

Randomization allows re-use
Auto-grading allows feedback
and trying again



Homeworks
with immediate
feedback



Computation
anywhere



Automated exams
in proctored facility



Exams for
remote
students

Case Study: Linear Algebra at Illinois

Assessments		AID	Students	Scores	Mean Score	Mean Duration
Computational lab lesson						
CL1	Python tutorial	Lesson1-Tutorial	439		0%	14m
CL1.1	Using PL for group work	Lesson0-Demo	409		98%	13m
CL2	Working with Vectors	Lesson2-Vectors	402		87%	1h 0m
CL2.1	Select your group (not for credit)	aa2-group-survey	362		0%	2m
CL2.2	Find out your assigned group (not for credit)	aa1-find-your-assigned-group	435		0%	8m
CL3	Matrix Operations	Lesson3-MatrixOperations	423		97%	1h 14m
CL4	Slinky: solving linear system of equations	Lesson4-LinearSystems	410		98%	1h 9m
CL5	Intro to Graphs and application to social network	Lesson5-Graphs	2		0%	52m
CL6	Discrete Cosine Transforms and Data Compression	Lesson6-DCT	0			
Computational lab HW						
CHW1	Intro to Python	CLHomework1	434		85%	17m
CHW2	Working with Vectors	CLHomework2	423		89%	49m
CHW3	Matrix operations	CLHomework3	424		93%	48m
CHW4	Linear System of Equations	CLHomework4	201		46%	45m
CHW5	Graphs and Algebraic Graph Theory	CLHomework5	0			
CHW6	Coordinate systems and data compression	CLHomework6	0			
CHW7	Markov chains	CLHomework7	0			
CHW8	Dynamical Systems	CLHomework8	0			
CHW9	Linear Regression	CLHomework9	0			
CHW10	Singular Value Decomposition	CLHomework10	0			
CHW11	Principal Component Analysis	CLHomework11	0			
Homeworks						
HW1	Week 1 - Modules 1-4	Homework1	443		82%	1h 46m
HW2	Week 2 - Modules 5-8	Homework2	422		87%	1h 14m
HW3	Week 3 - Modules 9-12	Homework3	435		101%	2h 19m
HW4	Week 4 - Modules 13-14	Homework4	425		104%	22m
HW5	Week 5 - Modules 15-18	Homework5	361		90%	1h 9m
HW6	Week 6 - Modules 19-21	Homework6	58		38%	28m
HW7	Week 7 - Modules 22-25	Homework7	0			
HW8	Week 8 - Modules 26-28	Homework8	0			
HW9	Week 9 - Modules 29-31	Homework9	0			
HW10	Week 10 - Modules 32-34	Homework10	0			
HW11	Week 11 - Modules 35-38	Homework11	0			
HW12	Week 12 - Modules 39-40	Homework12	0			
HW13	Week 13 - Modules 41-43	Homework13	0			
HW14	Week 14 - Modules 44-46	Homework14	0			
Exams						
E1	Midterm 1	Midterm1	435		89%	41m
E2	Midterm 2	Midterm2	0			
E3	Midterm 3	Midterm3	0			
E4	Final Exam	FinalExam	0			

Group-work computational labs with Python (Markov chains, image processing, etc)

Computational homework

“Regular” homework, unlimited attempts on randomized questions

Randomized, auto-graded exams with declining points

All created by Philipp Hieronymi, Mariana Silva, Nicolas Nytko, et al.

Case Study: Linear Algebra at Illinois

When is a vector in a column space

For which value of h is the vector $\begin{bmatrix} -10 \\ -15 \\ h \end{bmatrix}$ in the column space of $\begin{bmatrix} 1 & 2 \\ 3 & 1 \\ -3 & 0 \end{bmatrix}$?

$h =$

Determining coordinates with respect to a non-standard basis in \mathbb{R}^2

Find the coordinates of $\mathbf{b} = \begin{bmatrix} 2 \\ -1 \end{bmatrix}$ relative to the ordered basis $\mathcal{F} = (f_1, f_2)$ given by

$f_1 = \begin{bmatrix} -2 \\ 0 \end{bmatrix}, f_2 = \begin{bmatrix} -2 \\ -1 \end{bmatrix}$

That is, fill in the blanks below:

$\mathbf{b} =$ $\begin{bmatrix} -2 \\ 0 \end{bmatrix} +$ $\begin{bmatrix} -2 \\ -1 \end{bmatrix}$

and therefore the coordinate vector of \mathbf{b} relative to \mathcal{F} is:

$\mathbf{b}_{\mathcal{F}} =$

Drawing solution sets

Draw the solution sets for the following two equations for $-3 \leq x_1 \leq 3$:

$2x_1 + 7x_2 = -2$

and

$-1x_1 + 6x_2 = 3$

PL Workspace: CompLabs/Lesson6-DCT **RUNNING**

```

[1]: import numpy as np
import numpy.linalg as la
import matplotlib.pyplot as plt
matplotlib inline
    
```

Lesson 6: Discrete Cosine Transforms and Compression

A) Change of Basis / Lossy Compression

Suppose we were given the following orthogonal (but not orthonormal) basis, called a *Haar wavelet basis*:

$$H = \begin{pmatrix} 1 & 1 & 1 & 1 & 0 & 1 & 0 & 0 & 0 & 0 \\ 1 & 1 & 1 & -1 & 0 & 0 & 1 & 0 & 0 & 0 \\ 1 & 1 & -1 & -1 & 0 & 0 & 0 & 1 & 0 & 0 \\ 1 & -1 & 0 & 1 & 0 & 0 & 0 & 0 & 1 & 0 \\ 1 & -1 & 0 & 1 & 0 & 0 & 0 & 0 & 0 & 1 \\ 1 & -1 & 0 & -1 & 0 & 0 & -1 & 0 & 0 & 0 \\ 1 & 1 & 0 & 0 & 1 & -1 & 0 & 0 & 0 & 0 \\ 1 & -1 & 0 & 0 & -1 & 1 & 0 & 0 & 0 & -1 \end{pmatrix}$$

And the following vector $\mathbf{x} \in \mathbb{R}^8$:

$$\mathbf{x} = \begin{bmatrix} 240 \\ 170 \\ 200 \\ 200 \\ -150 \\ -200 \\ -225 \\ -220 \end{bmatrix}$$

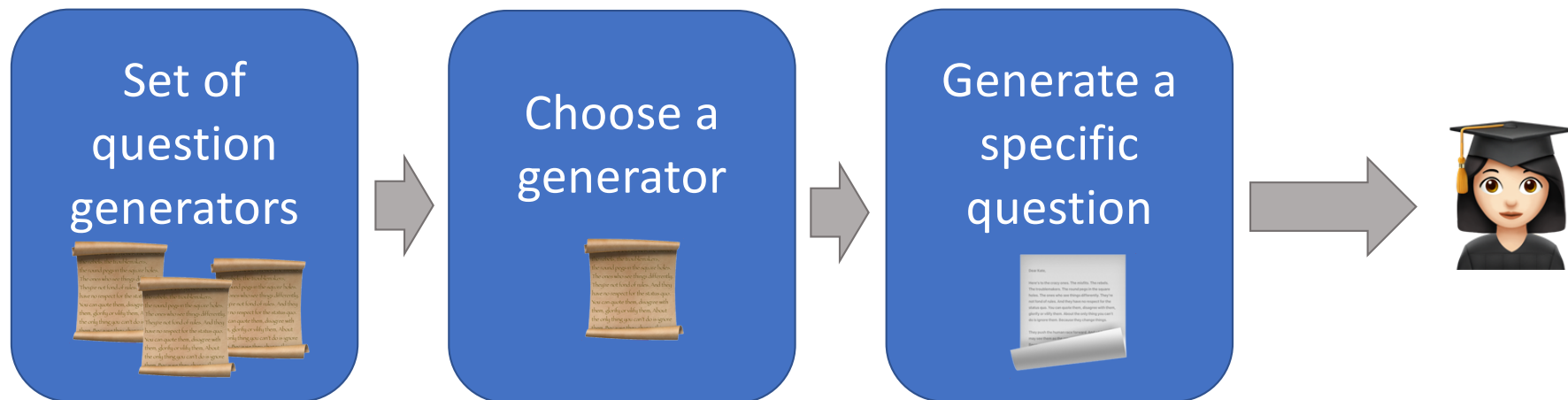
The matrix \mathbf{H} whose columns are the basis vectors above transforms vectors from the Haar basis to the elementary basis.

As such, we are able to compute $\mathbf{H}\mathbf{x}_H = \mathbf{x} \Leftrightarrow \mathbf{x}_H = \mathbf{H}^{-1}\mathbf{x}$

Python 3 | Idle Mode: Command Ln 1, Col 1 DCT_and_Compression.ipynb

Randomized exam generation

- Randomize question selection as well as question parameters:



- Statistics before and after exam to ensure fairness and quality

Retries give partial credit with mastery

Question 5: Add two numbers

Consider two numbers $a = 9$ and $b = 8$.

What is the sum $c = a + b$?

$c =$?

[Grade](#) [Save](#)

Question

Best submission: **unanswered**

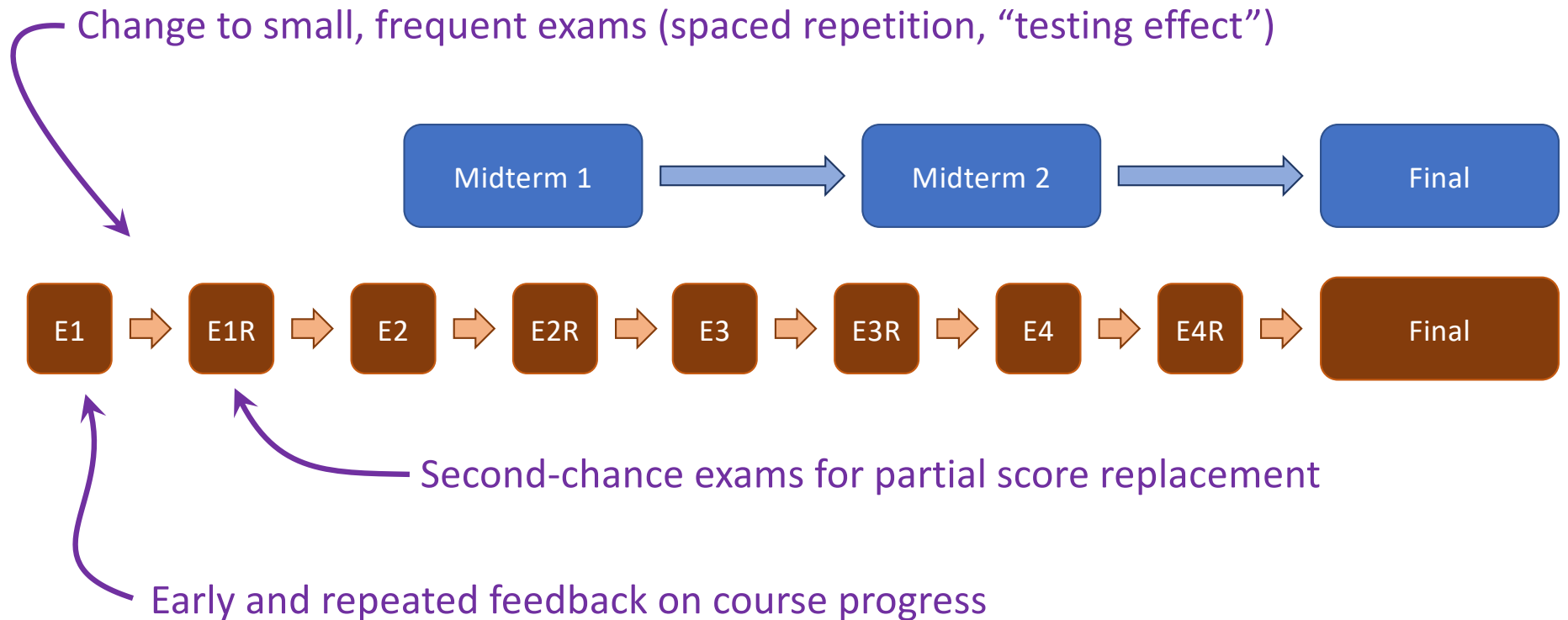
Available points: 5, 3, 1 ?

Awarded points: 0 / 5

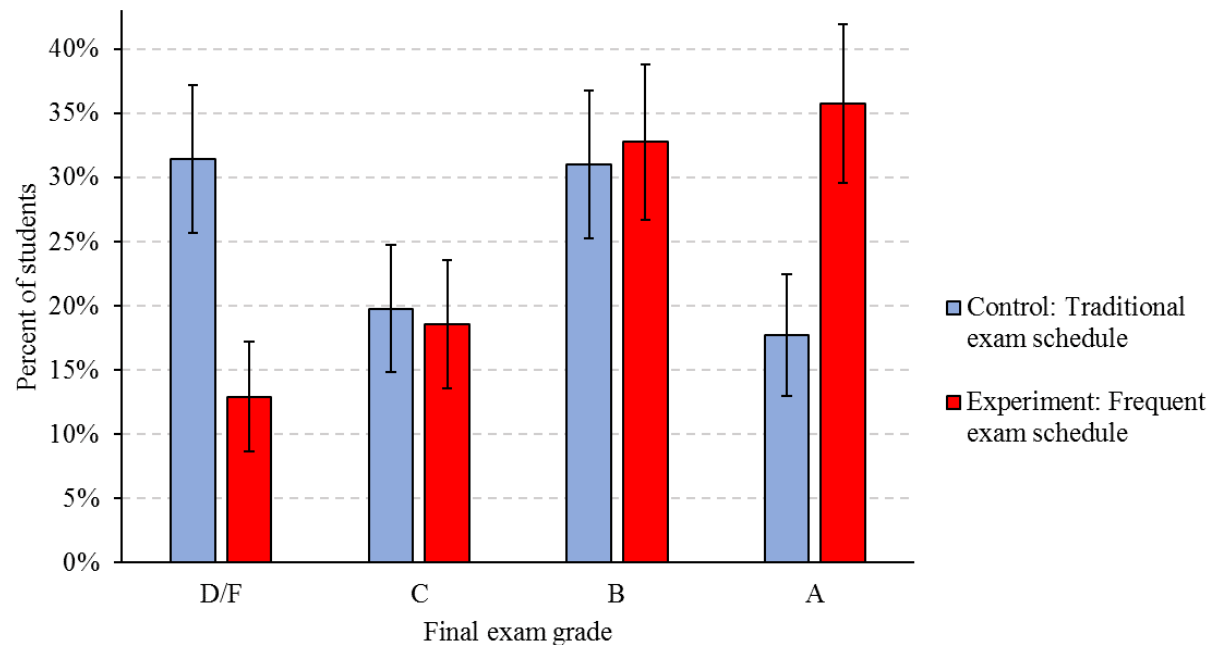
[Report an issue with this question](#)

Immediate auto-grading allows trying again for partial credit

Changing the way we test

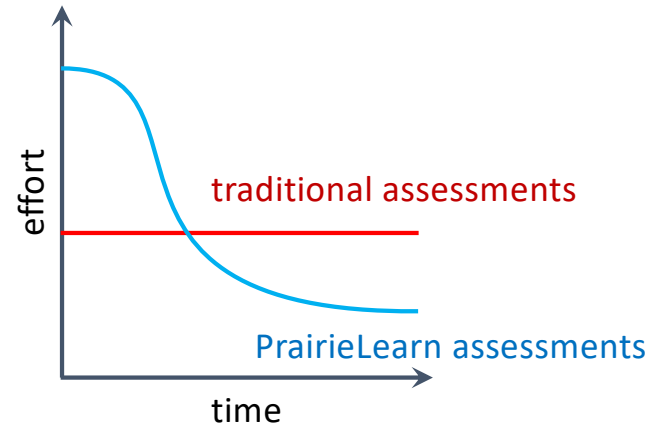
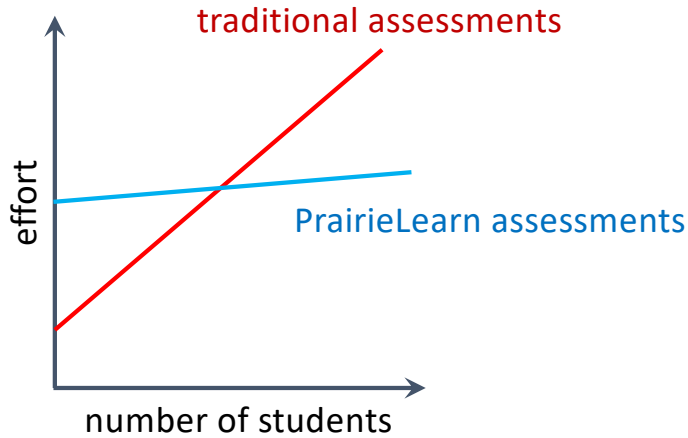


Learning outcomes improve



- “Introductory Solid Mechanics”: sophomore engineering, 250 students
- Same instructor, same content, same pen-and-paper final exam

Most efficient at scale and over time



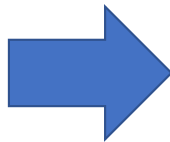
- Immediate benefits for student learning at any scale
- Free up course staff time to help students and create better learning activities

CBTF: Computer-Based Testing Facility

Each exam runs for about 4 days, 10am to 10pm



Student email:
Exam is available



Make a reservation for Sarah Connor (sconnor@college.edu) for CS 313: Exam 7

This is a 50min exam.

Pick an available session from those below:

Sunday, April 29th

11:00 am - 11:50 am available	12:00 pm - 12:50 pm available	1:00 pm - 1:50 pm available	2:00 pm - 2:50 pm available	3:00 pm - 3:50 pm available	4:00 pm - 4:50 pm available	5:00 pm - 5:50 pm available	6:00 pm - 6:50 pm full	7:00 pm - 7:50 pm full	8:00 pm - 8:50 pm available	9:00 pm - 9:50 pm full
----------------------------------	----------------------------------	--------------------------------	--------------------------------	--------------------------------	--------------------------------	--------------------------------	---------------------------	---------------------------	--------------------------------	---------------------------

Monday, April 30th

10:00 am - 10:50 am available	11:00 am - 11:50 am available	12:00 pm - 12:50 pm available	1:00 pm - 1:50 pm available	2:00 pm - 2:50 pm available	3:00 pm - 3:50 pm available	4:00 pm - 4:50 pm available	5:00 pm - 5:50 pm available	6:00 pm - 6:50 pm available	7:00 pm - 7:50 pm available	8:00 pm - 8:50 pm available	9:00 pm - 9:50 pm full
----------------------------------	----------------------------------	----------------------------------	--------------------------------	--------------------------------	--------------------------------	--------------------------------	--------------------------------	--------------------------------	--------------------------------	--------------------------------	---------------------------

Tuesday, May 1st

10:00 am - 10:50 am available	11:00 am - 11:50 am available	12:00 pm - 12:50 pm available	1:00 pm - 1:50 pm available	2:00 pm - 2:50 pm available	3:00 pm - 3:50 pm available	4:00 pm - 4:50 pm available	5:00 pm - 5:50 pm available	6:00 pm - 6:50 pm available	7:00 pm - 7:50 pm full	8:00 pm - 8:50 pm available	9:00 pm - 9:50 pm full
----------------------------------	----------------------------------	----------------------------------	--------------------------------	--------------------------------	--------------------------------	--------------------------------	--------------------------------	--------------------------------	---------------------------	--------------------------------	---------------------------

You can add or cancel a reservation up until 10 minutes **after** that session starts, pending availability. Adding or starting a session late does not change the end time.

Unlimited rescheduling allowed before the scheduled timeslot



Take the exam in a secure environment

Security cameras

Professional proctors

Privacy screens



Calculators

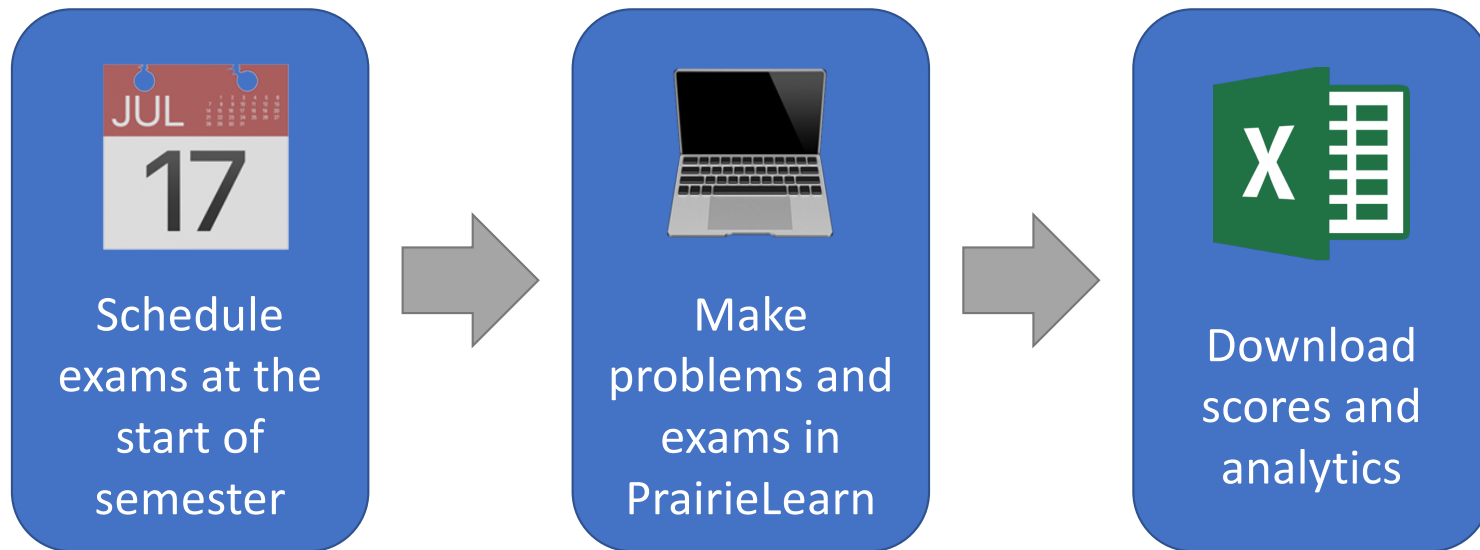
Firewalled internet

Full software platform
(Python, RStudio, etc)

ID card swipe
to check in

Many different
exams concurrently

Instructors focus on exam creation and data



No conflict handling, no proctoring, no sick students, no fuss.

Disability accommodations automatically handled



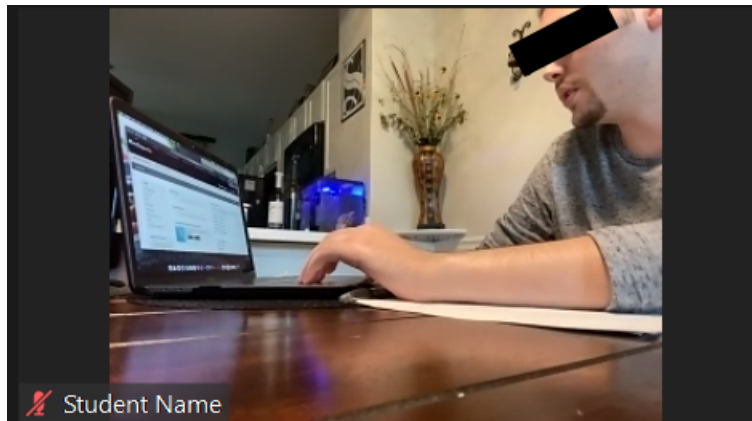
Reduced-distraction computers
in separate cubicles

Extended-time exams managed
by the scheduling software

↶ Reduced-distraction seating

Computerized exams in the time of COVID-19

- Up to 10,000 exams per week via dedicated Zoom proctors
- Students do exams on their laptops, using phones for proctor Zoom



- Managed by same scheduling software as the physical CBTF

Want to try PrairieLearn?

- Docs: <https://prairielearn.readthedocs.io/>
- Live site: <https://www.prairielearn.org>
- Code: <https://github.com/PrairieLearn/PrairieLearn>



The hardest thing is spelling
"Prairie" correctly