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

Standard tools to write questions

and more...
“Add numbers” question generator

server.py

```python
import random

def generate(data):
    a = random.randint(5, 10)
    b = random.randint(5, 10)

    data['params']['a'] = a
    data['params']['b'] = b

    c = a + b
    data['correct_answers']['c'] = c
```

question.html

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

Student view

Question 5: Add two numbers

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

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

$c =$ number (3 significant figures)
Make easy things easy, hard things possible

Learning principles:
- Scaffolded practice
- Immediate feedback
- Frequent testing
- Help from human instructors
Analytics and data

Record every action taken by students

Ready-made visualizations

All raw data is downloadable
Rich set of question components

- Multiple choice
- Symbolic
- Drawing
- Matrix

Easily add new custom elements that anyone can use
Elements: a flexible extension mechanism

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

Share between questions and courses
Symbolic math in Python

```python
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'] = str(df)
```

Student view

```html
<pl-question-panel>
  <p>Find the derivative of \( f(x) = {{\{params.f}\}} \) with respect to \( x \).</p>
</pl-question-panel>
$$\frac{df(x)}{dx} = 7 + 2*8*x$$
```

Symbolic comparison for grading

```
Correct answer
\[
\frac{df(x)}{dx} = 16x + 7
\]
```

`server.py`
Matrix elements

question.html

```html
<pl-question-panel>
<p>Suppose $A$ is the following matrix: $A = \begin{pmatrix} 0.42 & 0.02 \\ 0.17 & 0.07 \end{pmatrix}$

In code this is: `<pl-variable-output digits="2">\text{variable params name="A"}$A</variable>`

What is the matrix $B = A^T$? </p>
</pl-question-panel>

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

server.py

```python
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

Student view
Diagrams and 3D objects

Built using existing open-source web libraries
Proof blocks

Scaffolded practice for proof writing

Graded by matching to directed graph of “needed by” relations

Poulsen et al., “Drag and Drop Proofs With Automated Feedback”, 2021 (preprint)
Workspaces and containerized grading

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

Safely auto-graded at scale in course-specific containers
Advanced randomization

Python can generate HTML to change anything about the question.

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

Randomized parameters

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

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

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

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 \[
\begin{bmatrix}
1 & 2 \\
3 & 1 \\
-3 & 0
\end{bmatrix}
\]?

$h = \text{number (2 digits after decimal)}$

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

Find the coordinates of $b = \begin{bmatrix} 2 \\ -1 \end{bmatrix}$ 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:

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

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

$b_\mathcal{F} = \begin{bmatrix} \text{ } \\ \text{ } \end{bmatrix}$

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

\[-1x_1 + 6x_2 = 3\]

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:

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

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

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

The matrix $H$ whose columns are the basis vectors above transforms vectors from the Haar basis to the elementary basis.

As such, we are able to compute $Hx = x = H^{-1}x$. 

Save & Grade  Save only
Randomized exam generation

• Randomize question selection as well as question parameters:

  - Set of question generators
  - Choose a generator
  - Generate a specific question

• Statistics before and after exam to ensure fairness and quality
Retries give partial credit with mastery

Immediate auto-grading allows trying again for partial credit
Changing the way we test

Change to small, frequent exams (spaced repetition, “testing effect”)

Second-chance exams for partial score replacement

Early and repeated feedback on course progress
Learning outcomes improve

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

Morphew et al., *Applied Cognitive Psychology*, 2020
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

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

- Schedule exams at the start of semester
- Make problems and exams in PrairieLearn
- Download scores and analytics

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/](https://prairielearn.readthedocs.io/)
- Live site: [https://www.prairielearn.org](https://www.prairielearn.org)
- Code: [https://github.com/PrairieLearn/PrairieLearn](https://github.com/PrairieLearn/PrairieLearn)

The hardest thing is spelling “Prairie” correctly.