

- Background
- Motivations
- Challenge
- Choices
- Structure
- Results

Constraints in Physics Lab Courses

the Good, the Bad, and the Pandemic

Forrest Bradbury

Amsterdam University College (NL)

Co-author:

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Delft University of Technology (NL)

What am I doing at an APS March Meeting?

Serendipitously pandemic resilient lab course:

- Flipped teaching
- Open inquiries
- Maker tools

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Constraints in Physics Lab Courses

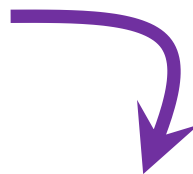
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Setting: Amsterdam University College

- Small liberal arts & sciences college
- ~100 “science” majors per year
- Limited lab course offerings
- No in-house laboratories



Goals:

- Serve multi-disciplinary science students
- Experience research cycle

Constraints in & of science labs

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“Doing science” involves constraints:

- Constraining other variables & environmental noise
- Constraints of tools (precision, accuracy, sampling rate, time)
- Constraints of mathematical models

Giving lab courses involves constraints:

- Class-room space
- Limited (functioning) equipment
- Limited contact time

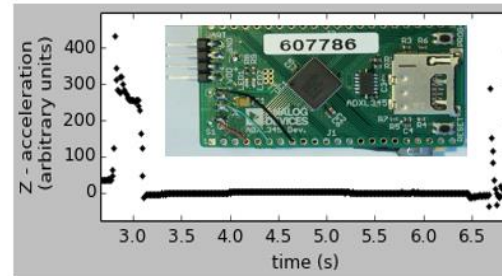
My path to “open inquiry” (doing science)

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Rocket project in classical mechanics

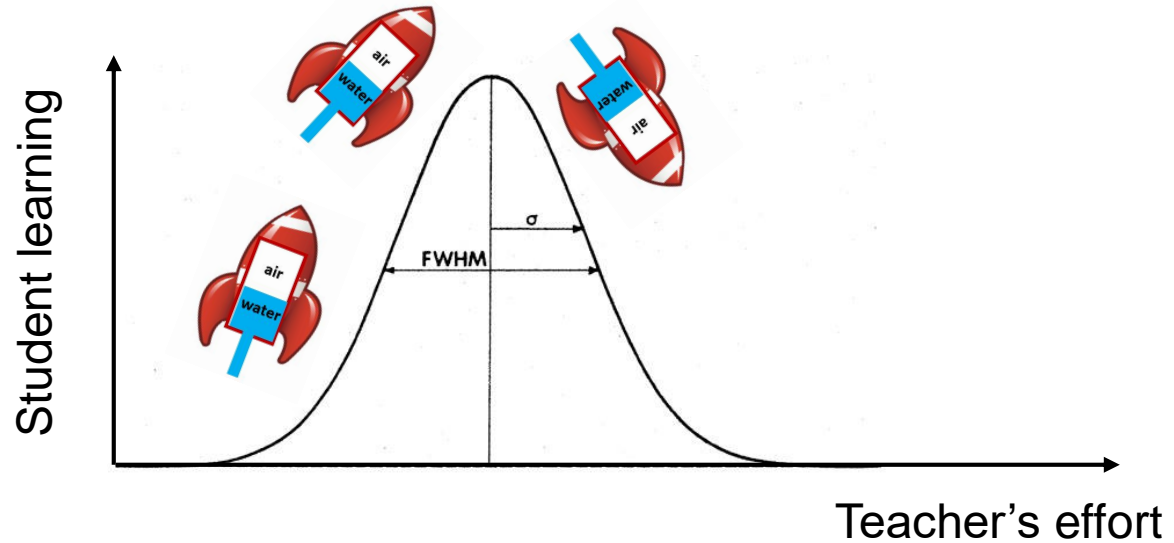
“Three dimensional project”:

- Theory
- Numerical simulation
- Experiment



My path to “open inquiry” (doing science)

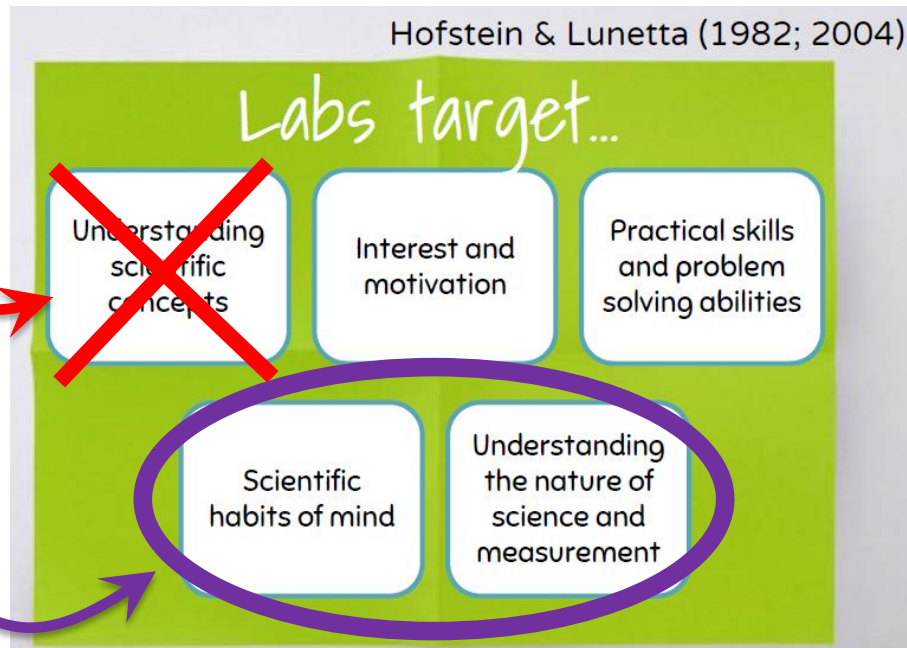
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Learning goals of science labs?

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- Not effective
- Open inquiry is advantageous



Slide from Cornell Professor Holmes' AAPT New Faculty Workshop presentation, 2017
 Learning goals: Hofstein & Lunetta, Rev. Educ. Res. 52(2), 201–217, 1982 and Sci Ed 88:28–54, 2004
 Ineffectiveness: Holmes, Olsen, Thomas & Wieman, Phys. Rev. Phys. Educ. Res. 13, 010129, 2017
 Open inquiry: Wilcox & Lewandowski, Phys. Rev. Phys. Educ. Res. 12, 020132, 2016

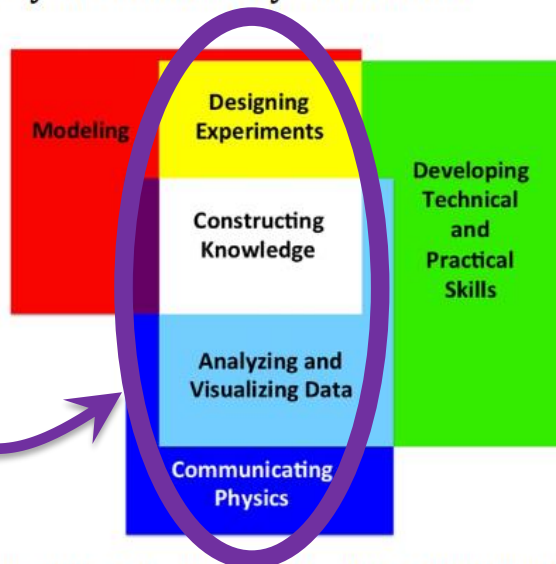
Learning goals of science labs?

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AAPT Recommendations for the Undergraduate
Physics Laboratory Curriculum

- Open inquiry
is advantageous



Report prepared by a Subcommittee of the AAPT Committee on Laboratories
Endorsed by the AAPT Executive Board
November 10, 2014

Empirical scientific inquiry is ...

- Background
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Cognitive Task Analysis Elements

1. Establishing research goals
2. Defining criteria for suitable evidence
3. Determining feasibility of experiment
4. Experimental design
5. Construction and testing of apparatus/code
6. Analyzing data
7. Evaluating results and analyzing implications
8. Presenting the work

Empirical scientific inquiry is ...

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1. **Establishing research goal:** What are the goal(s) and question(s) of the research?
 - a. Deciding if the goal is interesting, timely, worthwhile, etc.
 - b. Predicting if the goal is sufficiently ahead of current knowledge to be interesting but not so far ahead that it might have too high a risk of failing or be ignored.
 - c. Evaluating whether the research question is consistent with the constraints on funding, equipment, and laboratory capacity, including personnel.

2. **Defining criteria for suitable evidence:** Deciding what will constitute suitable evidence to achieve the goal by developing and utilizing explicit criteria:
 - a. What data would be convincing given the state of the field?
 - b. What variables are important and how might they be measured and controlled?
 - c. What types of experimental controls and checks would need to be in place?

3. **Determining feasibility of experiment:**
 - a. Predicting whether or not it is realistically possible to carry out the experiment, and, if the analysis of the scale of time and resources required and deciding if these are reasonable. (This involves more detailed reiteration of 1.c.)
 - b. The researcher must also analyze contingency options, if the results of the experiment are not what is hoped for. Will the data produced still provide novel publishable information? Will the results show how to improve the apparatus to achieve conditions needed to obtain hoped-for results?

4. **Experimental design**
 - a. Exploration of many possible preliminary designs (requires clear definition of the optimum for each analysis of the alternative designs).
 - b. Analyzing relevant variables that may lead to systematic errors in results and interpretation. This requires having complex cause and effect models for the experiment. (Will be repeated after measuring performance of the apparatus.)
 - c. Finalizing the design, taking into account construction details and performance requirements of each component. Often requires bringing in additional expertise.

- d. Developing detailed data acquisition strategy: How much data to take and over what parameter ranges, how to accumulate data in each measurement, in what order, which things measured, which measurements do you repeat and how often? Deciding on required precision and accuracy. This includes deciding what quantities need not be measured. This must take into account constraints of time, clarity of results, all potential statistical and systematic uncertainties, and the importance and requirements for distinguishing between different potential interpretations of results. (This step is repeated/revised after performance of apparatus has been measured.)

5. **Construction and testing of apparatus**
 - a. Deciding who should build the various parts and what schedule (in-house, purchase standard parts, special construction by outside companies, etc.). Reiteration and application of trade-offs of cost, construction expertise, time, degree of confidence as to specific design details.
 - b. Developing criteria and test procedures for evaluation of the apparatus components as they are completed.
 - c. Collecting data on performance of specific components and full apparatus.

- d. Developing procedures for tracking down the source of malfunction when the individual components or the assembled apparatus do not perform as designed. This necessarily involves deep familiarity with the respective hardware and a repertoire of troubleshooting regimes that are highly specific to the field, the apparatus, and the approach being used.

- e. Figuring how to modify particular parts, or overall apparatus, as needed according to test results.
- f. Iterate data acquisition strategy 4.d., taking into account actual performance of finished apparatus.
- g. After completion, collect experimental data.

6. **Analyzing data**
 - a. Modeling the data by suitable mathematical forms, including deciding which approximations are justified and which are not.
 - b. Deciding on what statistical methods and procedures are appropriate.

- c. Calculating the statistical uncertainty.
- d. Calculating the systematic uncertainties as needed (often already done as part of the data acquisition strategy).

7. **Evaluating results**
 - a. Checking the results, were they come out differently than expected. This involves calling on complex mental models incorporating a web of cause and effect relationships, strategies for identifying relevant and irrelevant information, complex pattern recognition and search algorithms. (Also usually involves extensive additional data collection, and possible modification of apparatus and redoing data collection.)
 - b. Testing data that come out as expected. Identify redundant tests for possible systematic errors. Identify particularly sensitive tests.

8. **Analyzing implications**
 - a. What are plausible implications for experiment?
 - b. Explain the weaknesses of the work and the conclusions drawn. Consider the degree of maximum interest and significance.

Cognitive Task Analysis Elements

1. Establishing research goals
2. Defining criteria for suitable evidence
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5. Construction and testing of apparatus/code
6. Analyzing data
7. Evaluating results and analyzing implications
8. Presenting the work

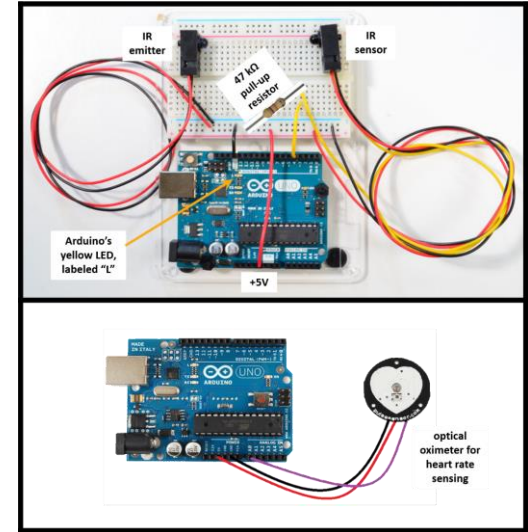
process is cyclical & iterative!

How to guide students in doing science?

Choice for enabling open inquiries:

*work at home
using sensors
controlled by
Arduino Unos:*

- Background
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- safe
- cheap
- large choice of modern sensors
(many based on solid-state and MEMS technologies)

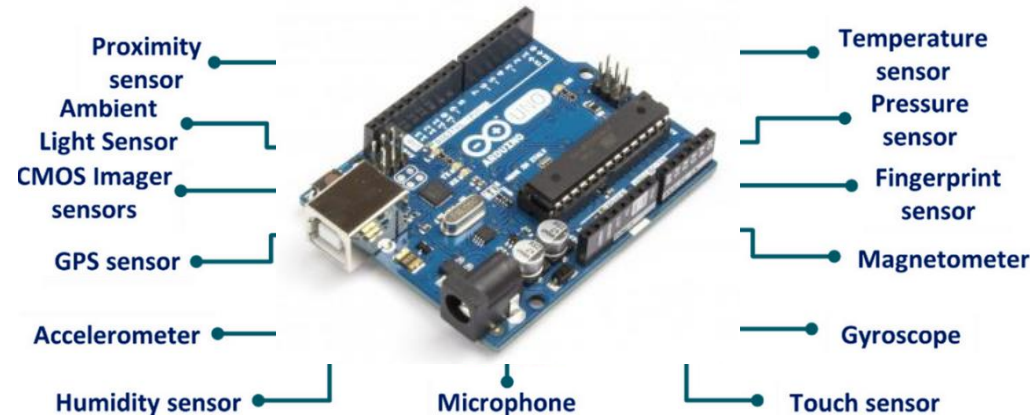
Large choice of modern sensors!

(many based on solid-state and MEMS technologies)

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many more options
with microcontrollers,
including:

- Ultrasound sonar
- IR break beam
- Soil moisture sensor
- Gas sensors
- Geiger counter board
- Heart rate sensor
- Skin conductance sensor
- EMG/EKG board with amplifying electronics
- etc...



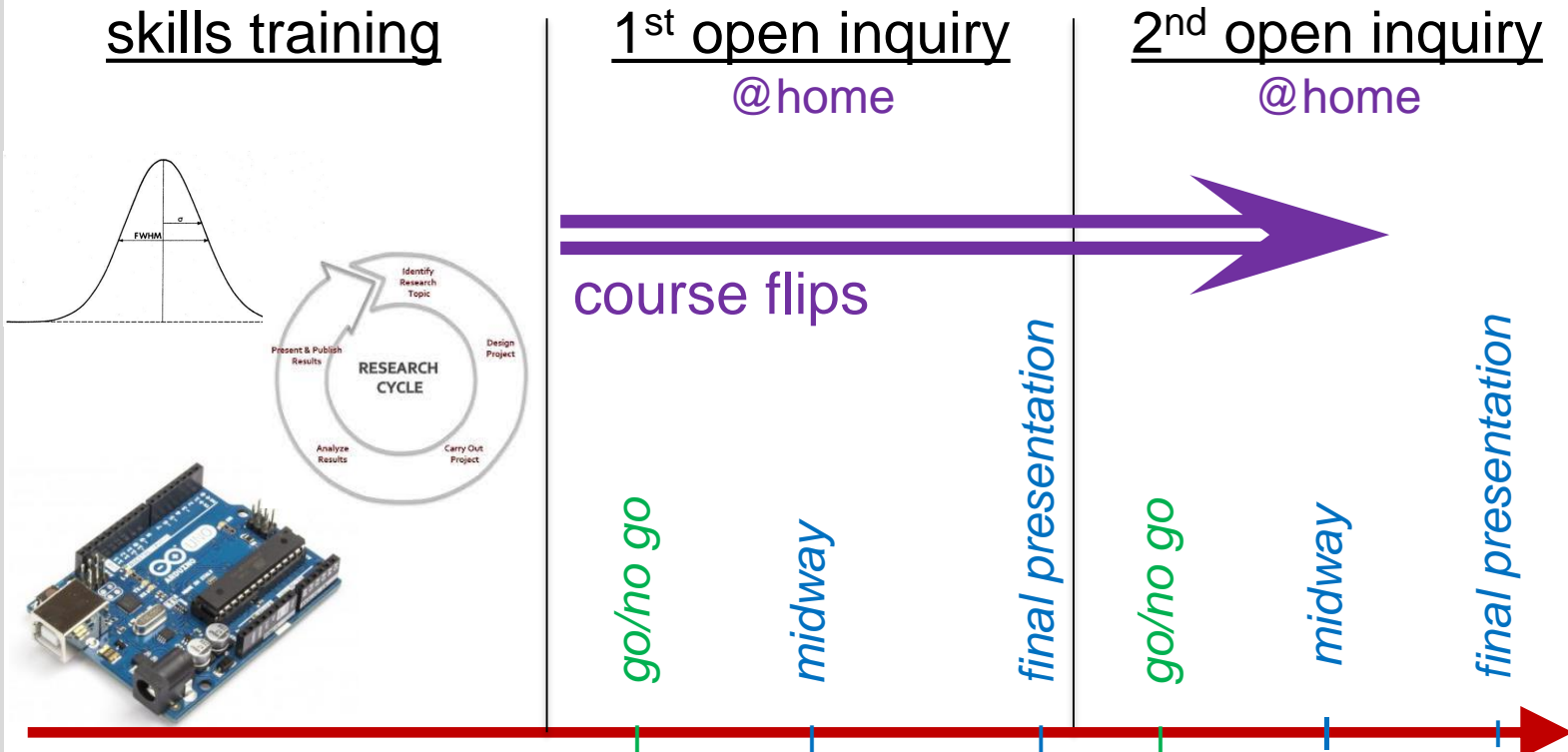
Open inquiries and student agency:

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- Epistemic agency (define research questions)
- Decision making agency (design experiments)

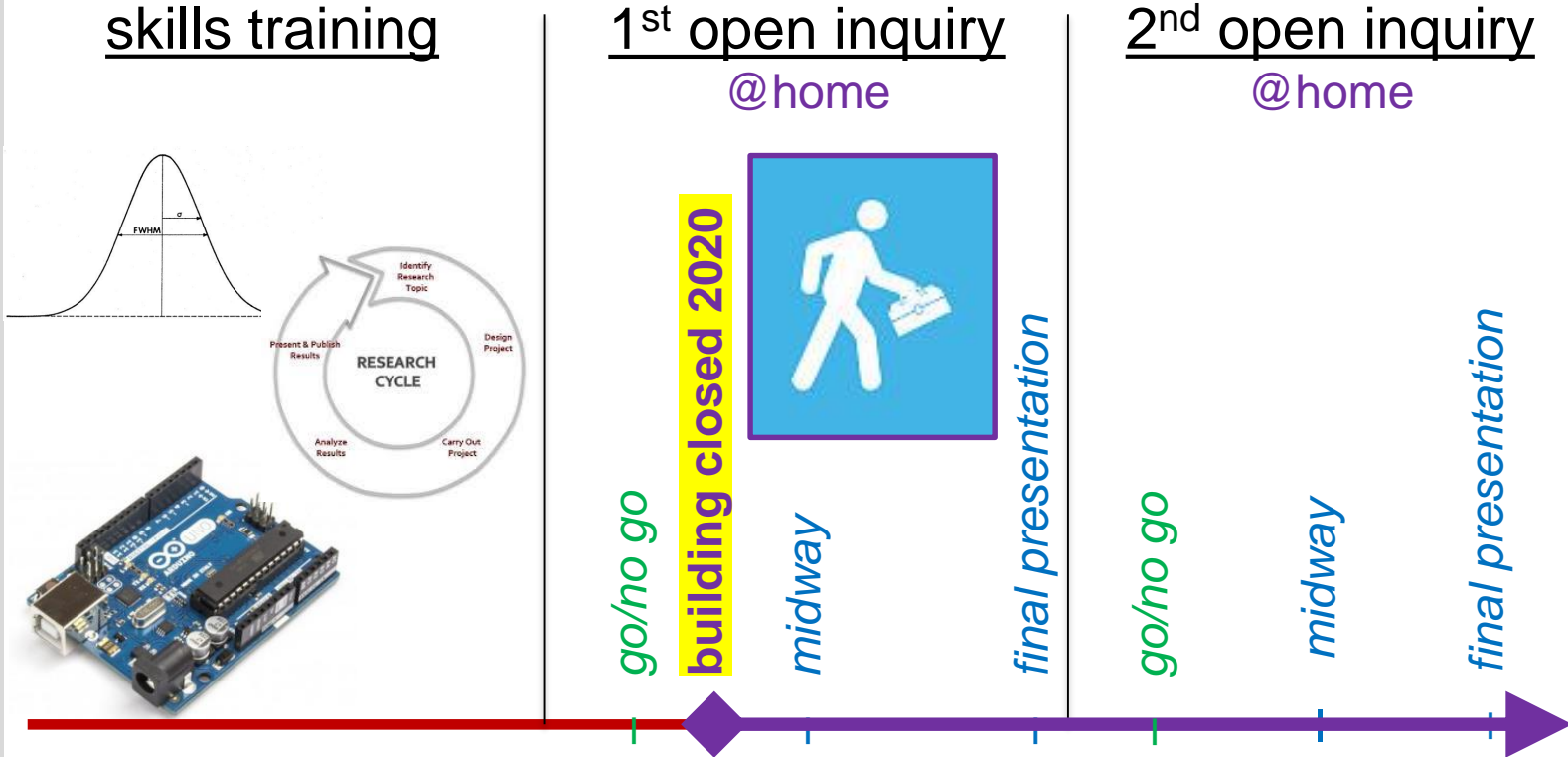
Timeline of AUC's Maker Lab course

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Timeline of AUC's Maker Lab course

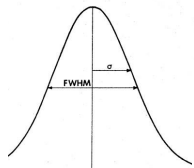
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Timeline of AUC's Maker Lab course

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fully remote 2021



skills training

@home

1st open inquiry

@home

2nd open inquiry

@home

go/no go

midway

final presentation

go/no go

midway

final presentation

Results

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- *Student ownership & responsibility*
 - *Control over entire cycle, instructors cannot take the reigns*
 - *Authentic training in science communications*
- *Pandemic resilience*
 - *Flipped teaching, open inquiries, and Maker tools
and their synergies and interdependencies*
- *Focus on science and sense-making*
 - *Individualized help with more difficult parts of research process*
 - *“Instructor” transformed into “Supervisor”*

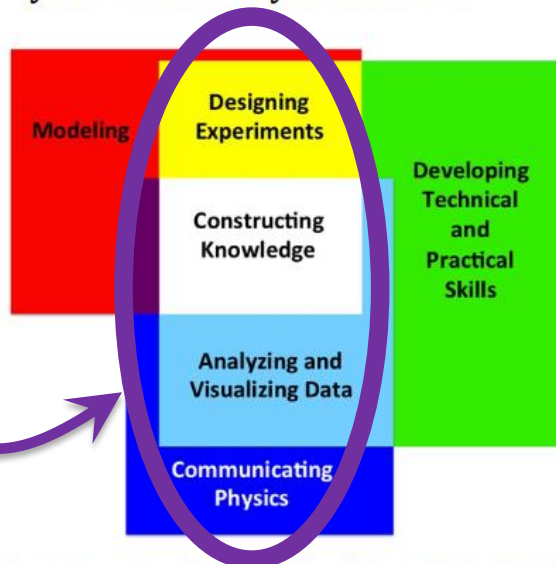
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“Doing science” involves constraints:

- Constraining other variables
- Constraints of tools
- Constraints of materials

open inquiries require students to control and utilize constraints

Giving lab courses involves constraints:

- Class-room space
- Limited (functioning) equipment
- Limited contact time

Maker tools and flipped instruction overcomes constraints

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Thanks for your attention!

Publications:

- Published article: F. R. Bradbury & C. F. J. Pols “A pandemic-resilient open-inquiry physical science lab course which leverages the Maker movement”, <https://ejrsme.icrsme.com/article/view/20416>
- Open-source course materials: <https://github.com/forrestbradbury/MakerLab>

2020 Maker Lab Open Inquiry Projects

First round of projects

- building and improving the signal processing of an Arduino theremin
- comparing water retention of alternative potting soils against those with unsustainably harvested peat-moss
- optically measuring heart rate and characterizing its post-exercise recovery to equilibrium
- measuring color fidelity of a MacBook's screen with an RGB sensor
- investigating the dependence of a photovoltaic cell's power on its illumination angle
- pushing the Arduino's sampling rate for precision sound frequency determination
- measuring local wind-speeds to determine suitable bee-habitat

Second round of projects

- comparing signatures of bicep muscle fatigue between dominant and non-dominant arms with median frequency evolution of the electromyography (EMG) power spectrum
- building and characterizing performance of a swiveling Arduino sonar radar
- comparing accelerometer measurements of a beam's fundamental oscillation frequency with the Euler-Bernoulli model
- comparing air pollution levels inside apartments on the road-side and courtyard-side of the student residence building
- investigating whether self-reported joke funniness correlates with EMG signals of facial muscles
- comparing two measurements of bread-dough rise/yeast activity: CO₂ gas sensing & volume changes via ultrasonic ranging
- studying effects of temperature on germination of cress seeds

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2021 Maker Lab Open Inquiry Projects

First round of projects

- *How does music tempo influence human heart rate, and is the effect genre dependent?*
- *How does biochar influence soil moisture retention?*
- *Does the stress of challenging games have physiological correlations (heart rate & skin resistivity)?*
- *Comparing the light transmission through synthetic and natural nail polishes.*
- *Do someone's night sounds display expected sleep cycle periodicities?*
- *Do sport drinks affect muscle fatigue, as measured by median frequency of the EMG power spectrum?*
- *Do air pollution levels in several categorized locations depend on green space and/or urbanization density?*
- *How does coffee cup size/shape/material affect rate of cooling?*
- *Measuring UV radiation dependence on humidity.*
- *Comparing magnetic field distributions from differently shaped solenoids*

Second round of projects

- *Still to come!*