How to Use Mathematical Modelling to Inform the Design of General Education Courses?: Reducing Trade-offs and Creating Synergisms

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Decisions Made by Organisms Have Implications….

Educators also make decisions that have consequences

Decisions Made in the Face of Limited Resources, Trade-offs, and Other Constraints

Theories in Science are Often Expressed Mathematically

- $F = ma$

- $PV = nRT$

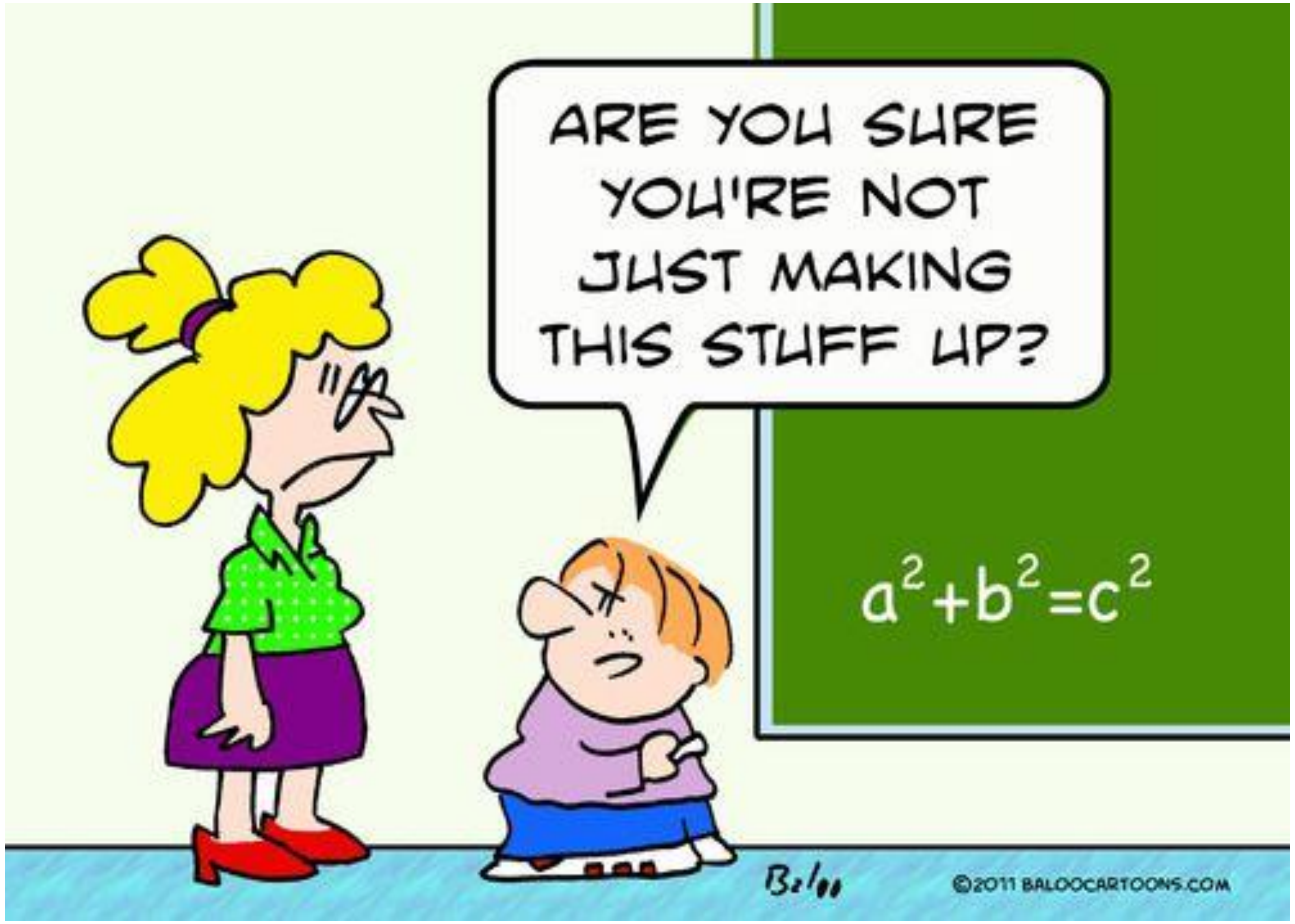
- $F = G(m_1 m_2/r^2)$

- $dN/dt = r_{max}N\ (K - N)/K$

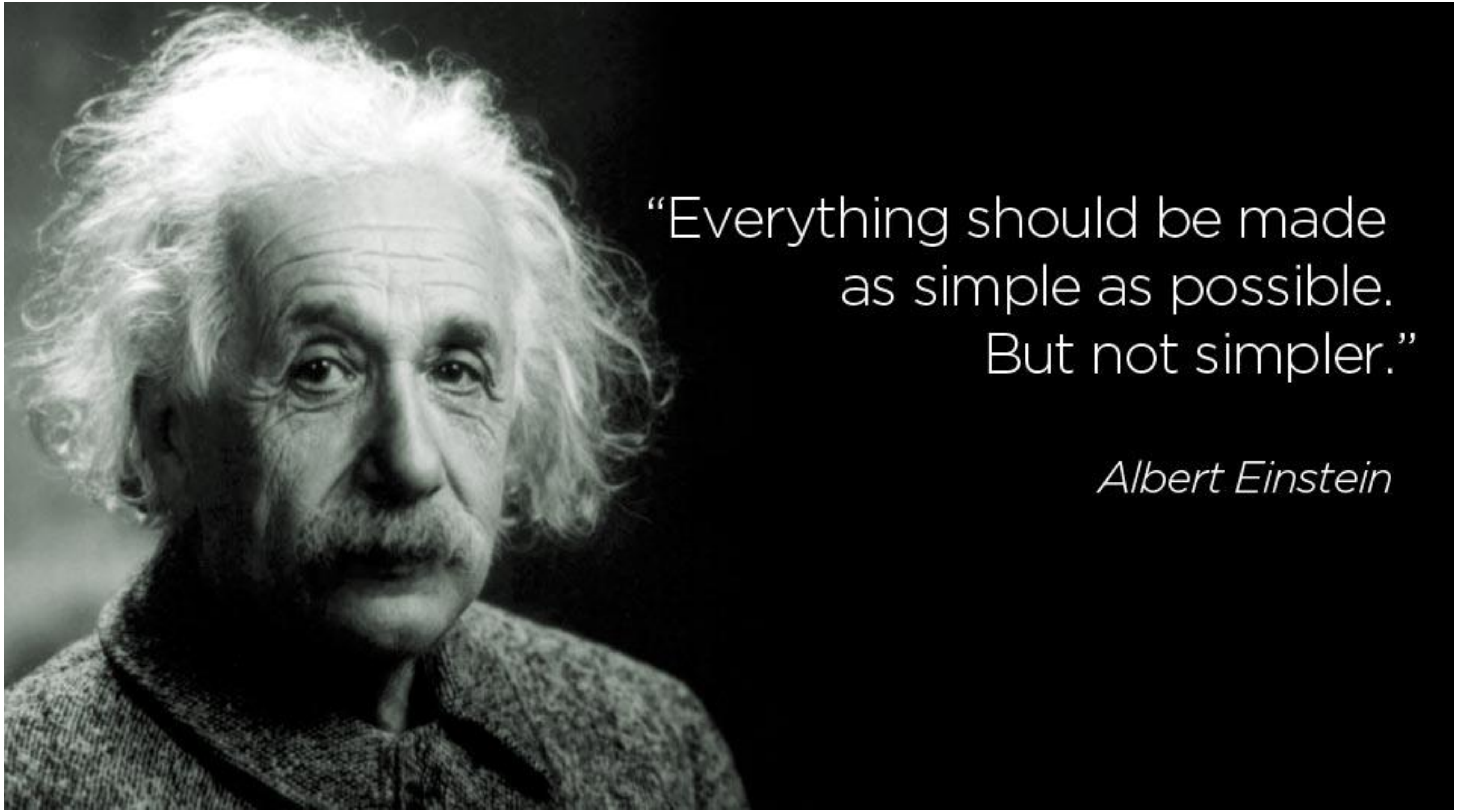
Why Do Scientists Use Mathematical Models?

- Forces us to clearly state our assumptions
- Forces us to formalize our logic
  - Eliminates “arm waving arguments”

- Optimality Models: indicate which decisions maximize results in the face of trade-offs and constraints.



- Mathematical modelling is an intentional and systematic way of addressing and answering questions


"Everything should be made
as simple as possible.
But not simpler."
Albert Einstein

The Models

- I have developed a series of models to study how instructors should allocate resources between two course learning outcomes
  - GE History and Culture of Hong Kong
    - Learn about history vs. culture
  - GE Science course
    - Learn science content vs. scientific method
  - GE Service-Learning Course
    - Academic learning vs. community service

- Started with the simplest assumptions possible and then relaxing these assumptions one at a time to explore the important factors that influence education effectiveness

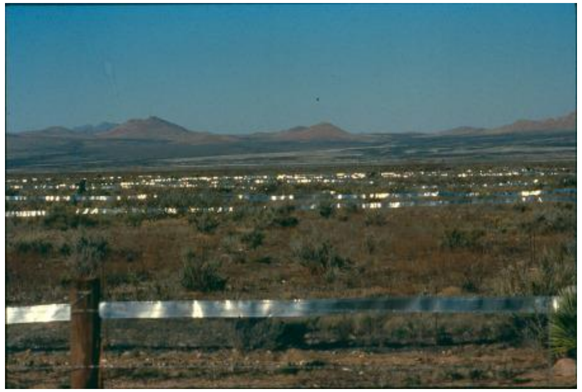
- I will not go into the models in any detail here

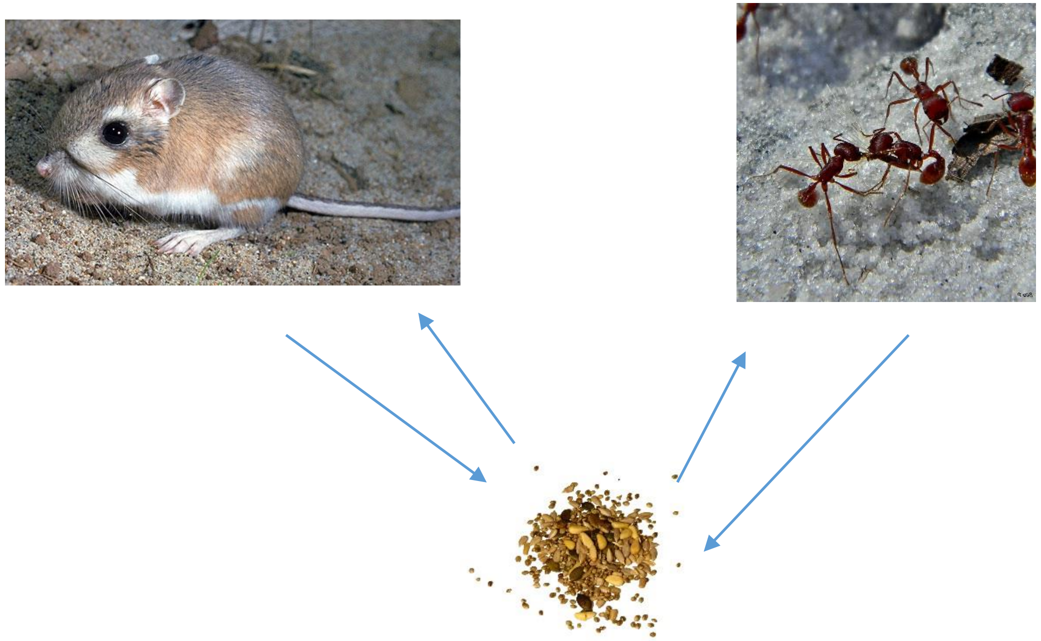
Conclusions

- All else being equal, the total “value” of a course is maximized by
    1. Maximizing the total time spent learning
    2. Teaching the topics with the with the steepest learning curves
    3. Teaching the topics with the highest educational value
    4. Teaching in a way that addresses both goals simultaneously (no trade off)
    5. Teaching in a way that allows course goals to interact in a positively synergistic manner

Some lessons seemed to work well over the years!

- Community Ecology
  - Brown and colleagues' study of competition between rodents and ants in the Chihuahuan Desert, USA
    - Illustrate the concept of indirect interactions
    - Introduce the components of good experimental design
      - Manipulate density of rodents and ants in the field
    - Cool story, with an unexpected twist, and important message
      - The world is complicated!!!





Why has this lesson been effective?

- Eliminate trade-offs
  - Students learning about experimental design (process) while they are learning about indirect effects in ecology (concept)
- Positive Synergism
  - Students care more about the process when they are interested in understanding the concept
  - Students gain a better understanding of the concepts as they have a better understanding of the process

  - Learn more about the process and the concept by studying them together

How Can I Purposefully Teach More Effectively?

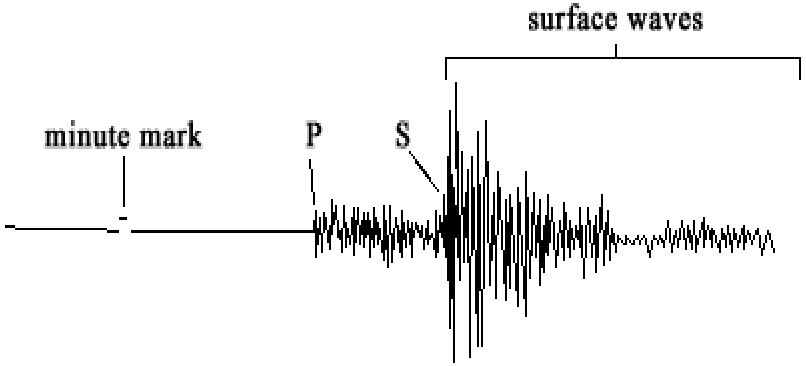
- Reduce trade-offs
  - Natural Disasters: Science and Society
  - Ecology: the Science of Environmental Issues
- Create positive synergisms
  - Ecology: the Science of Environmental Issues

Example 1: Natural Disasters: Science and Society

- Science, Technology, and Society Cluster of Core Curriculum at Lingnan University

- Two of the course goals
  - Apply the “process of science”
  - Learn about earthquakes

How Do Scientists Determine the Location of an Earthquake?



How to Determine the Distance From Seismograph to the Epicenter?

- P waves travel faster than S waves
  - P waves arrive at a seismograph before the S waves
- The farther away the seismograph is from the epicenter of the earthquake the greater the interval between the arrival of P and S waves
- The time interval between the arrival of P and S waves can be used to determine distance of the seismograph from the epicenter of earthquake

Goal #1. Help students understand this concept

- Develop from first principles

$$I = D(1/S_S - 1/S_F)$$

As the distance travelled increases the interval of arrival between the fast and slow moving objects increases.

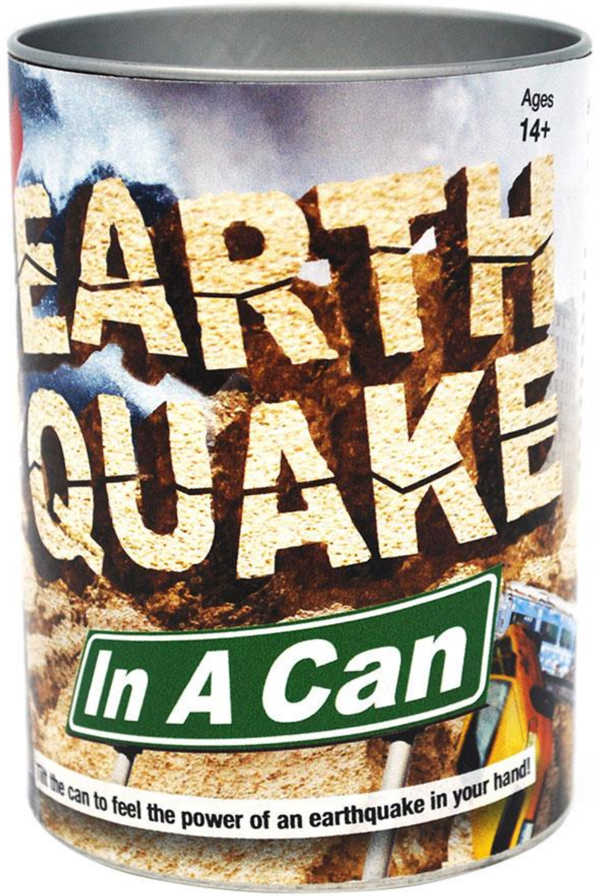
Goal #2: introduce students to the process of science/hypothesis testing protocol

- Perhaps I could eliminate the trade-off between learning about the process and the concept by developing an investigative activity to explore the process and the concept simultaneously

Hypothesis Testing Protocol

- Ask Question
- Develop hypothesis
- Design study
- Make predictions if hypothesis true or false
- Conduct the study
- Analyze the data
- Draw conclusions

Experiment

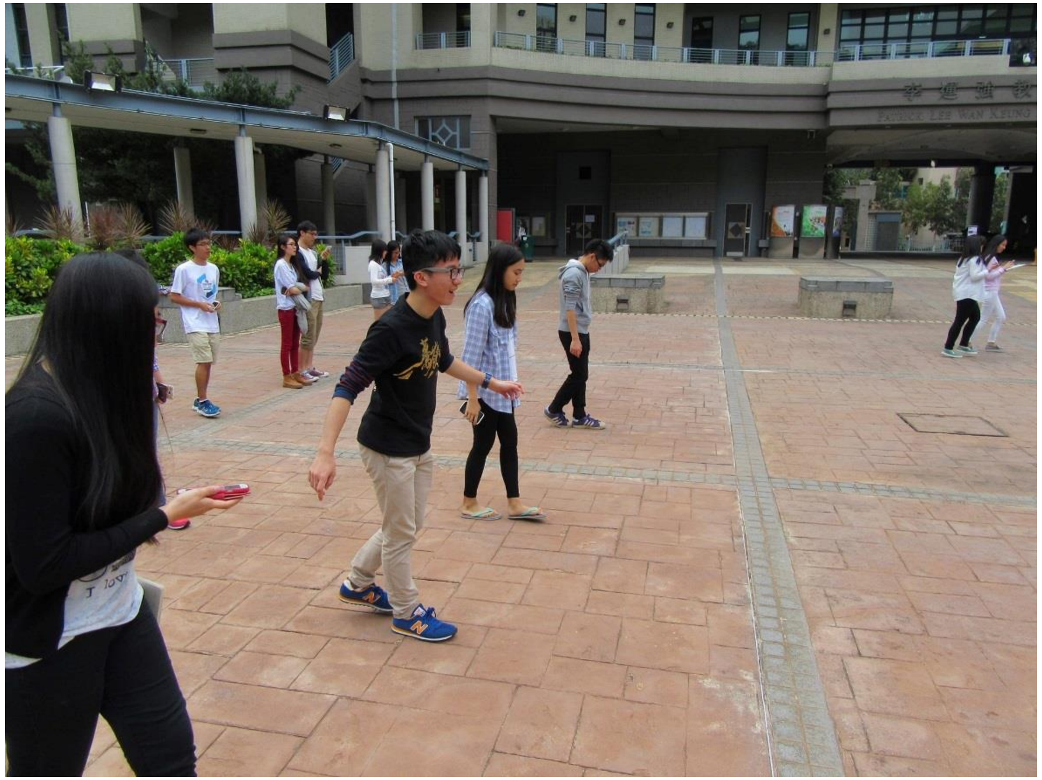


- Key factor
  - P waves move faster than S waves

Human Earthquake Waves!!

P Waves

S Waves



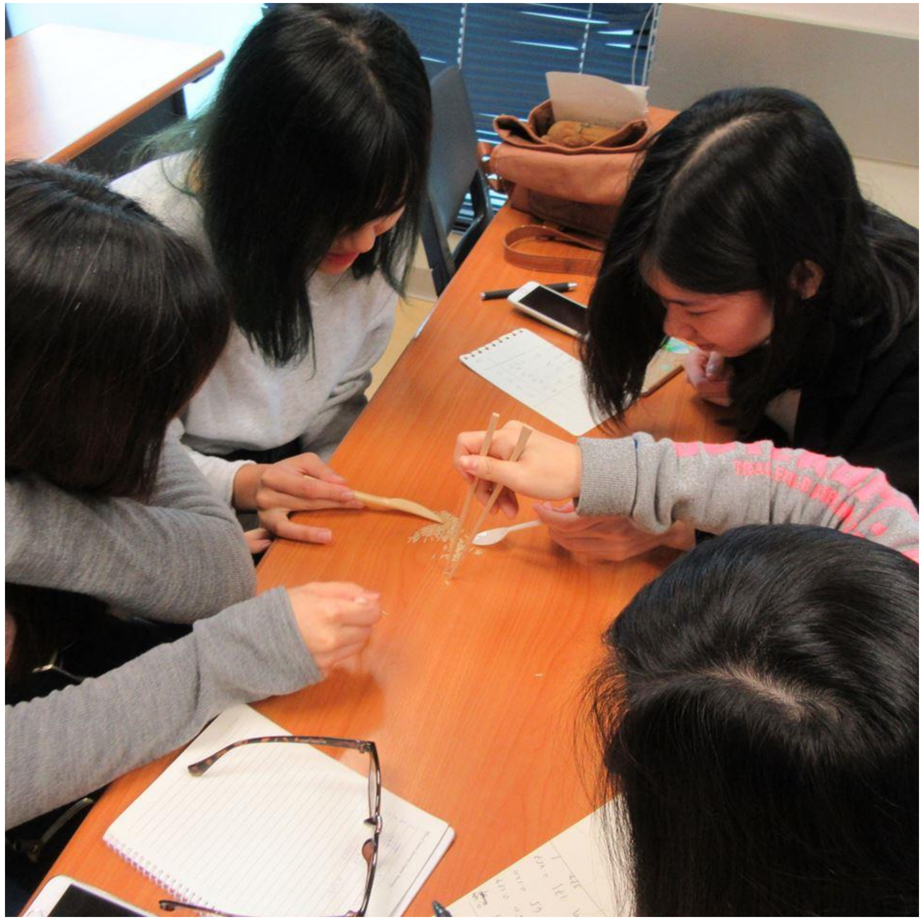
Example 2: Ecology: the Science of Environmental Issues

- Service-learning
    - Students develop activities to teach science to primary students

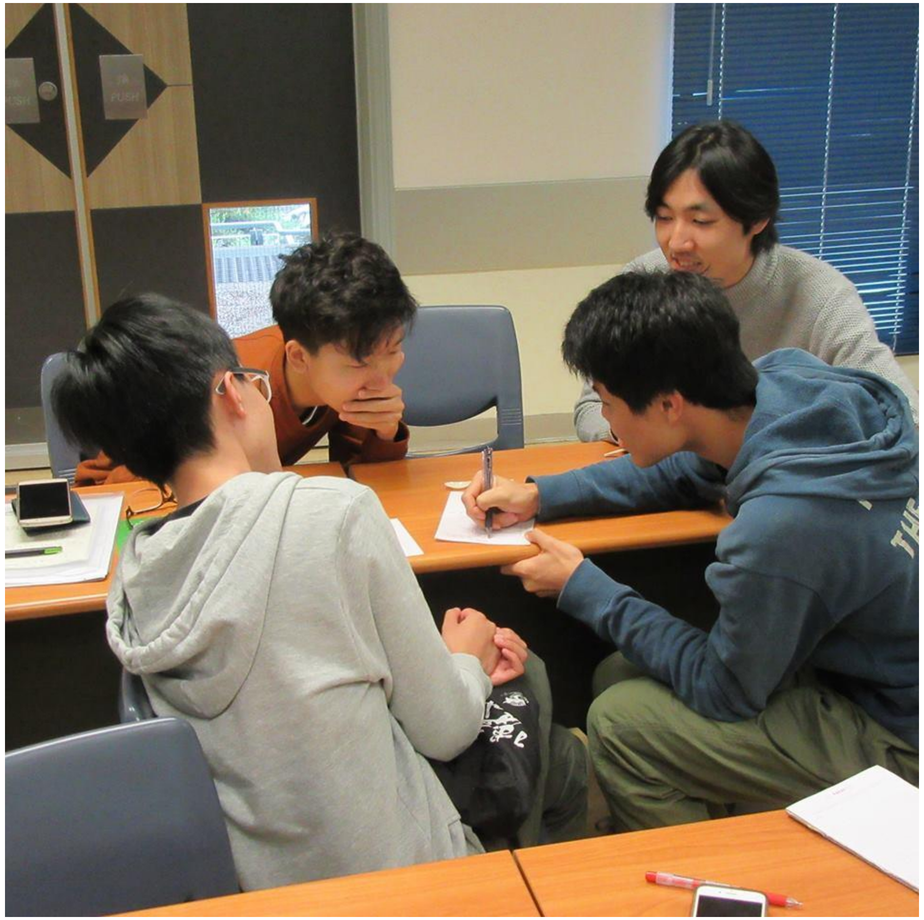
- My goals are to-
    - Teach students about natural selection
    - Prepare students for their service-learning experience

- I developed an in-class activity that would help students learn the concept of natural selection while modelling how to develop and conduct an experiential science learning exercise

Modelling the Teaching of Natural Selection

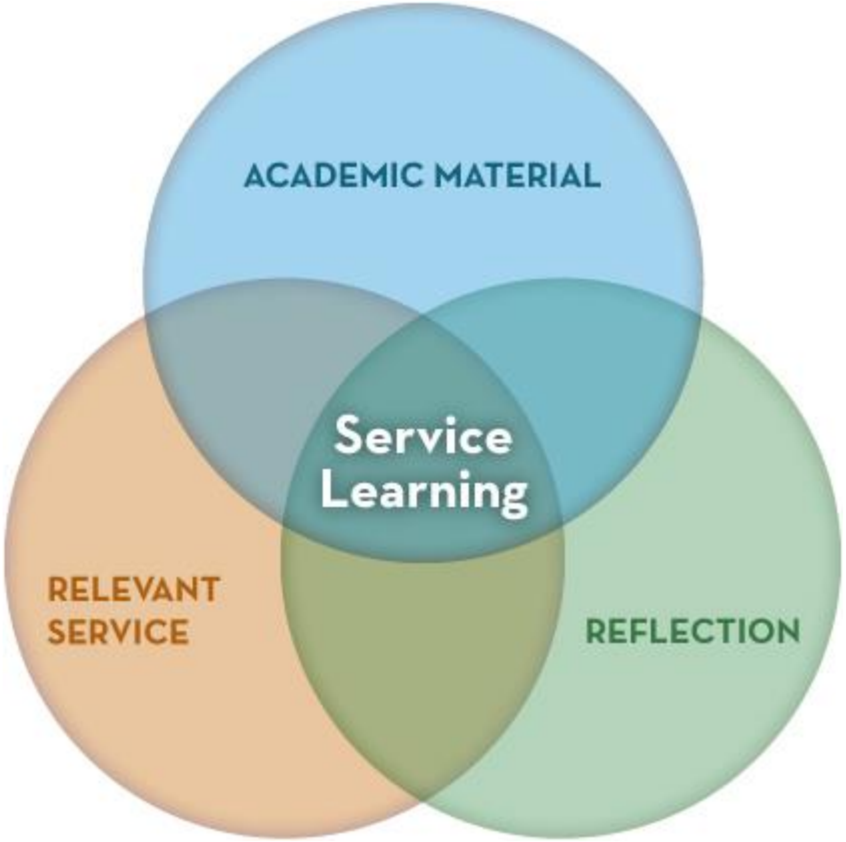


Natural Selection



Example 3: Ecology: the Science of Environmental Issues

- Service-Learning
  - Enhance academic learning by combining with community service



Trade-offs Between Service and Learning?

- Music Education Class
  - Service: teaching music to children at local community center
    - No trade-off between academic learning and service
- Nutrition Class
  - Service: working at local food bank
    - Trade-off between academic learning and service
    - Time spent on service at local food bank might not be used for academic learning about nutrition

Ecology: the Science of Environmental Issues

- Service: students work with local primary schools to teach them about ecology and environmental issues
- Concerns
  - How to provide meaningful service?
  - Will teaching primary level science help students achieve university level academic learning?

Service-Learning

Direct Service- Working With Primary Students

Indirect Service- Creating Lesson Plans and Curriculum Guides for Primary Teachers

Indirect Service to Teachers/Educators

- Curriculum Guides
  - Provide background that teachers/educators require to effectively use the lessons
    - Teachers are more likely to use activities if they are confident that they know enough science to successfully teach the activity
  - My students would master material while attempting to summarize the material for a non-expert audience (teachers/educators)
  - Replace traditional year end term paper
  - Plan to translate these curriculum guides and make them available to local teachers
    - LU students might take assignment more seriously when they know that their work may be used in the future

Conclusions

- Mathematical models can be a valuable tool in an educator’s tool kit
  - Practice and research
- True for all Educators….. Not just Science Educators!!
  - Potentially useful approach for teachers and researchers in all fields!!!