The impact of infusing computation and visualization into introductory physics subjects

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Mary wants to throw a ball straight up and then hit it with a second ball. She wants the balls to collide at height $h=10$. Find the time between successive throws. Take the second ball to have a negligible radius. Take the times to be equal.

(a) How long does it take for the balls to collide?

(b) Find the initial speed of the balls at the throw point.
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

Mary wants to throw a ball so that it goes above the wall. Let's assume that the wall is 10 m above the throw point. We will solve the problem using both hand calculations and code.

Hand Calculation:

Given:
- Initial speed \( v_0 \)
- Angle \( \theta_0 \)
- Height of the wall: \( h = 10 \) m

We want to find the time \( t \) when the ball will be at height \( h \) again.

1. The vertical component of the initial velocity:
   \[ v_{0y} = v_0 \sin(\theta_0) \]
2. The horizontal component of the initial velocity:
   \[ v_{0x} = v_0 \cos(\theta_0) \]
3. The vertical equation of motion:
   \[ y = y_0 + v_{0y} t - \frac{1}{2} g t^2 \]
4. The horizontal equation of motion:
   \[ x = x_0 + v_{0x} t \]
5. When the ball reaches the wall, \( y = h \):
   \[ h = y_0 + v_{0y} t - \frac{1}{2} g t^2 \]
6. Solving for \( t \):
   \[ t = \frac{-v_{0y} \pm \sqrt{v_{0y}^2 - 2g(h - y_0)}}{g} \]

Code Solution:

We will use code to simulate the ball's motion.

- Define the initial conditions.
- Use a numerical method to solve the equations of motion.
- Plot the trajectory of the ball.

Visualization:

- Time since first ball thrown:
  - 1 second
- Time between successive throws:
  - 1 second
- Initial speed of balls:
  - 15 m/s
- Throw point:
  - 4 meters

Graph of the ball's trajectory showing the height and time.
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?
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.
Pre-test and Balancing Cohorts

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.

<table>
<thead>
<tr>
<th>How likely are you to complete this course:</th>
<th>Unlikely</th>
<th>Maybe</th>
<th>Likely</th>
<th>I will</th>
</tr>
</thead>
<tbody>
<tr>
<td>Attrition rate:</td>
<td>85.7%</td>
<td>88.2%</td>
<td>82.6%</td>
<td>79.7%</td>
</tr>
</tbody>
</table>

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?

<table>
<thead>
<tr>
<th>group</th>
<th>count</th>
<th>Physics</th>
<th>Spatial</th>
<th>CS</th>
</tr>
</thead>
<tbody>
<tr>
<td>0 - Control</td>
<td>14</td>
<td>3.86</td>
<td>3.64</td>
<td>2.50</td>
</tr>
<tr>
<td>1 - Viz + coding</td>
<td>16</td>
<td>4.00</td>
<td>3.94</td>
<td>2.56</td>
</tr>
<tr>
<td>2 - Just coding</td>
<td>7</td>
<td>4.43</td>
<td>3.00</td>
<td>2.57</td>
</tr>
<tr>
<td>3 - Just viz</td>
<td>12</td>
<td>4.42</td>
<td>4.00</td>
<td>3.00</td>
</tr>
<tr>
<td>4 - Neither</td>
<td>11</td>
<td>3.45</td>
<td>3.64</td>
<td>2.55</td>
</tr>
<tr>
<td>0, 2, 4 - No viz</td>
<td>32</td>
<td>3.84</td>
<td>3.50</td>
<td>2.53</td>
</tr>
<tr>
<td>1, 4 - Viz</td>
<td>28</td>
<td>4.18</td>
<td>3.96</td>
<td>2.75</td>
</tr>
<tr>
<td>No coding</td>
<td>37</td>
<td>3.92</td>
<td>3.76</td>
<td>2.68</td>
</tr>
<tr>
<td>Coding</td>
<td>23</td>
<td>4.13</td>
<td>3.65</td>
<td>2.57</td>
</tr>
</tbody>
</table>

Not Significant Due to Insufficient Sample Size

When we measured the effect of the interventions 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

Effect of Intervention
Non-standard Tools
Predictive of Final Grade?

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.

<table>
<thead>
<tr>
<th>Treatment Group</th>
<th>Count</th>
<th>Average Grade</th>
</tr>
</thead>
<tbody>
<tr>
<td>0 - Control</td>
<td>14</td>
<td>82%</td>
</tr>
<tr>
<td>1 - Viz + coding</td>
<td>16</td>
<td>89%</td>
</tr>
<tr>
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<td>7</td>
<td>85%</td>
</tr>
<tr>
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<tr>
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<td>94%</td>
</tr>
<tr>
<td>0, 2, 4 - No viz</td>
<td>32</td>
<td>87%</td>
</tr>
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<td>28</td>
<td>89%</td>
</tr>
<tr>
<td>0, 3, 4 - No coding</td>
<td>37</td>
<td>88%</td>
</tr>
<tr>
<td>1, 2 - Coding</td>
<td>23</td>
<td>88%</td>
</tr>
</tbody>
</table>
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!**
Intervention 1

Intervention 2

Intervention 3

UST #1 with cohorting

UST #2 without cohorting

Pre-test

Pset Problem

Post-test
Wolfram on edX
Embed the Following Types of Content with or without Grading

- iFrame
- Forms
- Coding Notebook

A notebook to code in!
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: 499

Name one person 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

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

Wolfram LTI Tools

Course Details

Wolfram in your course
- Getting started with Wolfram
- What can you do with Wolfram in your course?

Wolfram LTI in your course
- Getting Started with Wolfram LTI
- Pre-Built Wolfram LTI tools - no coding!
- Pre-Built Wolfram LTI tools - requires some coding

Making Wolfram LTI Tools From Scratch
Interactive Deployment Guides

Universal Study Tool

1. Cloud Connect
   - Connect to the account you will be using to deploy the study
   ```
   @folder::CloudConnect@folder::@stg@mit.edu
   @folder::@stg@mit.edu
   ```

2. Evaluate all Helper Functions

3. Edit and Evaluate all initial information

4. Define each section

5. Edit Cohorting information

6. Edit participant selection criteria

7. Evaluate Build Assessment
   - Build Assessment
     - Run the code below that will set up the assessment and return a LTI URL to insert into the course.
     ```
     @folder::Module@folder::
     {
       @dataDirectory@folder::URLBuild@folder::@dataDirectory@folder::"data",
       main
     };
     ```
Upcoming Trainings

Wolfram Summer School
17th Annual Wolfram Summer School, held at Bentley University
June 23–July 12, 2019

MITx
SIGNIFICANT INTEREST GROUP EVENT
FRIDAY, MAY 17, 2019
11:30AM - 1:30PM
SAMBERG CONFERENCE CENTER (E52)
The MITx SIG Event provides an opportunity for MIT faculty, staff, and fellows to come together to discuss innovations, lessons learned, and best practices across both residential and global digital learning. Please join us for lunch and presentations from your colleagues. We will also award the MITx Prize for Teaching & Learning in MOOCs. A full agenda will be shared shortly.

Please RSVP by May 6th.

Note: This event is by invite only. If you would like to bring a guest, please contact mitxonedX@mit.edu.