The impact of infusing computation and visualization into introductory physics subjects

Kyle Keane, Michelle Tomasik, Anna Musser, Lauren Berk, and Andrea Griffin

MITx:
Mech

View this course as:

Course Textbook

Mechanics

Audit Access
You lose all a

Mary wants to throw a ball straight up and then hit it with a second ball. She wants the balls to collide at height h=10.0

between successive thr

a negligible radius. Ta

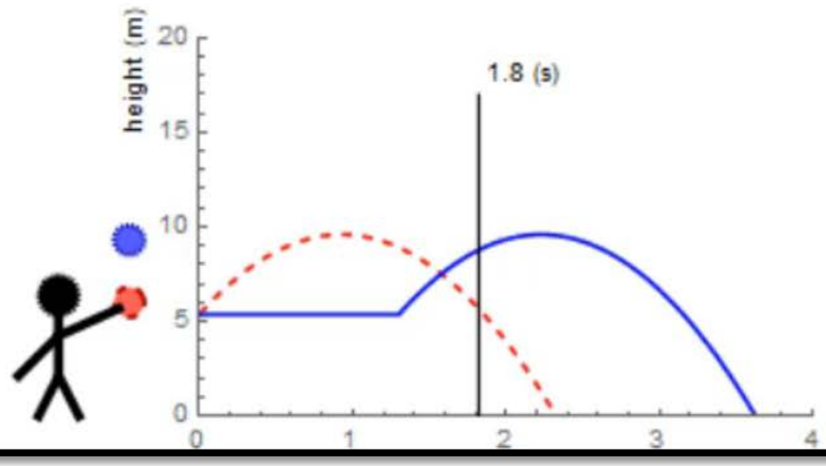
are equal.

Enter your answers t

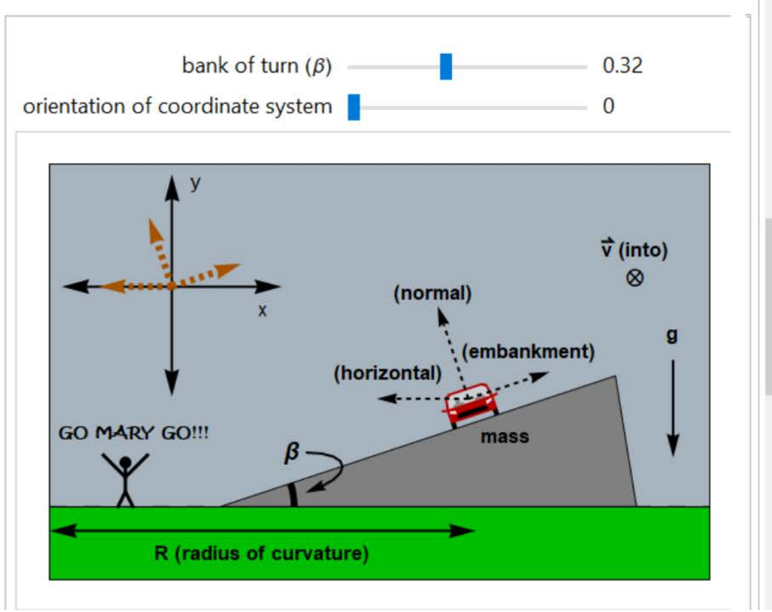
(a) How long does it ta
collide?

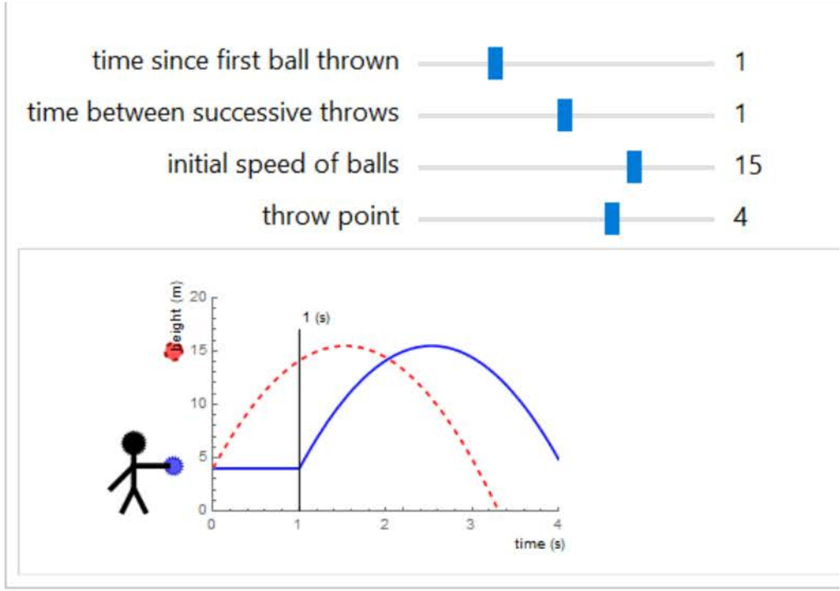
(b) Find the initial spee

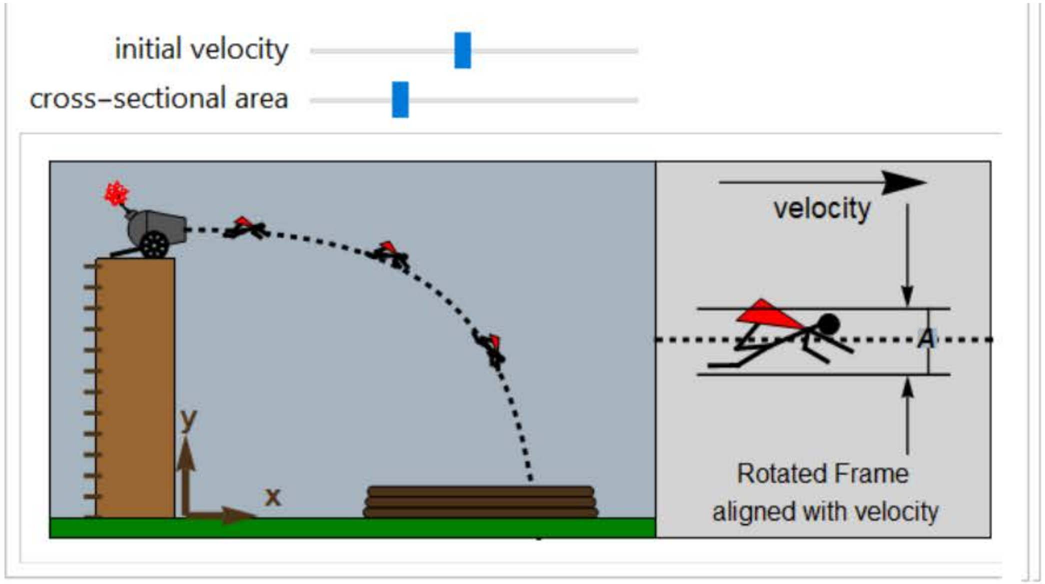
time since first ball thrown	1.82
time between successive throws	1.3
initial speed of balls	9.1
throw point	5.36

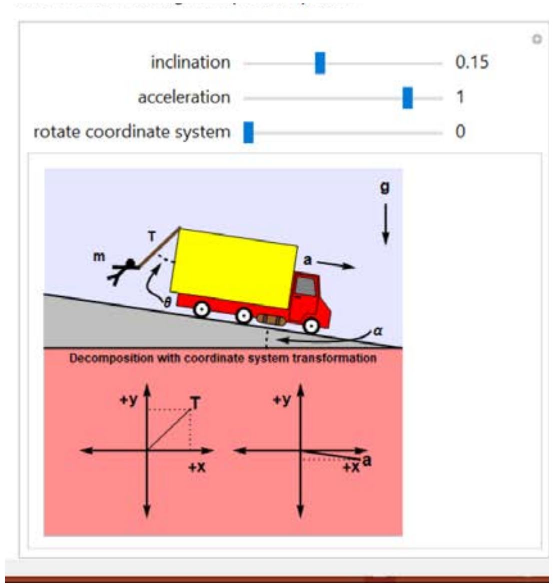


- Course Information
- Prerequisite Math and Su
- Week 1: Kinematics
- Week 2: Newton's Laws
- Week 3: Circular Motion
- Week 4: Drag Forces, Constraints and Continuous Systems
- Exam
- Exit Survey


bank of turn (β) 0.32
orientation of coordinate system 0
y
x
v⃗ (into)
(normal)
(embankment)
(horizontal)
g
GO MARY GO!!!
β
mass
R (radius of curvature)


time since first ball thrown 1
time between successive throws 1
initial speed of balls 15
throw point 4
height (m)
1 (s)
time (s)

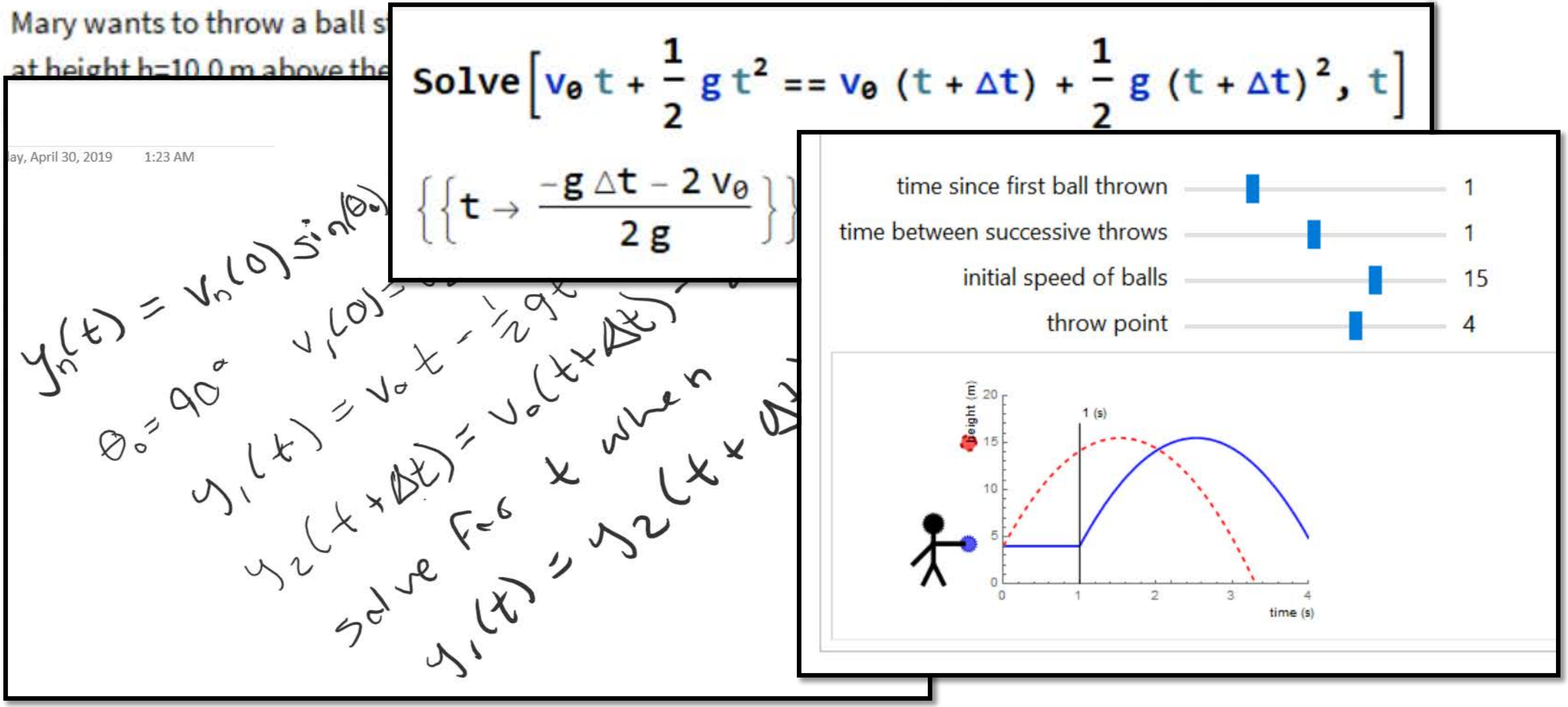

initial velocity
cross–sectional area
velocity
A
y
x
Rotated Frame
aligned with velocity


inclination 0.15
acceleration 1
rotate coordinate system 0
g
T
m
a
θ
α
Decomposition with coordinate system transformation
+y
+x
T
+y
+x
a

We are Educators **and Scientists…**

- Dr. Kyle Keane
  Research Scientist
- Dr. Michelle Tomasik
  Digital Learning Scientist
- Anna Musser
  Research Methodologist
- Andrea Griffin
  Software Engineer
- Lauren Berk
  Data Scientist

Solution By Hand, By Code, or By Visualization

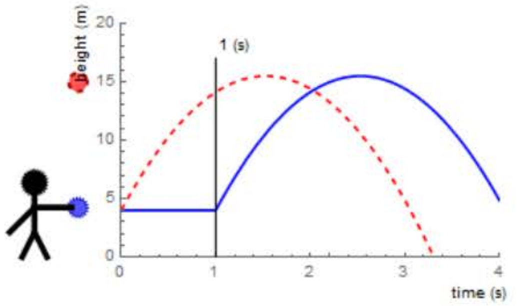


time since first ball thrown 1

time between successive throws 1

initial speed of balls 15

throw point 4



Ma ... a second ball.

at h ... knows that sh

suc ... the same spe

rad ... ve for when tw

Ent ... ther down th

(a) ... thrown into th

time between successive throws 1

initial speed of balls 15

throw point 4

	time since first ball was thrown (s)								
	0.	0.5	1.	1.5	2.	2.5	3.	3.5	4.
Height of first ball (m)	4.	10.3	14.1	15.5	14.4	10.8	4.85	0	0
Height of second ball (m)	4	4	4.	10.3	14.1	15.5	14.4	10.8	4.85

Here are some related questions you can consider, but you will not be graded on these.

- When do the balls collide if they are thrown 0.5 seconds apart from 2 meters high at a speed of 5 m/s?
- Does the height of the throw point matter? Why or why not?

Click on each of the following blocks of code hold the SHIFT key while hitting the ENTER key to compute the result of running the following Wolfram Language code

```
(*CLICK HERE AND HOLD SHIFT WHILE PRESSING ENTER TO RUN THE CODE*)
(*define two equations*)
eq1 = 2 + v * t - 2 t^2
eq2 = 2 + v (t - 2) - 2 (t - 2)^2
```

$2 - 2t^2 + t v$

$2 - 2(-2+t)^2 + (-2+t)\, v$

```
(*CLICK HERE AND HOLD SHIFT WHILE PRESSING ENTER TO RUN THE CODE*)
(*set them equal and solve*)
solveThis = FullSimplify[eq1 == eq2]
solution = First@Solve[solveThis, t]
```

$4t == 4 + v$

$\{t \to \frac{4+v}{4}\}$

```
(*CLICK HERE AND HOLD SHIFT WHILE PRESSING ENTER TO RUN THE CODE*)
(*substitute that solution back into the equation and solve
 for the remaining variable*)
substitutedValues = ReplaceAll[10 == eq1, solution]
FullSimplify@Solve[substitutedValues, v]
```

$\frac{1}{4} v (4+v) - \frac{1}{8} (4+v)^2$

$4\sqrt{5}\}, \{v \to 4\sqrt{5}\}\}$

2x2 Factorial Design

Group 0 - Control: Students are given traditional PSET questions, which are considered standard practice for undergraduate physics courses.

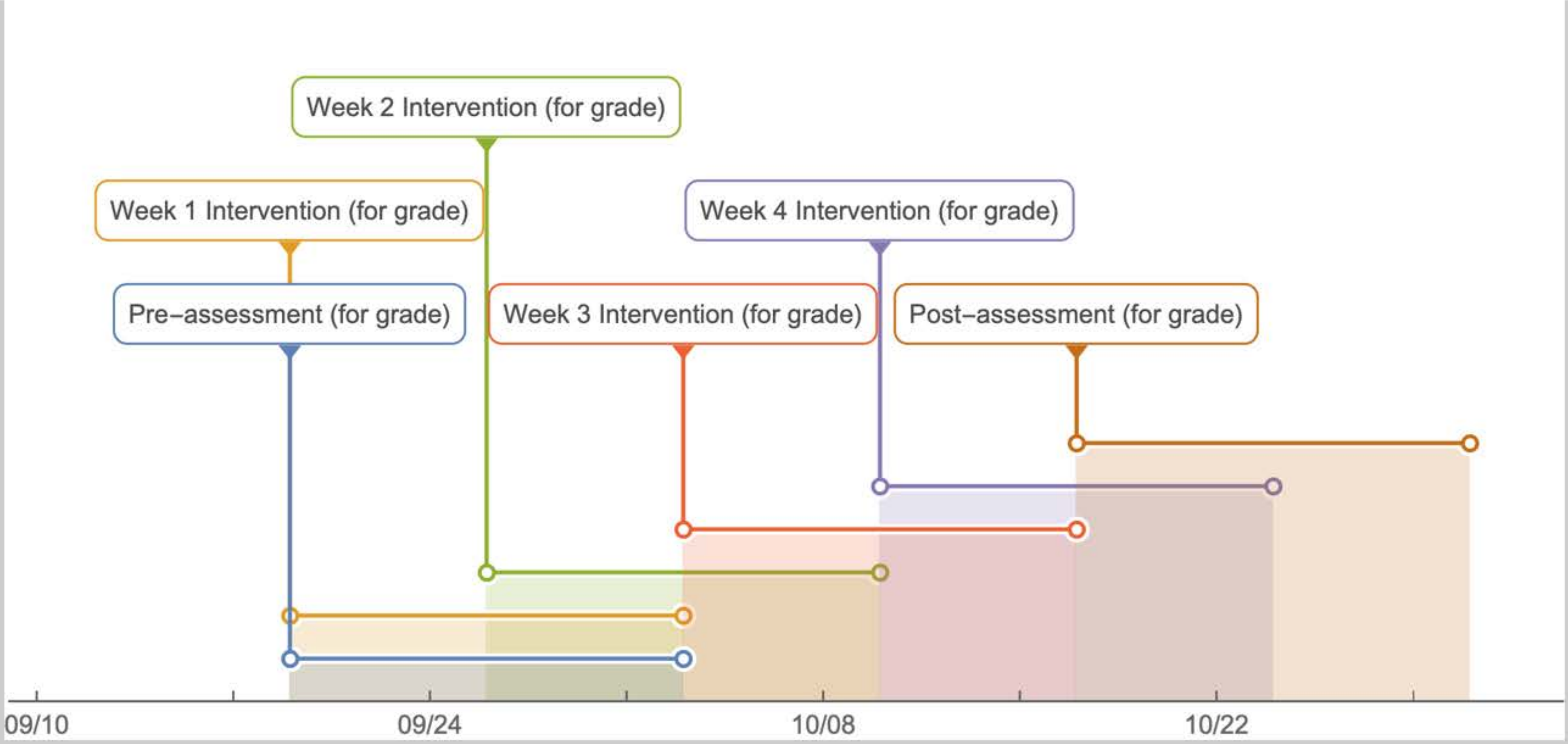
Group 1 - P+V: Students are instructed to modify pieces of code to complete computer PROGRAMMING tasks to solve physics problems by creating VISUAL WIDGETS designed to reinforce physics concepts.

Group 2 - P+N: Students are instructed to modify pieces of code to complete computer PROGRAMMING tasks to solve physics problems by creating NON-VISUAL WIDGETS designed to reinforce physics concepts.

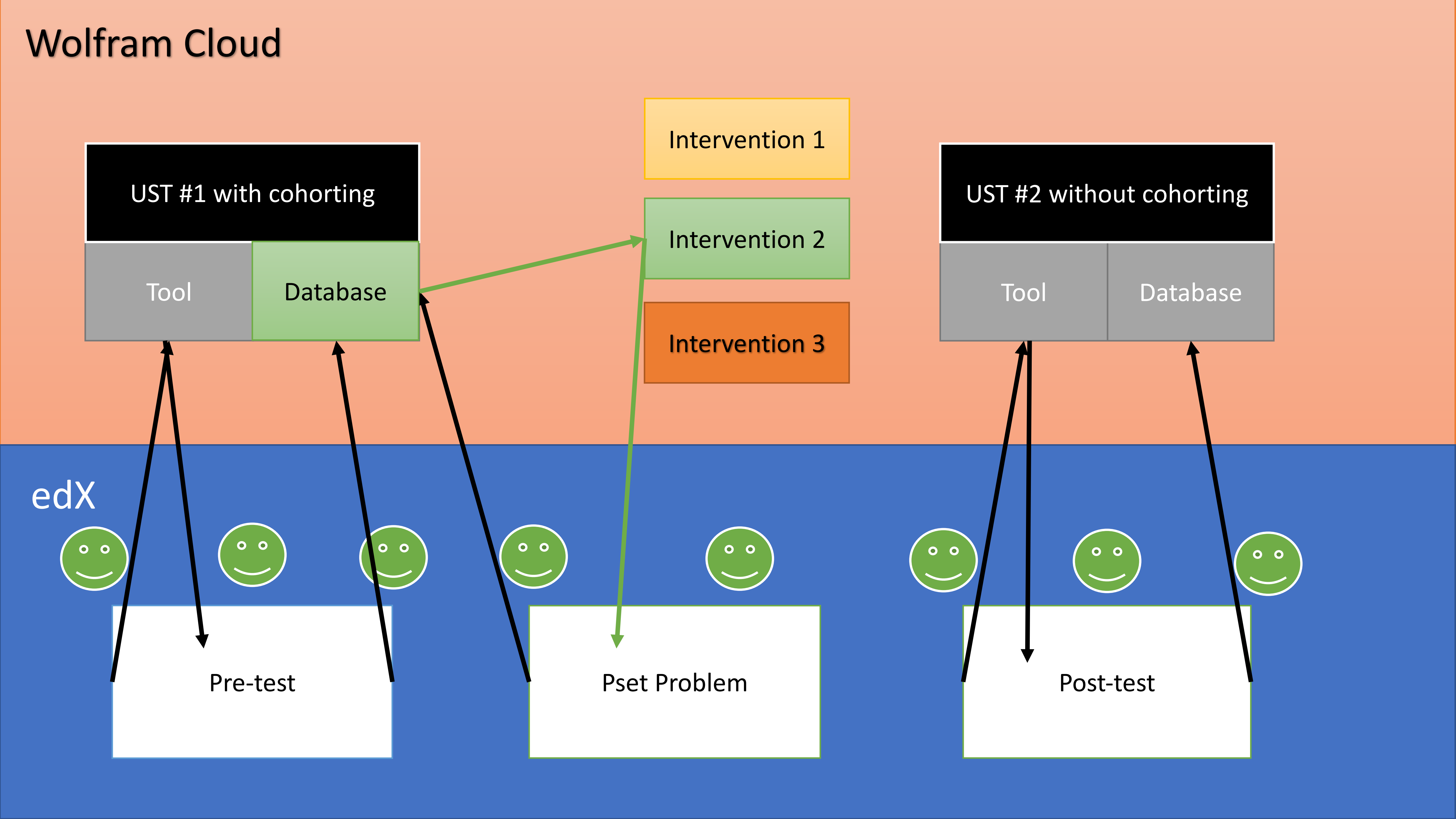
Group 3 - Q+V: Students are given the same VISUAL WIDGETS as Group 1, but they are asked to answer additional QUESTIONS that require them to engage with the widgets.

Group 4 - Q+N: Students are given the same NON-VISUAL WIDGETS as Group 2, but they are asked to answer additional QUESTIONS that require them to engage with the widgets.

Sequencing in an Asynchronous Course



In practice, we allowed students to work on each part of the course past the due dates as this was the practice of the rest of the course, however we were diligent to be sure those used in the study followed the intended path of the experiment.


Wolfram Cloud
UST #1 with cohorting
Tool
Database
Intervention 1
Intervention 2
Intervention 3
UST #2 without cohorting
Tool
Database
edX
Pre-test
Pset Problem
Post-test

Pre-test and Balancing Cohorts

- Demog
- Physic
- Visuali
- Compu
- Self As

As we mentioned earlier, we took an algorithmic approach to assign participants to treatment groups, using dynamic allocation. The covariates we selected to balance were:

- "WL" indicates whether a student has previous experience with the Wolfram Language.
- "Lang" indicates whether a student has other computer programming experience
- "Complete" measures the likelihood of a student completing the course
- "Hours" measures the number of hours per week the students anticipate they will be able to dedicate to the course
- "Support" indicates whether a student has someone such as a friend or family member available to them who can help them with the course
- "Physics" indicates the student's prior physics knowledge, as measured by the FCI questions asked during the pre-test.
- "Consc" is the conscientiousness score from the Five Factor personality model, and may correlate with a student's ability to follow-through on their intentions to complete the course.

We gave the Physics pre-test score a weight of four times the weights of the other covariates to reflect its importance and ensure that balancing the Physics covariate was a higher priority in the algorithm.

Preliminary Results - Attrition

One of the survey questions from the beginning of the course asked how likely the students were to complete the course. To begin the analysis of our data, we looked at how predictive this question was of attrition or completion of the course.

How likely are you to complete this course:	Unlikely	Maybe	Likely	I will
Attrition rate:	85.7%	88.2%	82.6%	79.7%

Because we used this survey question as a covariate in the dynamic assignment of participants to treatment groups, we were able to protect against drastically different final sample sizes across treatment groups.

Preliminary Results

Effect of Intervention

Non-standard Tools

Predictive of Change in Standard Assessments?

group	count	Physics	Spatial	CS
0 - Control	14	3.86	3.64	2.50
1 - Viz + coding	16	4.00	3.94	2.56
2 - Just coding	7	4.43	3.00	2.57
3 - Just viz	12	4.42	4.00	3.00
4 - Neither	11	3.45	3.64	2.55
0, 2, 4 - No viz	32	3.84	3.50	2.53
1, 4 - Viz	28	4.18	3.96	2.75
[illegible]o coding	37	3.92	3.76	2.68
[illegible]ing	23	4.13	3.65	2.57

Not Significant Due to Insufficient Sample Size

When we measured the effect of the interventions was using an Analysis of Variance (ANOVA) approach, we found no significant results. We first performed a one-way ANOVA test, treating each treatment group as distinct, and obtained p-values for Physics, Spatial, and CS scores of 0.992, 0.831, and 0.659 respectively. We also performed a factorial ANOVA analysis, which yielded for every combination of groups and final scores, p-values above 0.1. While these results are not statistically significant, they are directionally consistent with our original hypothesis, and we believe with a larger sample size in future trials, we will be able to find significant results.

Preliminary Results

We also considered non-standardized tools In order to measure the benefits of these interventions on the students in 8.01x. Instead of taking the post-tests in physics, spatial reasoning, and computer science as our metrics, we looked at the final course grades of the students in each group, and again performed descriptive and ANOVA analysis.

Effect of Intervention

Non-standard Tools
Predictive of Final Grade?

Treatment Group	Count	Average Grade
0 - Control	14	82%
1 - Viz + coding	16	89%
2 - Just coding	7	85%
3 - Just viz	12	89%
4 - Neither	11	94%
0, 2, 4 - No viz	32	87%
1, 4 - Viz	28	89%
0, 3, 4 - No coding	37	88%
1, 2 - Coding	23	88%

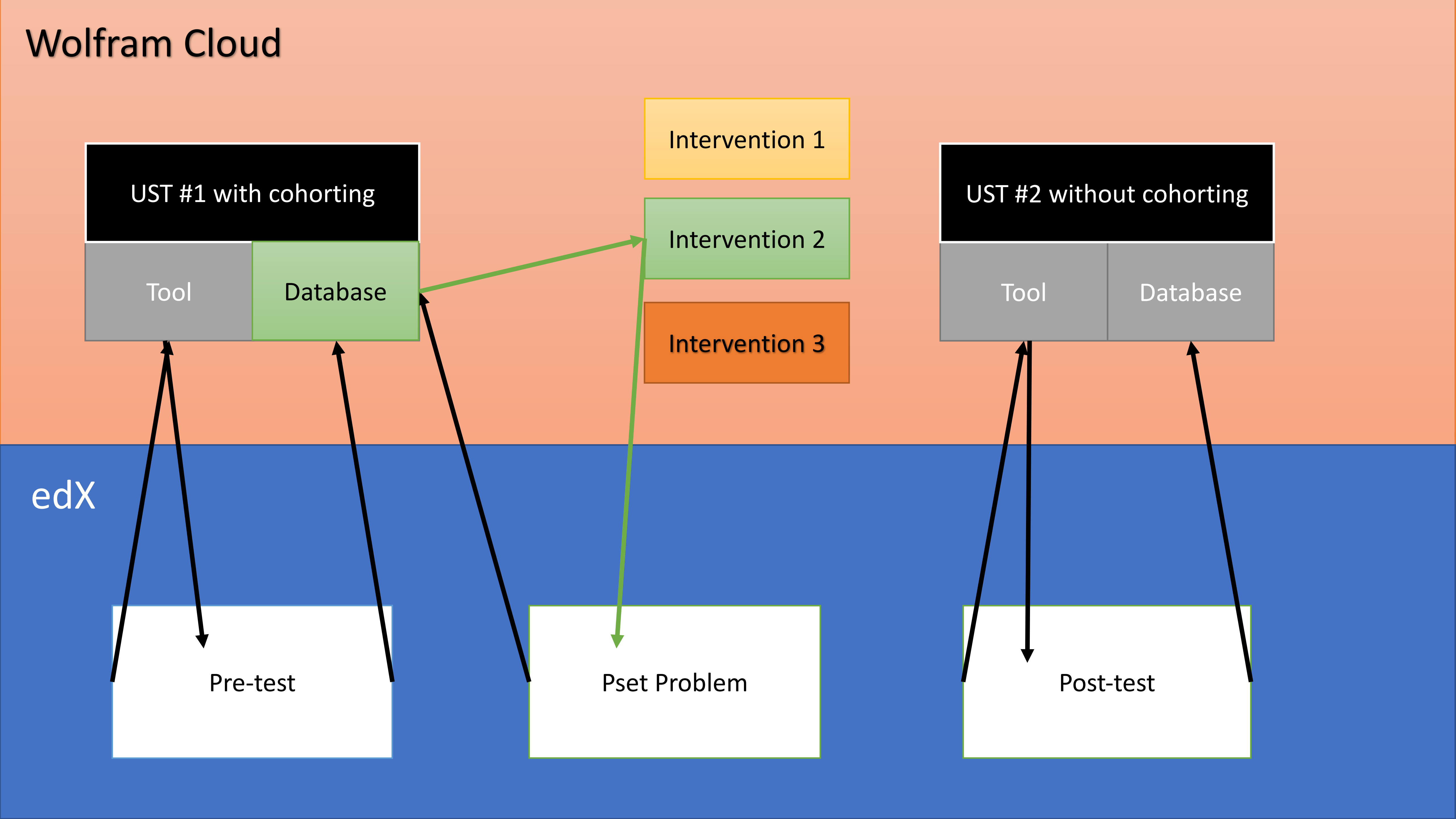
Not Significant Due to Insufficient Sample Size

Next Steps

- We plan to run more of these studies as collaboration bandwidth will permits.
- If this study’s hypotheses are born out in future studies, such findings may be relevant beyond the realm of undergraduate physics.
  - Chemistry, biology, mathematics, as well as other fields may find that they too can boost subject comprehension by incorporating coding and visualization into their curriculum.
- Share what we have built!

Outcomes

- Demonstration of **2x2 factorial design** on MITx with cohort-balancing based on pre-test and personality assessment
- **Real time cohorting** to balance skills and likelihood of attrition based on standard techniques used in medical and clinical trials where patients enroll on a rolling basis
- Ability to serve **differentiated instruction** based on learner profiles
- **Tools for others to run similar experiments in their online courses!**


Wolfram Cloud
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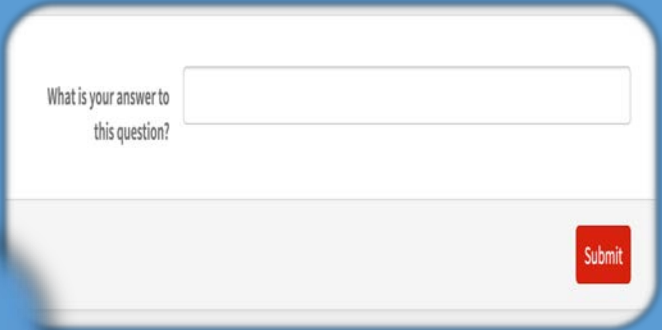
Intervention 1
Intervention 2
Intervention 3
UST #2 without cohorting
Tool
Database
edX
Pre-test
Pset Problem
Post-test

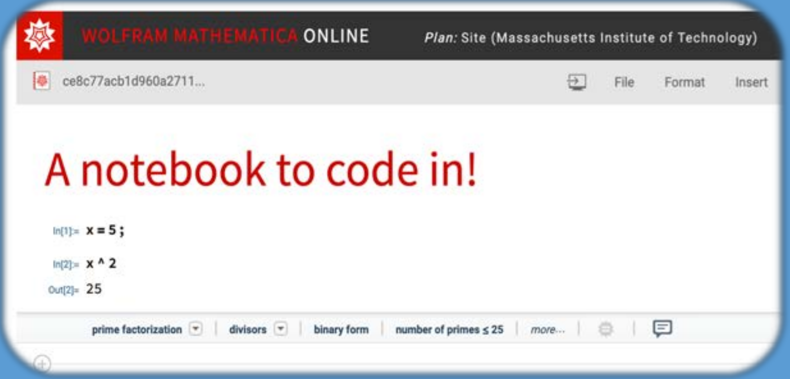
Wolfram on edX

Embed the Following Types of Content with or without Grading

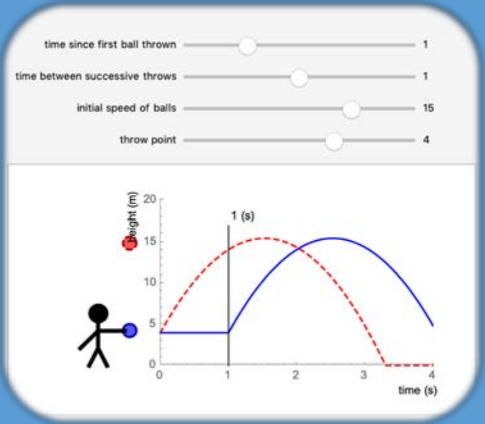
Forms



Coding Notebook



iFrame



An example of the Work Plan (External resource) (1.0 / 1.0 points)

Your name as it will appear on this Work Plan.

Kyle Keane

Character limit: 35

Why are you taking this course?

To learn about making my online courses more interactive and computational.

Character limit: 400

Name one person who you will discuss your coursework with:

Andrea Griffin

Character limit: 35

Which days during the week do you plan to work on this course?
Select all that apply.

Sunday | Monday | Tuesday | Wednesday | Thursday | Friday | Saturday

When, approximately, do you plan to do the work?
Select all that apply.

Morning | Afternoon | Evening

List at least one goal for your first week of work.

Add a widget into my course.

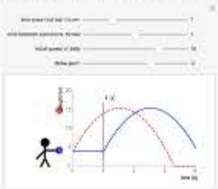
Character limit: 120

Describe goals for your participation over the whole course.

Create the fancy widget I keep telling my friends about.

Character limit: 260

In an earlier submission, you submitted this as a picture that motivates you:



To replace that image with a new one, submit your new motivational image here:

Work Plan

Kyle Keane

To learn about making my online courses more interactive and computational.

I will discuss my course work with Andrea Griffin.

I plan to work on this course:

Sunday | **Monday** | **Tuesday** | **Wednesday** | **Thursday** | **Friday** | Saturday

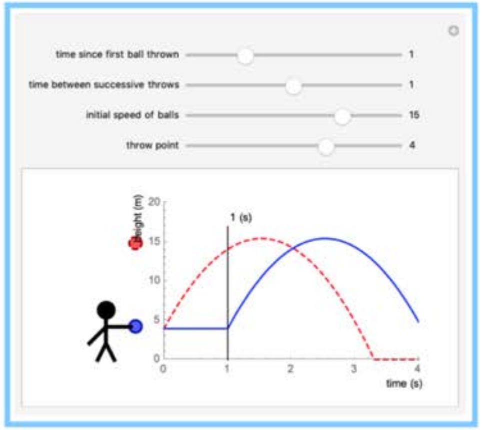
I will typically work: Morning | Afternoon | **Evening**

Goals for my first week of work:

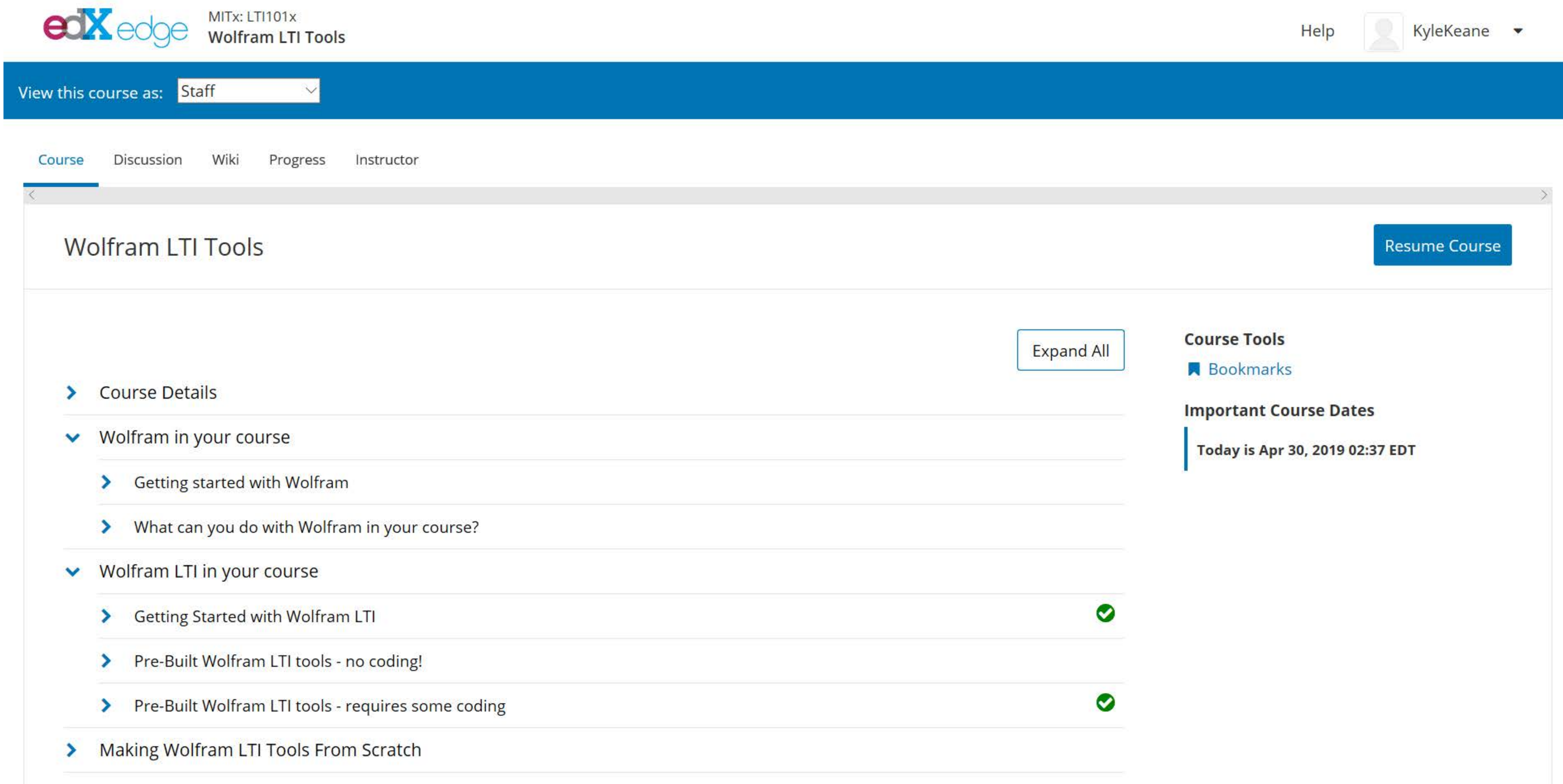
Add a widget into my course.

Goals for my work over the whole course:

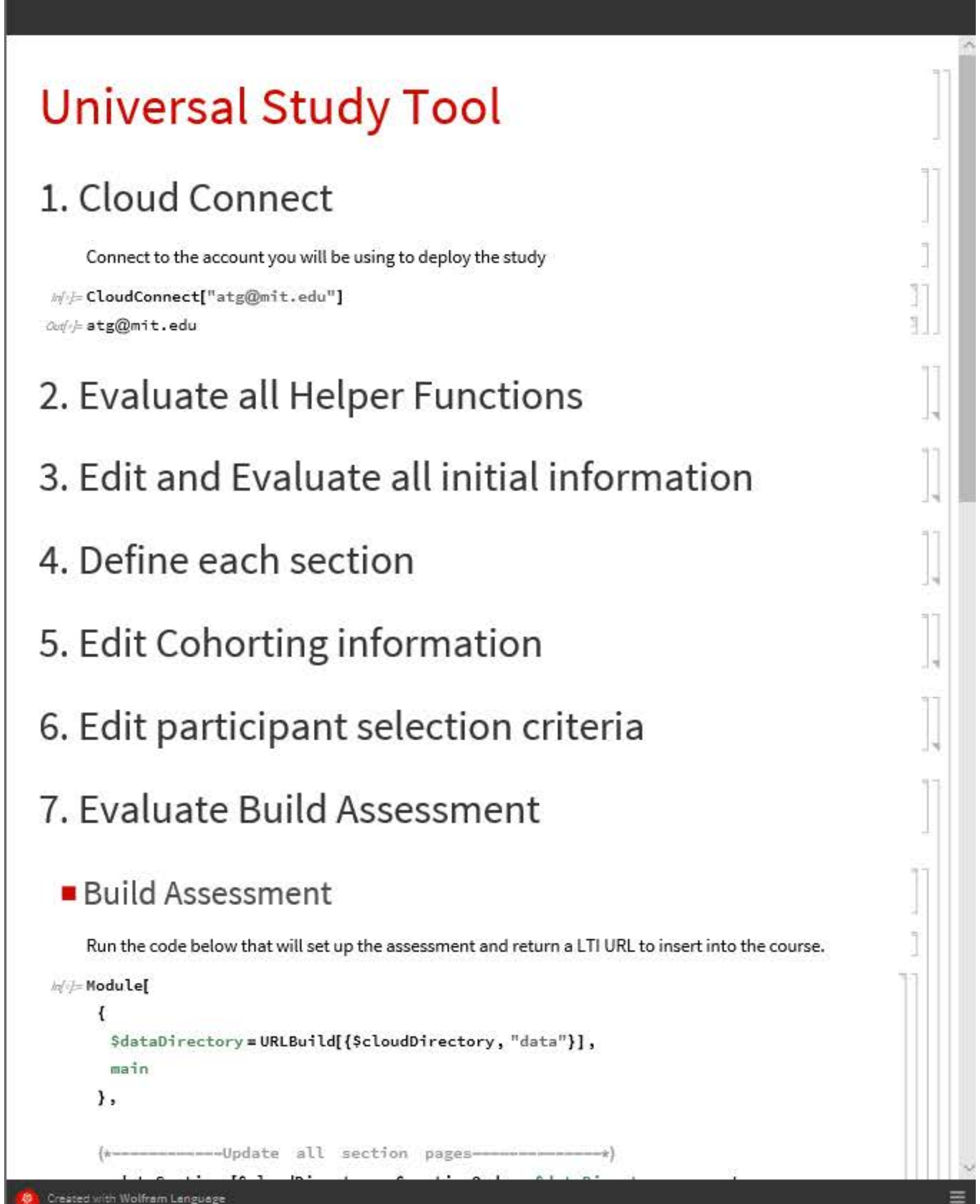
Create the fancy widget I keep telling my friends about.



Step-by-Step Edge Course



Interactive Deployment Guides



Upcoming Trainings