

Carnegie Mellon University



Learning Engineering: Applying Research & Data to Improve Outcomes

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16,000



Like teaching

Change is hard

Relevant research and rich data can inform
and guide *effective* innovations in teaching

Creating 21st Century Instruction

Research-based instruction significantly outperforms intuition in improving learning outcomes.

Intuition suggests:

Instruction is best when it matches the learner's style.

Adding images will enhance engagement and hence learning.

But research shows:

There is no effect (or negative effect) of matching learner's style.

Extraneous images distract and reduce learning outcomes.



High-Impact Educational Practices



WHAT THEY ARE,
WHO HAS ACCESS TO THEM,
AND WHY THEY MATTER

BY GEORGE D. KUH

WITH AN INTRODUCTION BY CAROL GEARY SCHNE
AND FINDINGS ON STUDENT SUCCESS FROM AAC&
LEAP INITIATIVE

E-LEARNING *and the* Science of Instruction

Proven Guidelines for Consumers and
Designers of Multimedia Learning

RUTH COLVIN CLARK | RICHARD E. MAYER

Organizing Instruction to Improve Student Learning A Practice Guide

HOW LEARNING WORKS

7 Research-Based Principles
for Smart Teaching

Susan A. Ambrose
Michael W. Bridges | Michele DiPietro
Marsha C. Lovett | Marie K. Norman



NCER 2007-2004
U.S. DEPARTMENT OF EDUCATION

ies NATIONAL CENTER FOR
EDUCATION RESEARCH
Institute of Education Sciences

U.S. DEPARTMENT OF EDUCATION

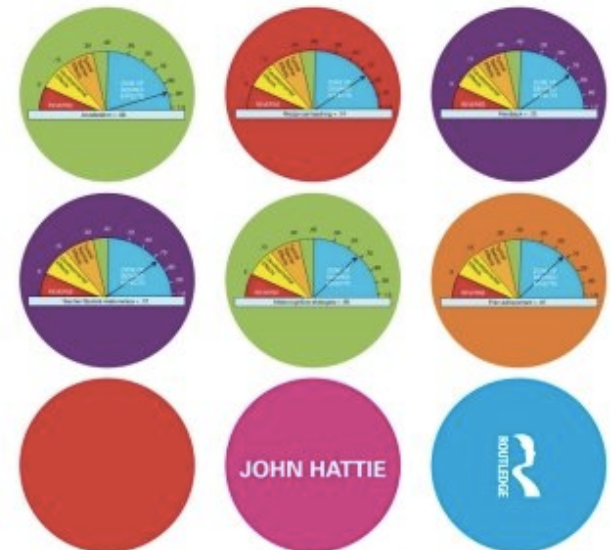


Evaluation of Evidence-Based Practices in
Online Learning
A Meta-Analysis and Review of Online Learning Studies



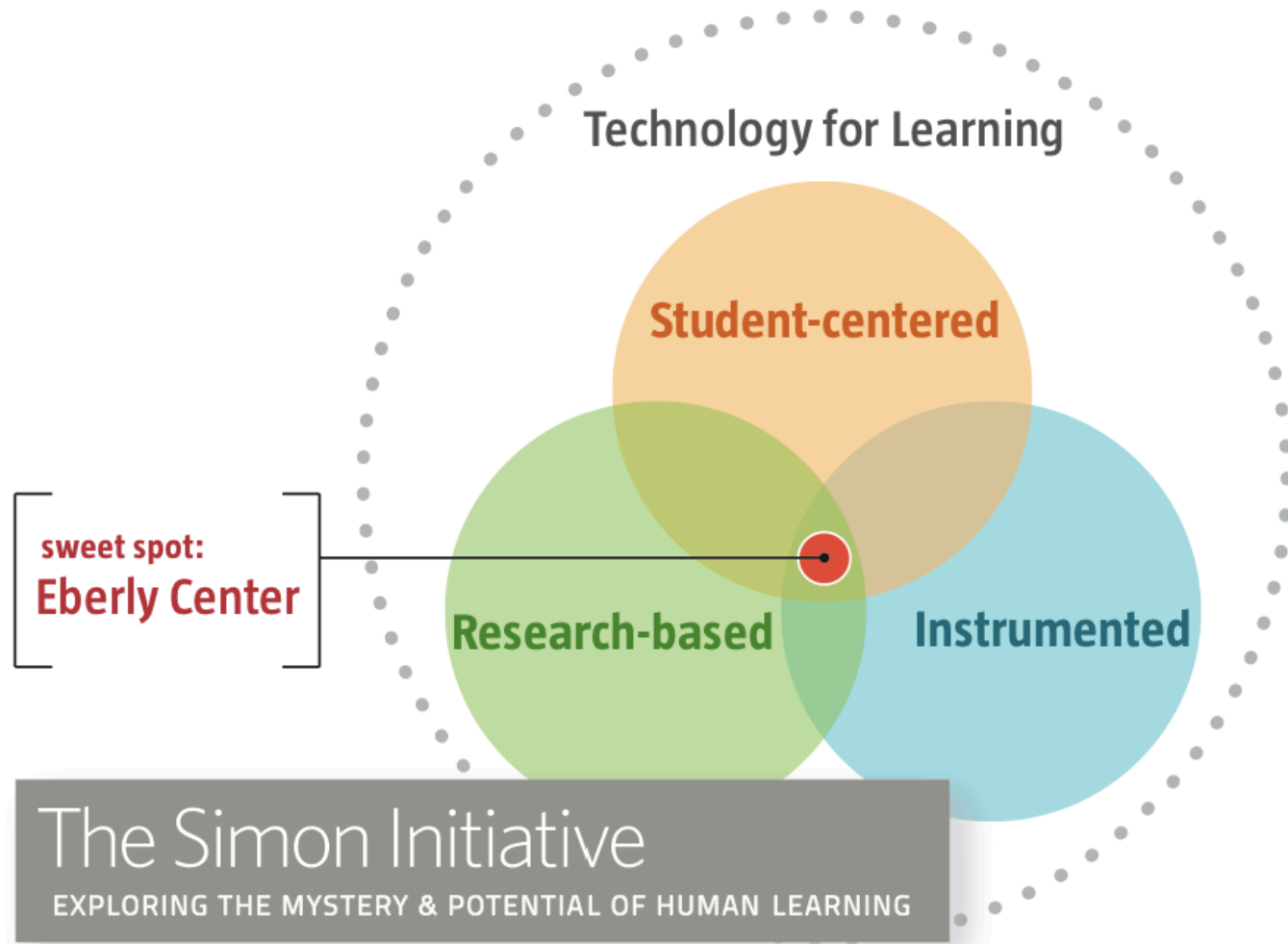
VISIBLE LEARNING A SYNTHESIS OF OVER 800 META-ANALYSES RELATING TO ACHIEVEMENT

"Reveals teaching's Holy Grail"
The Times Educational Supplement



Eberly Center

Teaching Excellence & Educational Innovation



Learning Science → Instructional Design

Practicing a given skill
improves performance ***on that skill***

Practice activities are effective to the degree that they

1. **Align with the skills** students need to learn
2. Offer opportunities for **repeated practice**
3. Provide **targeted and timely feedback**

Research-based online instruction

Online courses and modules built within the Open Learning Initiative platform

Learn by Doing

Hint

Now you complete the table by computing the conditional percentages for the males.
What is the correct number for the cell indicated by the question mark?

<div>Body Image Gender</div>				
	About Right	Overweight	Underweight	Total
Female	$560/760=73.7\%$	$163/760=21.5\%$	$37/760=4.9\%$	$760/760=100\%$
Male	?			100%

☐ $295/560=52.7\%$ ☒ $295/855=34.5\%$ ☐ $295/440=67\%$ ☐ $295/1200=24.6\%$

Page 1 of 4 **Next**

Learning activities are instrumented to *continuously* assess student learning

Feedback to
Student

Learn by Doing

Hint

Now you complete the table by computing the conditional percentages for the males.
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Body Image Gender	About Right	Overweight	Underweight	Total
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Page 1 of 4 Next

Feedback to
Instructor

Learn by Doing

Hint

Now you complete the table by computing the conditional percentages for the males.
What is the correct number for the cell indicated by the question mark?

Body Image Gender	About Right	Overweight	Underweight	Total
Female	560/760=73.7%	163/760=21.5%	37/760=4.9%	760/760=100%
Male	?			100%

☐ 295/560=52.7% ☒ 295/855=34.5% ☐ 295/440=67% ☐ 295/1200=24.6%

Page 1 of 4 Next

✗ That's not quite right. Focus only on the 440 males. What percentage of them responded "About right"?

Module 2

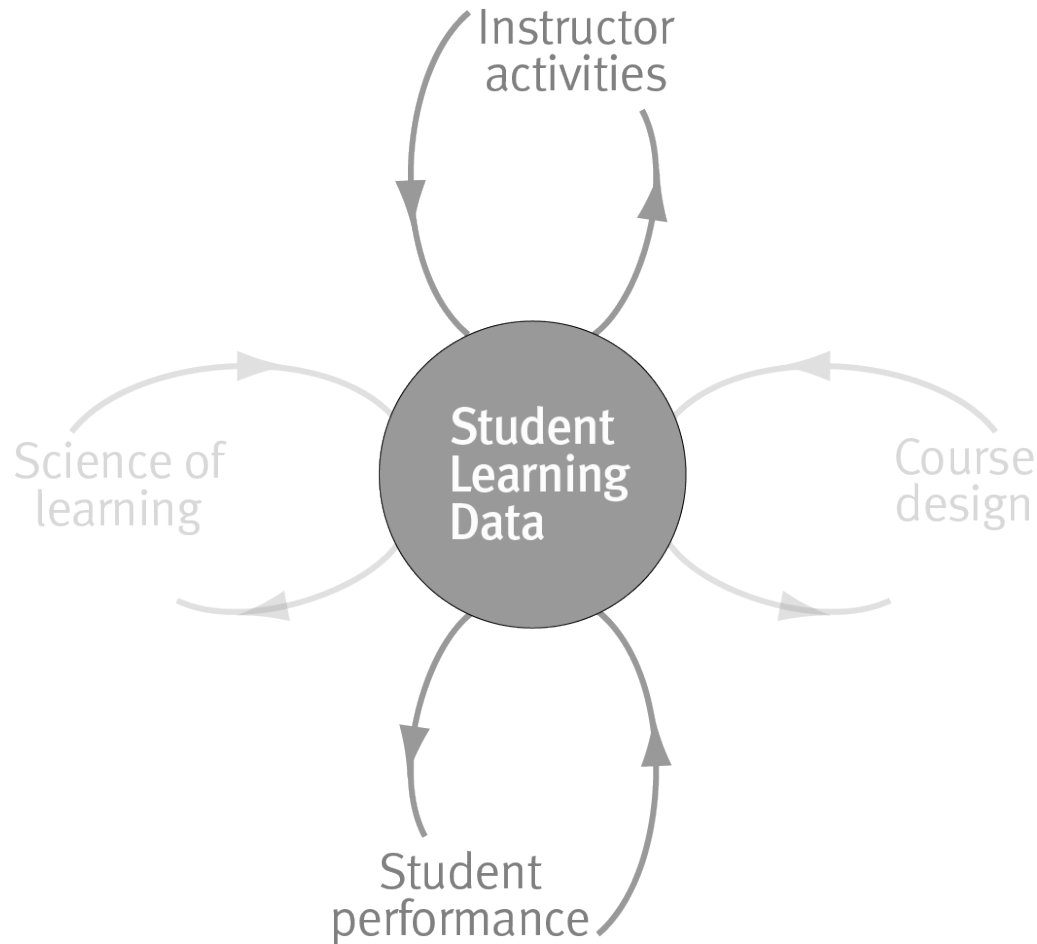
Examining Relationships

PREDICTED MASTERY LEVELS

Learning Objectives

- Classify a data analysis situation (involving two variables) according to the "role type classification," and state the appropriate display and/or numerical measures that should be used in order to summarize the data. [Show Sub-Learning Objectives]
- Produce a two-way table, and interpret the information stored in it about the association between two cat. variables by comparing conditional percents. [Show Sub-Learning Objectives]
- Graphically display the relationship between two quantitative variables and describe:
a) the overall pattern, b) striking deviations from the pattern. [Show Sub-Learning Objectives]
- Interpret the value of the correlation coefficient, and be aware of its limitations as a numerical measure of the association between two quantitative variables. [Show Sub-Learning Objectives]
- In the special case of linear relationship, use the least squares regression line as a summary of the overall pattern and use it to make predictions. [Show Sub-Learning Objectives]
- Recognize the distinction between association and causation, and identify potential lurking variables for explaining an observed relationship. [Show Sub-Learning Objectives]
- Recognize and explain the phenomenon of Simpson's Paradox as it relates to interpreting the relationship between two variables. [Show Sub-Learning Objectives]

Interaction data drive feedback loops



A Few Sample Projects

Statistics Course

Accelerated Learning +
Retention

DNA Replication Module

Learning Gain for
Common “Crunch point”

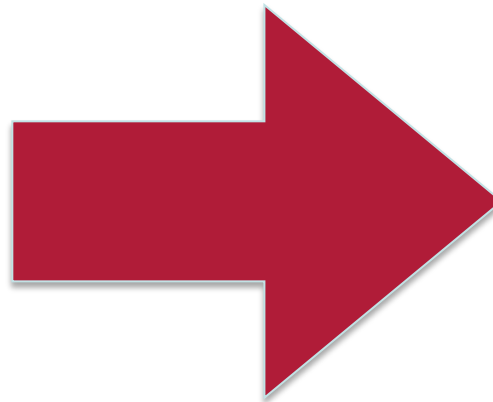
Prose Style Modules

Scaffolding + Transfer to
Authentic Task

CMU Statistics Study

Traditional
College Course

> 100 hours
~3% learning gain



Adaptive, Data-
Driven OLI Course

< 50 hours
~18% learning gain

Replicated 3 times at CMU
External report by ITHAKA

Lovett, Meyer, & Thille (2008, 2010).
See jime.open.ac.uk/jime/article/view/2008-14

Adaptive/Accelerated vs. Traditional

Two 50-minute classes/wk < **Four** 50-minute classes/wk

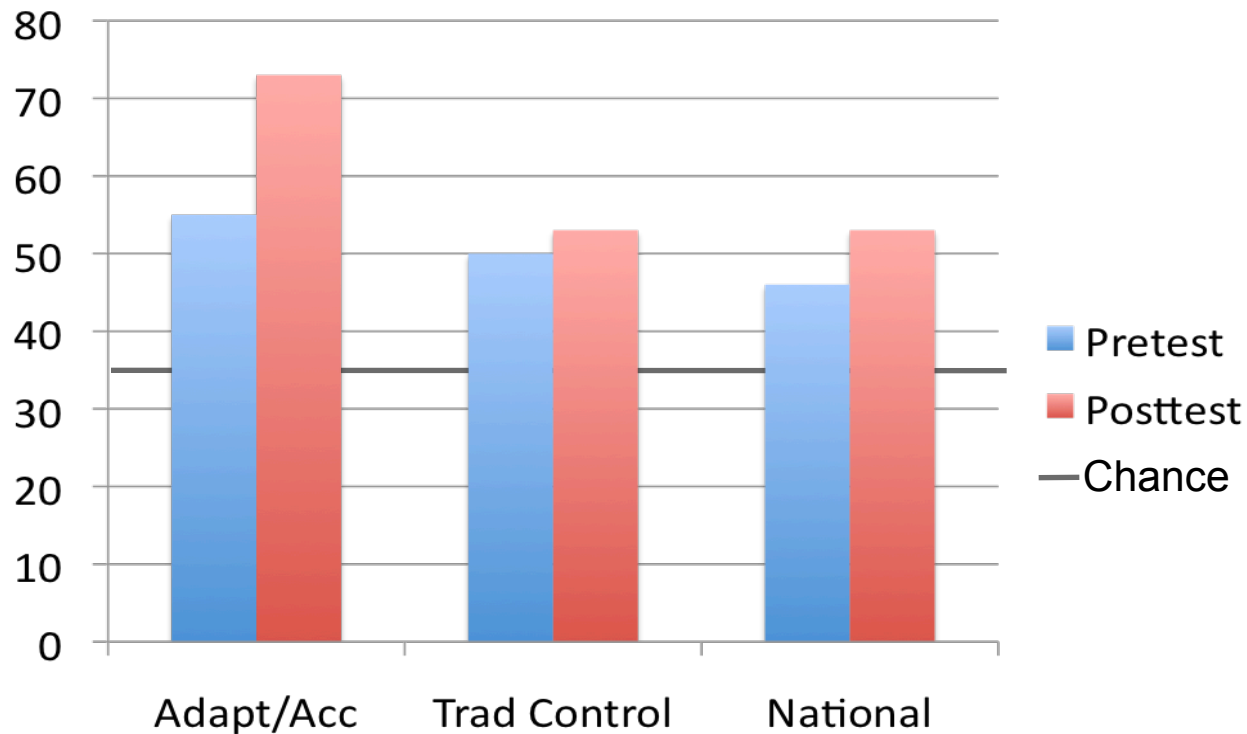
Eight weeks of instruction < **Fifteen** weeks of instruction

Homework: complete OLI activities on a schedule < Homework: read textbook & complete problem sets

Tests: Three in-class exams, final exam, and CAOS test = Tests: Three in-class exams, final exam, and CAOS test

Same content but different *kind* of instruction

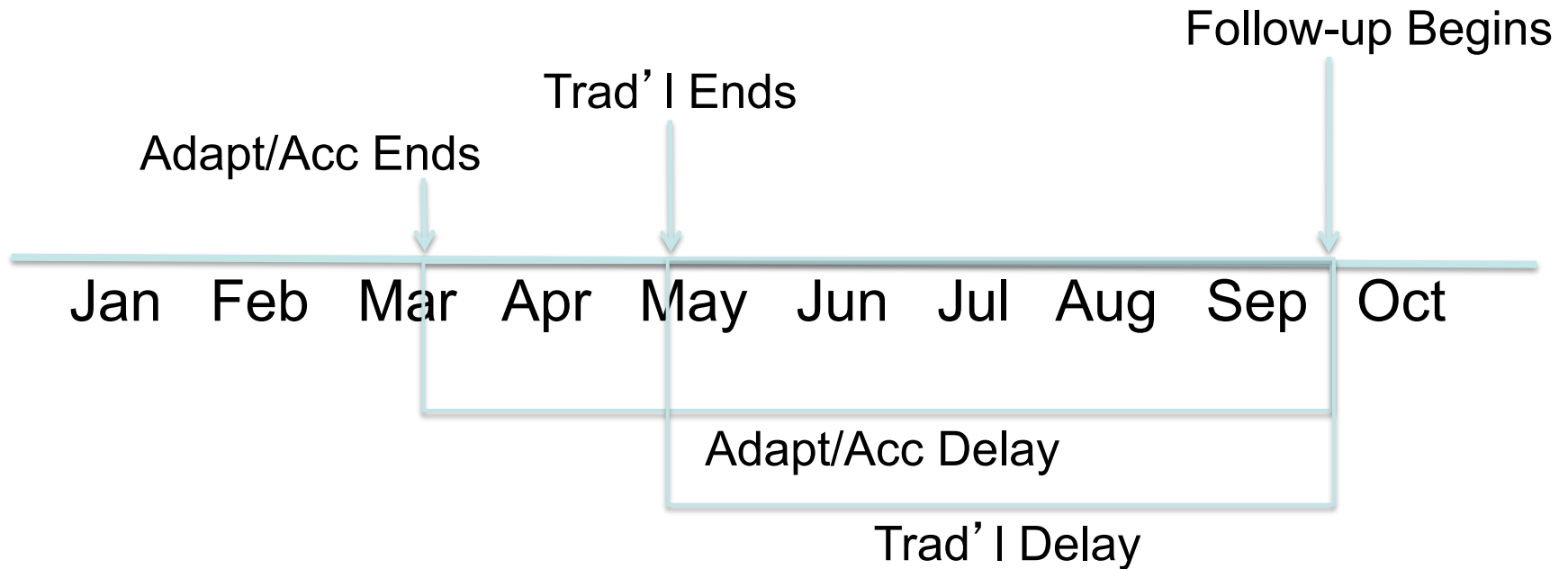
Standardized Test Results



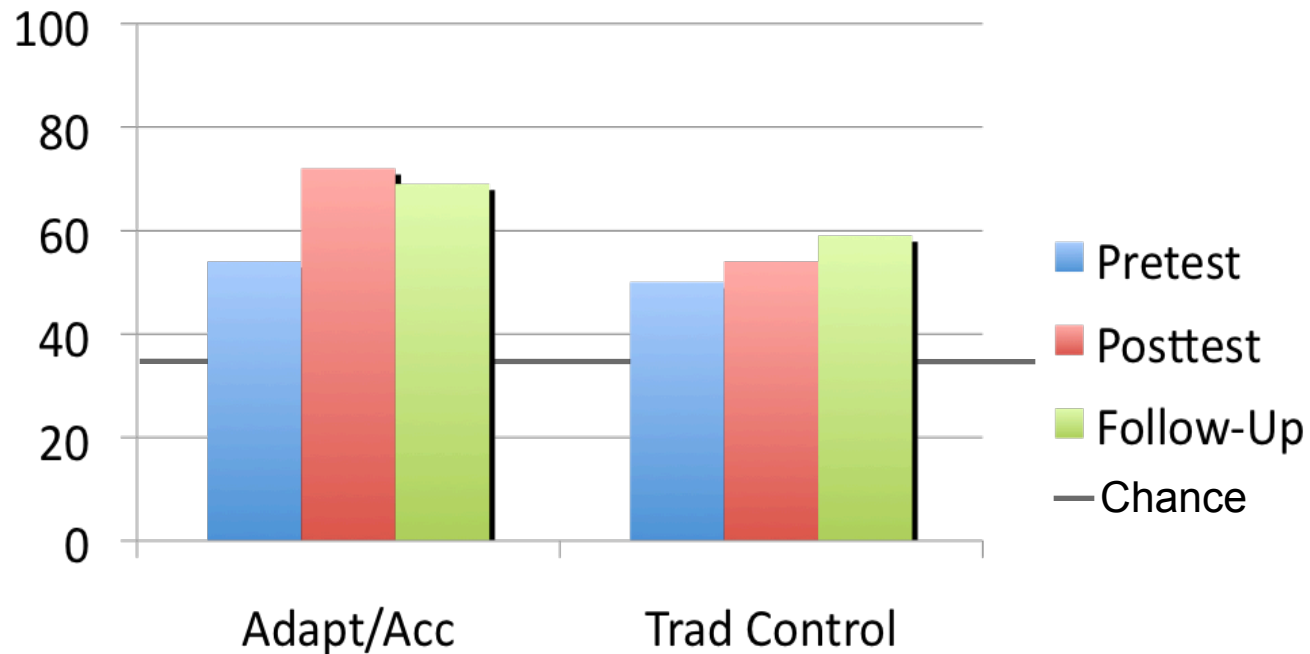
Adaptive/Accelerated group gained significantly more pre/post than the Traditional Control group, 18% vs. 3%

Follow-up: Retention & Transfer

Goal: Study students' retention and transfer in both groups
Students were recruited at the beginning of the following semester

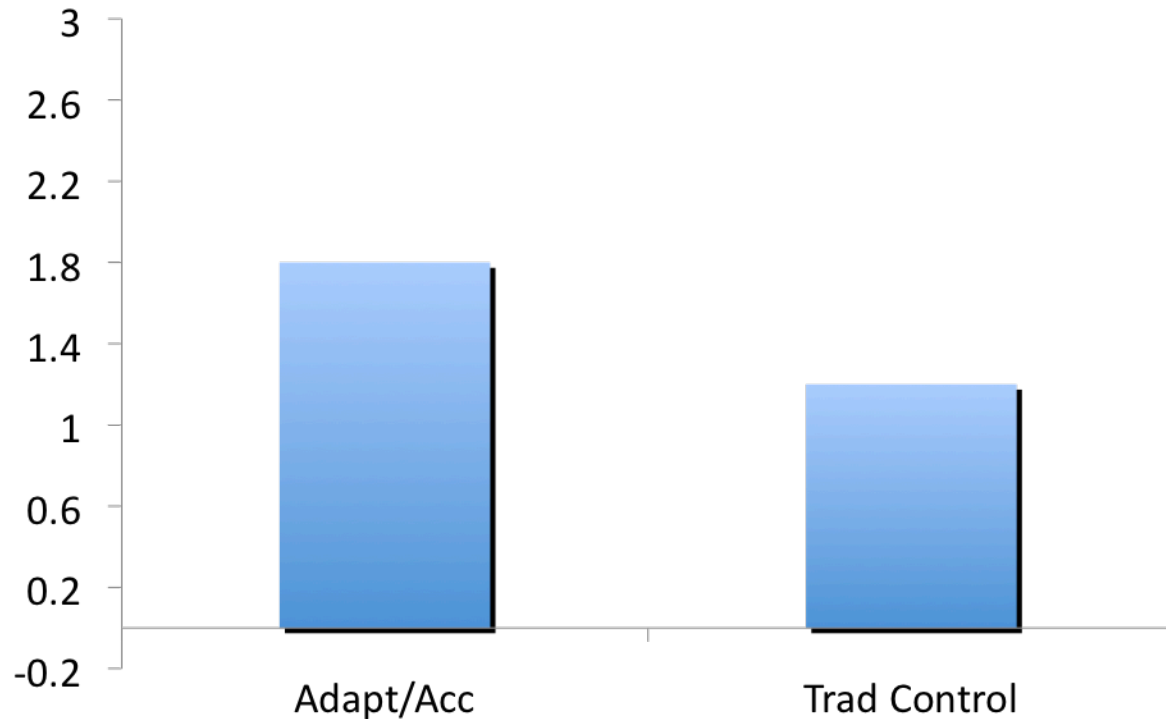


Retention: Standardized test



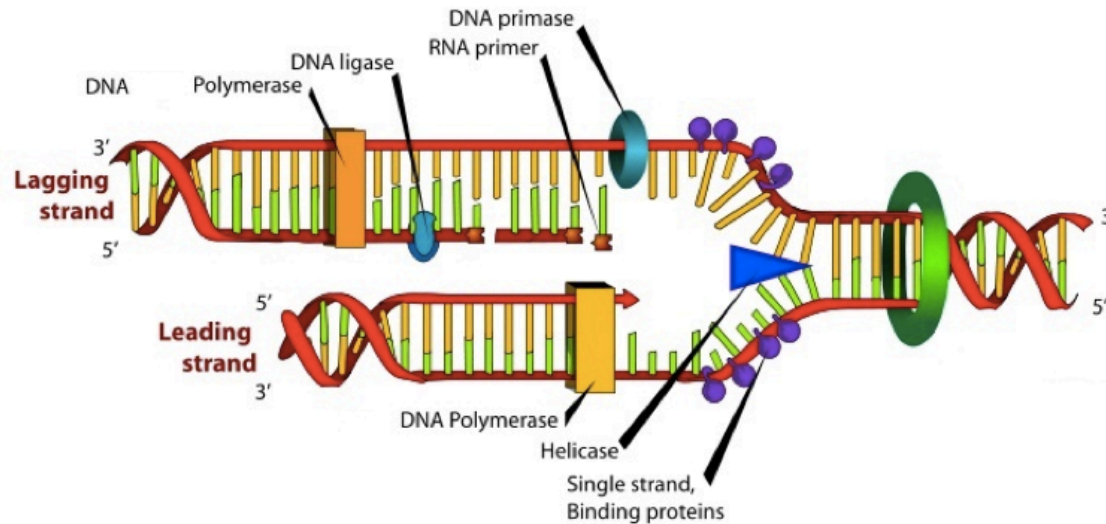
At 6-month delay, Adaptive/Accelerated group scored higher on CAOS than Traditional Control, $p < .01$.

Transfer: Open-Ended Data Analysis



Adaptive/Accelerated group scored significantly higher than Traditional Control.

DNA Replication Module



By Mariana Ruiz ([DNA replication](#)) Public Domain

did I get this

Which of these separates the two complementary strands of DNA?

- ☐ single-strand binding protein ☐ helicase ☐ DNA polymerase ☐ RNA primer






Which of these attaches complementary bases to the template strand?

- ☐ helicase ☐ single-strand binding protein ☐ RNA primer ☐ DNA polymerase

Which of these is later replaced with DNA bases?

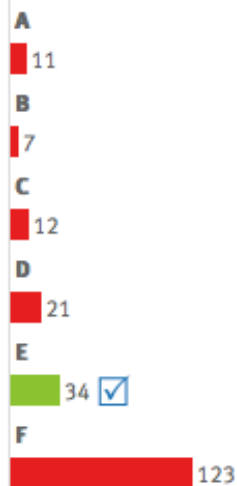
- ☐ DNA polymerase ☐ RNA primer ☐ single-strand binding protein ☐ helicase

Where did students make the most mistakes?

Question	Students	% Correct
Question 1	208	 16%
Question 2	203	 63%
Question 5	192	 76%
Question 3	202	 86%
Question 4	192	 89%

Question 1

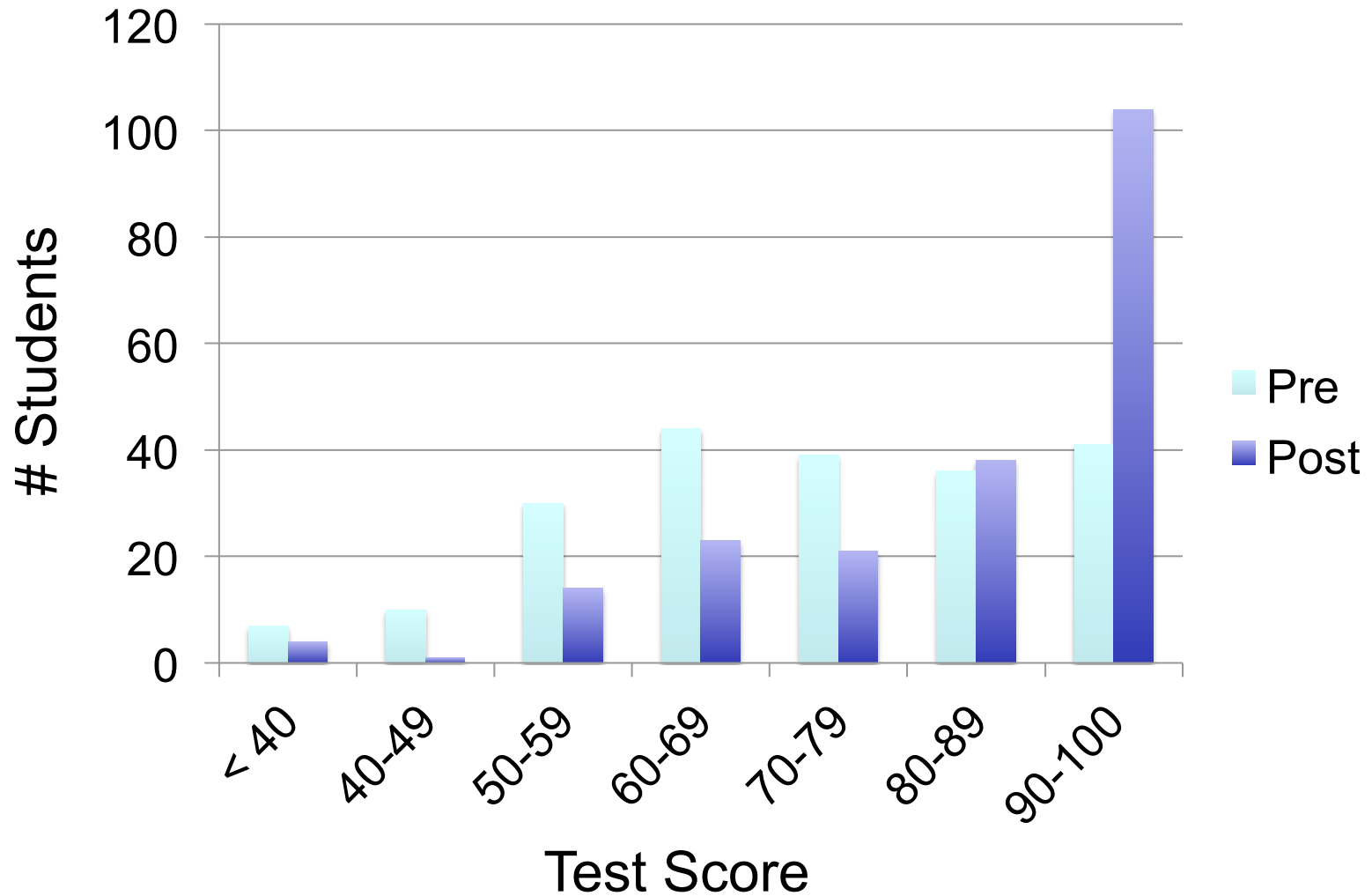
208 responses, 16% correct



A closed circular prokaryotic chromosomes replicates from a single origin of replication. If the rate of DNA synthesis by DNA polymerase is 500 bp/sec and the chromosome contains a million bp, how long will it take to replicate the chromosome?

- A. ☐ 10 sec
- B. ☐ 20 sec
- C. ☐ 100 sec
- D. ☐ 200 sec
- E. ☐ 1000 sec
- F. ☐ 2000 sec

Distribution of Scores Pre/Post DNA Module





Module 5 / Identifying Nominalizations Derived from Verbs

14

LEARNING
OBJECTIVEIdentify and transform
nominalizations.


Prose Style Modules

The key to identifying nominalizations derived or converted from verbs is to look for nouns that refer to actions. In looking for them, however, it might be helpful to know that many nominalizations have common endings. Table 1 lists the common endings for nominalizations derived from verbs, along with an example nominalization with that ending and its corresponding verb.

Table 1. Common Endings for Nominalizations Derived from Verbs

<i>Ending</i>	Example Nominalization	<i>Verb</i>
-age	storage	store
-ance/ence	contrivance	contrive
-ant	adulterant	adulterate

learn by doing

Identify all the nominalizations that refer to an action in the following sentence: 

Adolf Loo's famous essay, 'Ornament and Crime,' decisively linked unornamented architecture with the culture of modernity and, in doing so, became one of the key formulations of modern architecture.



NEXT »

[Reset this Activity](#)

[Learning Dashboard](#)

NOTE: Click on the word(s) in the sentence to select/identify nominalization(s).

The following *did I get this?* exercise tests your understanding of the material covered in this unit.

did I get this

Revise the following sentence:

By contrast, Lubell wants to highlight the inevitable incompleteness of one's knowledge of one's past.

Submit and Compare

Revise the following sentence:

Under this standard, the event of death is determined as the time at which there is irreversible loss of whole brain function.

Submit and Compare



Use **scientific methods** to study learning

Apply **results** to improve learning

Themes Underlying Our Approach

Learning science research provides rich theory and results on how students learn

Designing instruction based on learning science principles produces positive results

Key role for technology is to automate and augment putting them into practice

Learning Engineering: Applying Research & Data to Improve Outcomes

Norman Bier

@normanbier



**Open Learning
Initiative**

Carnegie Mellon University

April 27, 2015



What is the Open Learning Initiative?

Scientifically-based online learning environments based on the use of technology and the science of learning with intelligent instruction. OLI is **designed** to simultaneously improve learning and facilitate learning research.



The screenshot displays the OLI interface with several components:

- Top Window:** A chemistry lab setup titled "WYden Chemistry Lab - Default Lab Setup". It includes a "Substance Explorer" on the left with a list of chemicals (e.g., $\text{1M NaH}_2\text{CH}_2\text{COO}$, 1M NaOH , 1M NaHCO_3 , $\text{1M NaHCO}_2\text{COO}$, 1M NaOH , 1M NaOH) and a "Workbench 1" area showing a 10mL Pipet.
- Bottom Left Window:** A physics problem titled "did I get this?". It asks to determine the sum of three concurrent forces:
 - Force F_1 has a magnitude of 9N; its line of action passes through points A (1, 1) and B (4, 3).
 - Force F_2 has a magnitude of 5N; its line of action is parallel to a 3-4-5 triangle.
 - Force F_3 has a magnitude of 5N; its line of action is at 60 degrees to the horizontal.A diagram shows a coordinate system with points A (1, 1) and B (4, 3). Force F_1 is a vector from A to B. Force F_2 is a vector pointing downwards and to the right. Force F_3 is a vector pointing downwards and to the left. The angle between F_2 and the horizontal is 60 degrees.
- Bottom Right Window:** A "Solidate Info" panel showing a bar chart of "log Molarity" for various species. The table below shows the molarities:

Species	Molarity
H^+	4.624e-9
OH^-	2.163e-6
Na^+	1.000e0
HCO_3^-	9.797e-1
H_2CO_3	1.015e-2
CO_3^{2-}	1.015e-2
- Right Side Panel:** A "NEXT GROUP" button and a grid of black and white squares.

The Open Learning Initiative

Established in 2002 to produce and improve exemplars of scientifically-based online courses that enact instruction and support instructors. Current goals:

- Support better learning and instruction with high-quality, scientifically-based, classroom-tested online courses and materials.
- Share our courses and materials openly and freely so that anyone can learn.
- Develop a community of use, research, and development.



Open Learning Initiative

Transforming higher education through the science of learning.

An approach to
designing, developing,
delivering and improving
learning experiences

Science

- Science of Learning
- Evaluation
- Improvement

Technology

- Platform
- In-course Affordances

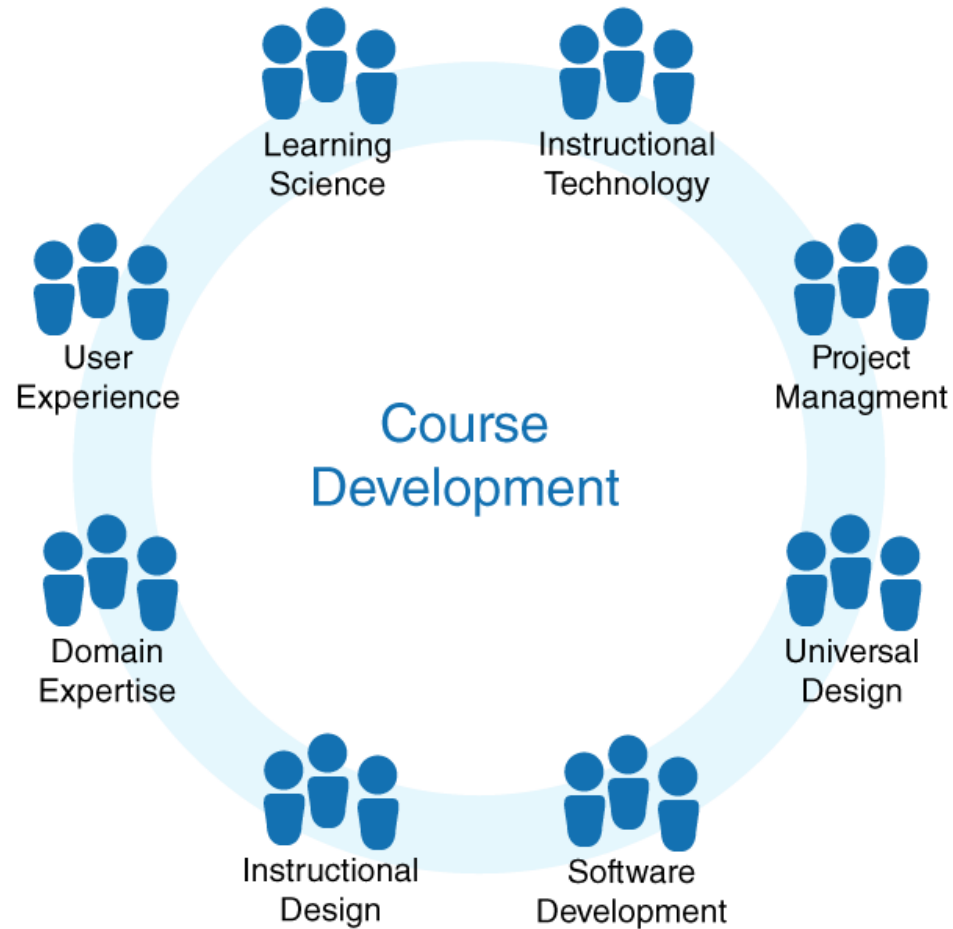
Teams

- Team-based Development
- Communities of Research and Use

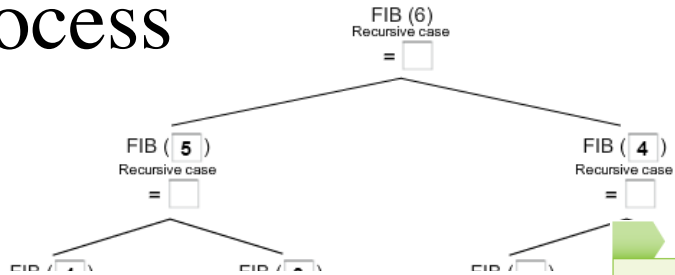
Data

- Capture
- In-course Use
- Iterative Improvement
- Research

Team-based design and development

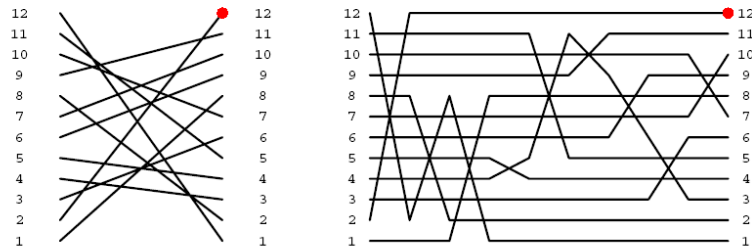


Embed lessons in technology and in process



So $(1, 2)(2, 3)(3, 4)(4, 5) = (5, 4, 3, 2, 1)$.

Here is a more complicated permutation on $n = 12$, and its decomposition into transpositions.



There are many other identities relating to transpositions. For the next proposition, we abuse notation and use exponents for permutations given in cycle notation.

Proposition

$$(a, b) \circ (b, c) \circ (a, b) = (a, c)$$

$$(1, \dots, n)^t \circ (1, 2) \circ (n, \dots, 1)^t = (i+1, i+2)$$

where $0 \leq i \leq n-2$

As already mentioned, the decomposition into transpositions is not unique. In fact, not even the number of transpositions used is unique. However, there is still an invariant.

Even permutation

(definition) A permutation is even if it can be written as the product of an **even** number of transpositions, and **odd** if it can be written as the product of an odd number of transpositions.

learn by doing

Click on the appropriate template to fill in the indicated cell in the next generation.

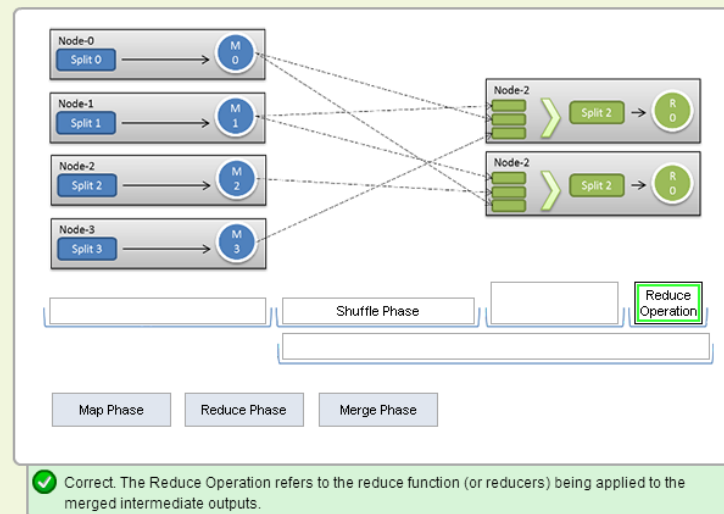
[NEXT GROUP](#)

We can continue this over and over to see how the automaton develops over generations.

did I get this

MapReduce Phases

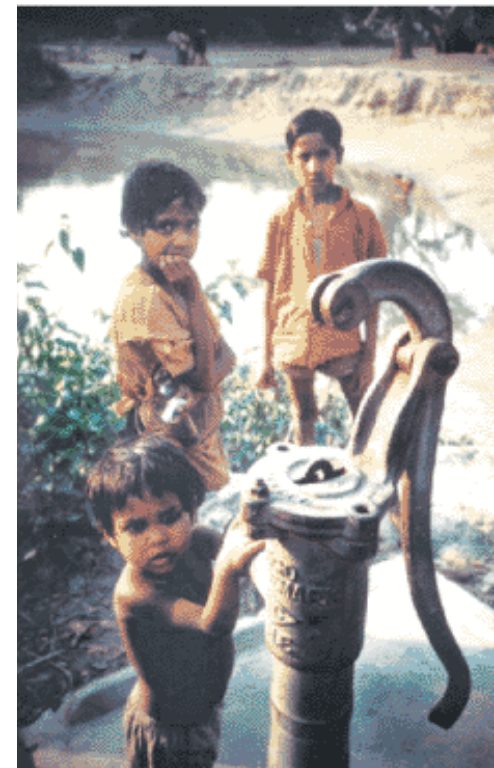
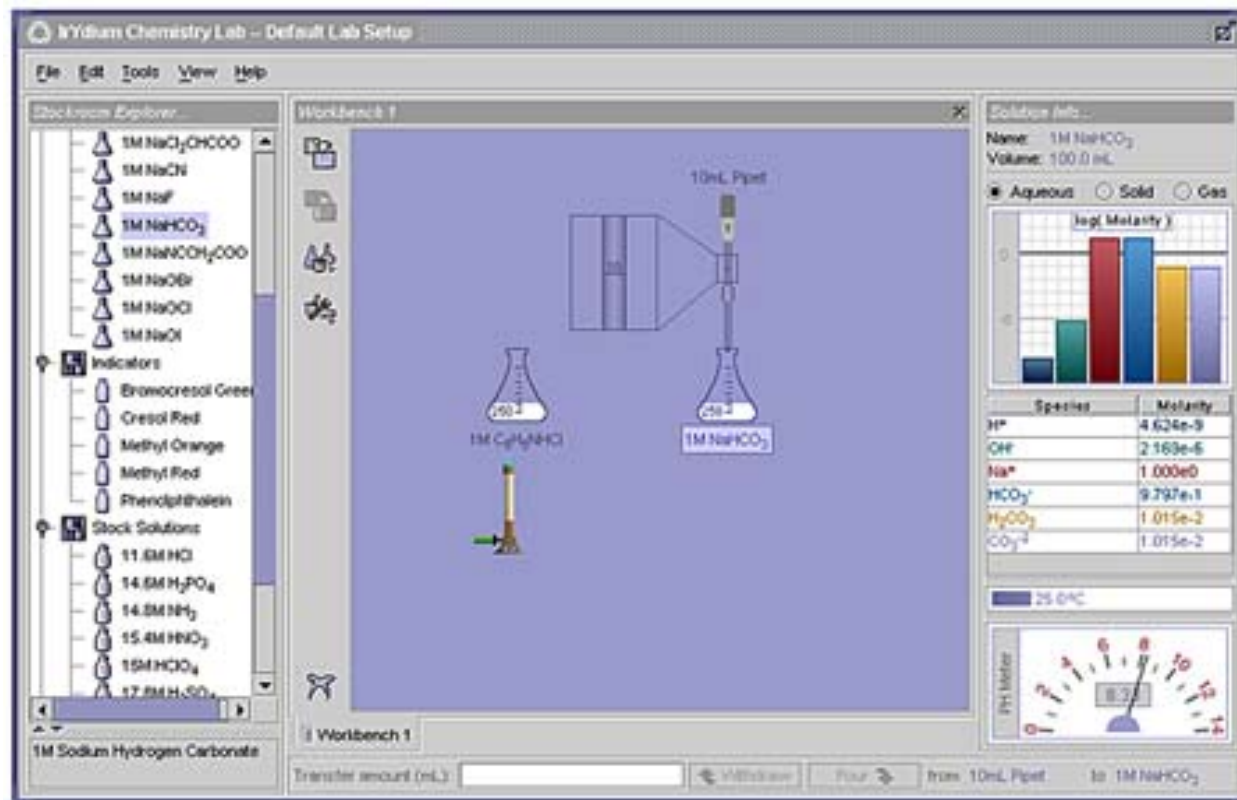
The following image illustrates the various phases of MapReduce. Match the letters (A,B,C,D and E) with their corresponding phase names below:



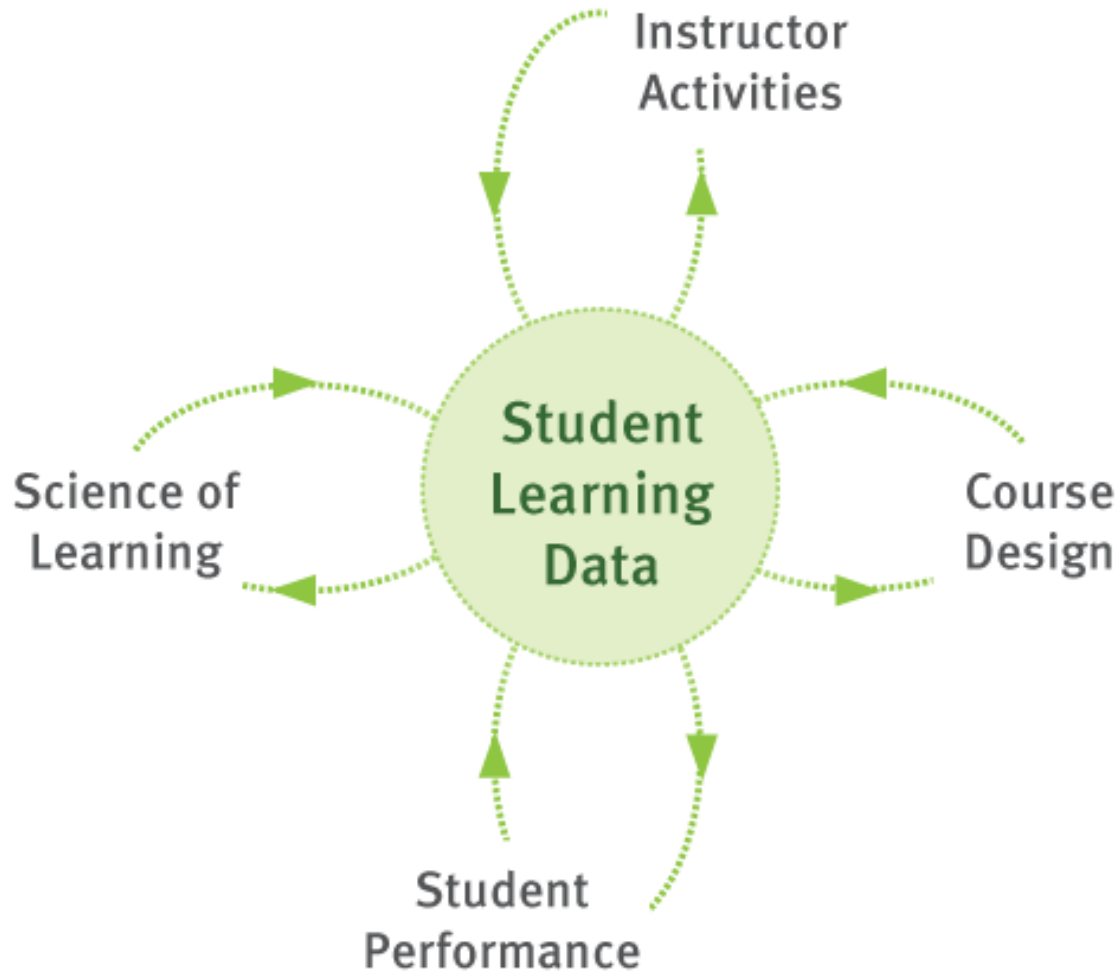
[Learning Dashboard](#)

Identifying Specific Learning Challenges:

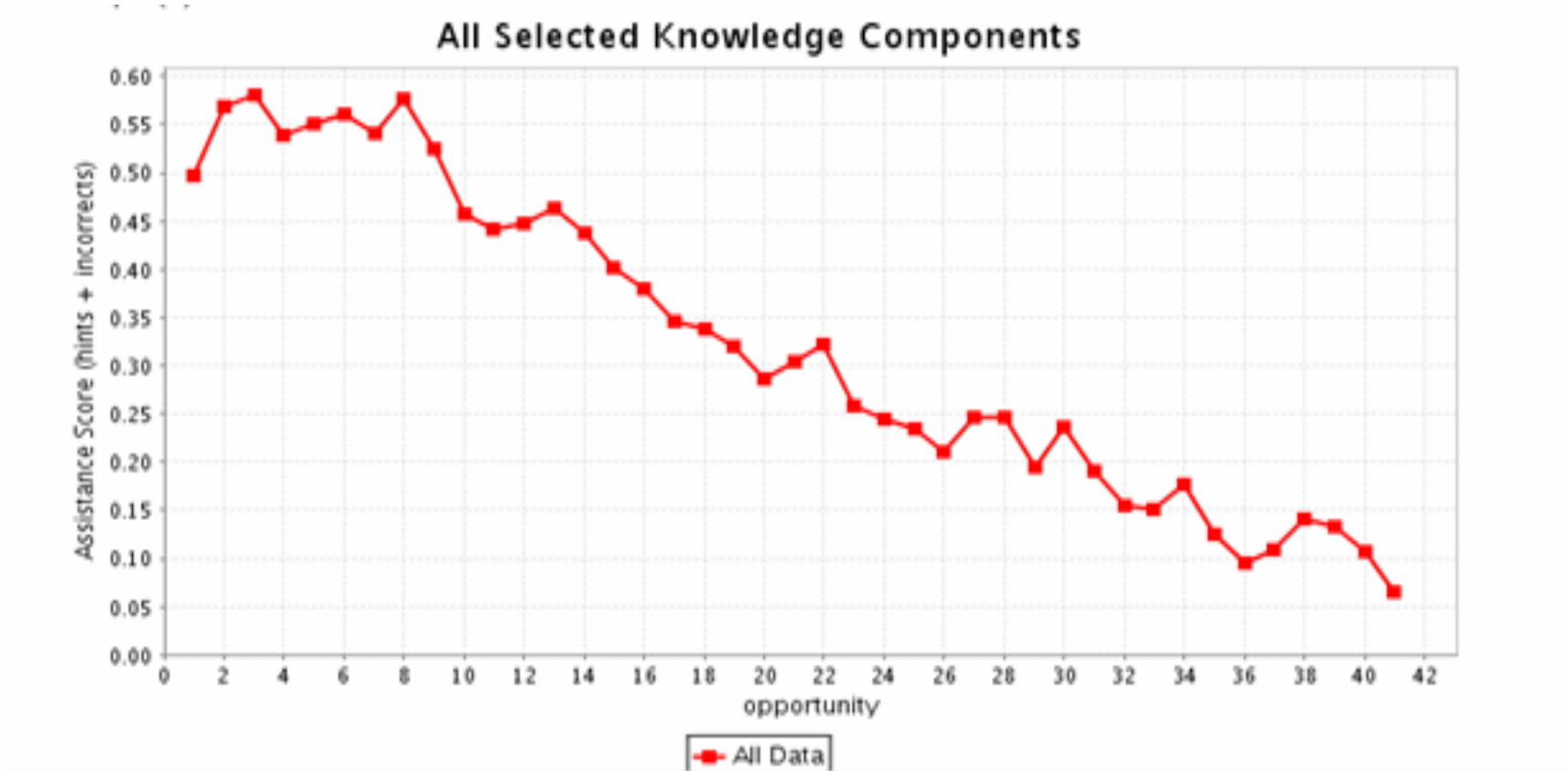
Practice Synthesizing and Applying Skills & Knowledge



Feedback loops for **continuous improvement**

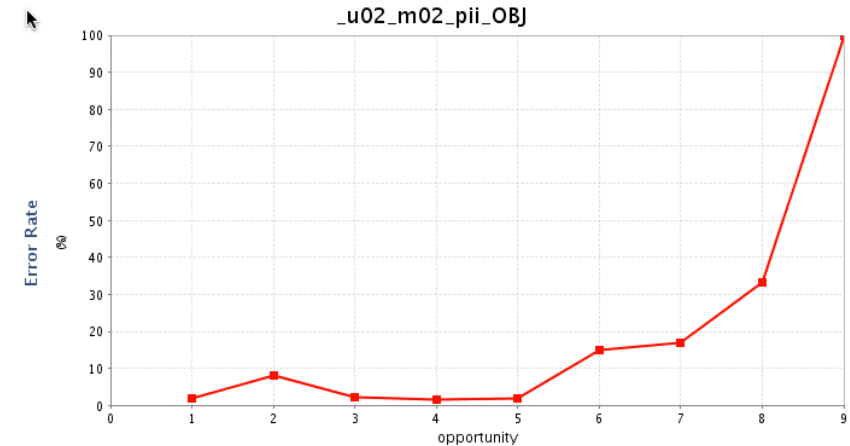
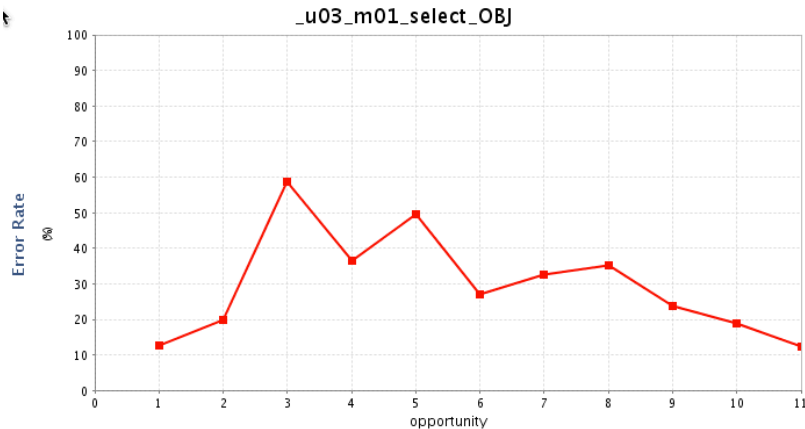
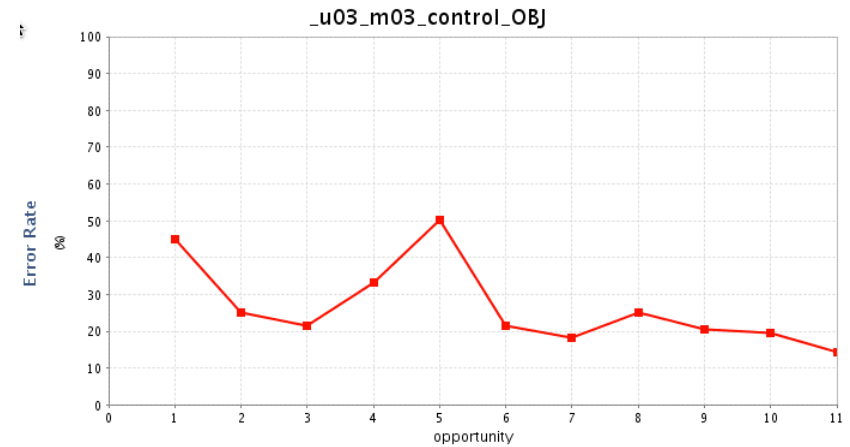
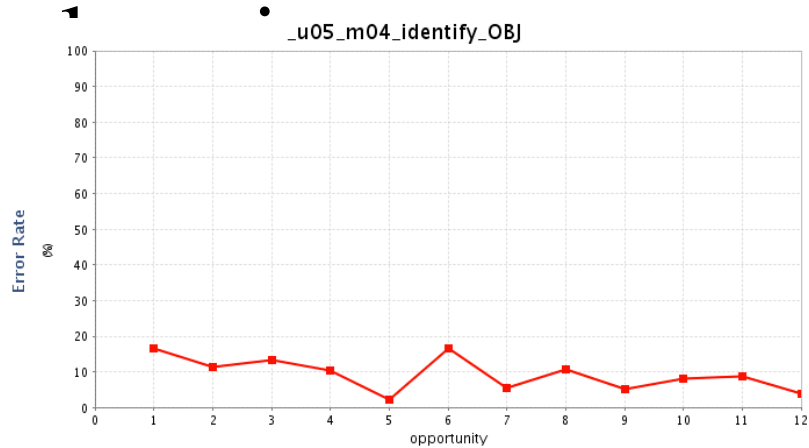


Learning Curve Analysis



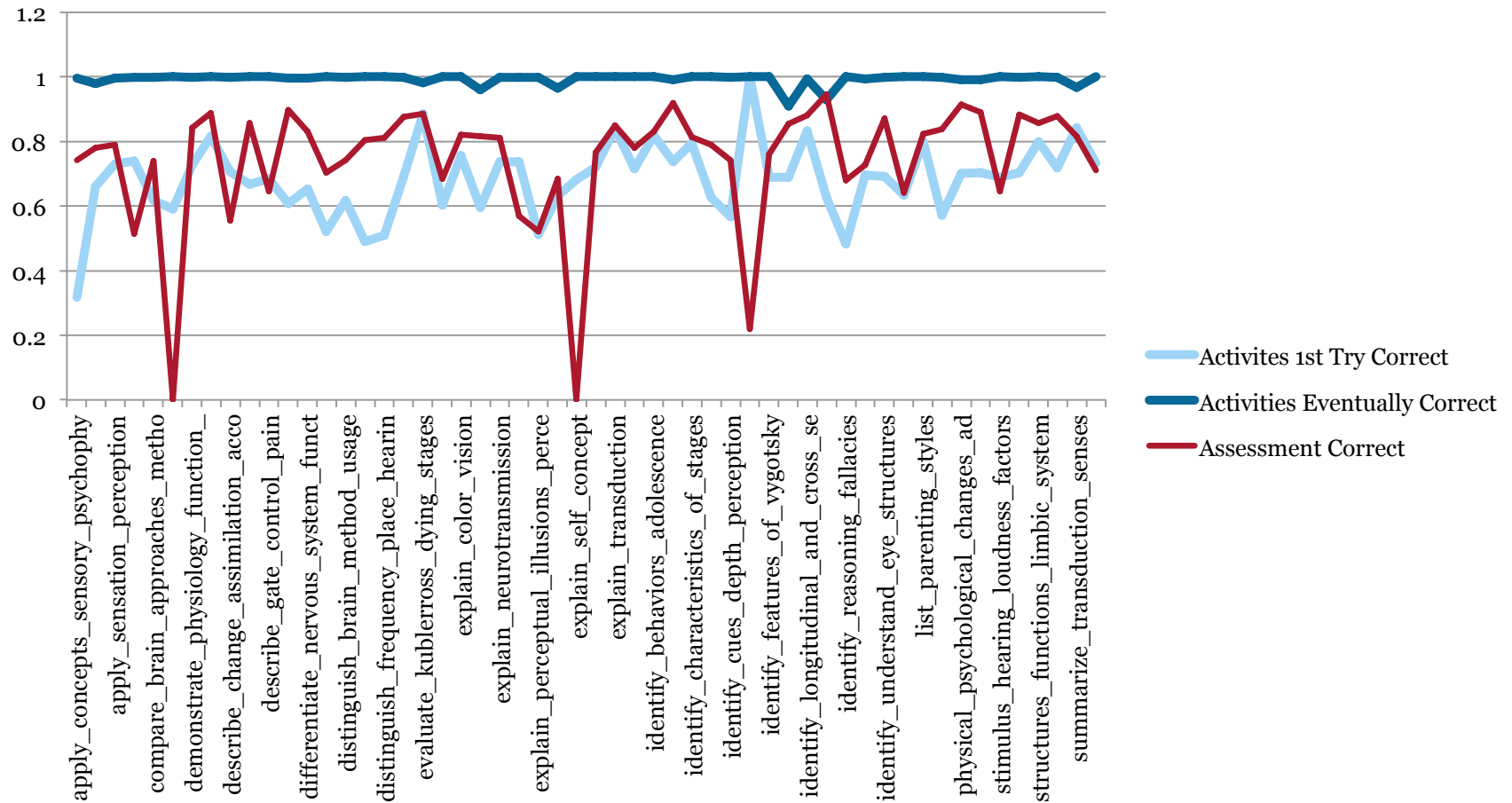
DataShop: Pittsburgh Science of Learning Center

Other Learning Curves



DataShop: Pittsburgh Science of Learning Center

Practice and Assessments



Is the hypothesis I built holding up?

Reports

Performance | [Usage](#) | [Feedback \(3\)](#) | [Model Checker](#)

Modern Biology v. 1.4 [EDIT]

SUMMARY

Enrollment	Courses	Institutions	LOs	Student Input Opportunities
900: 700 academic 200 open	220	50	18	50

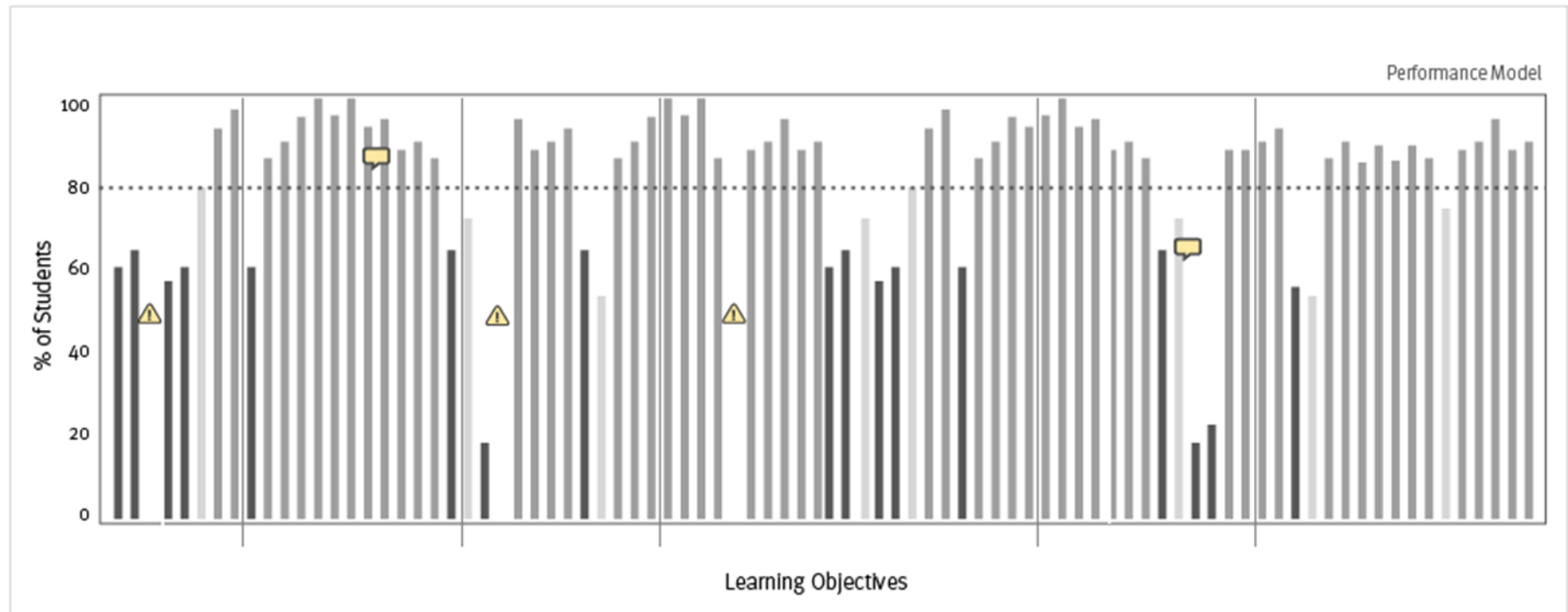
Learning Objectives ▼

All Learning Objectives ▼

All Modules ▼

☒ Objectives Chart

☐ PSLC Help Curve



LEARNING OBJECTIVES

Module 4 ▼

1. List atoms (elements) found in biological systems that are most important to life, including the most common atoms and trace elements.
2. Identify the more electronegative atom when comparing two atoms.

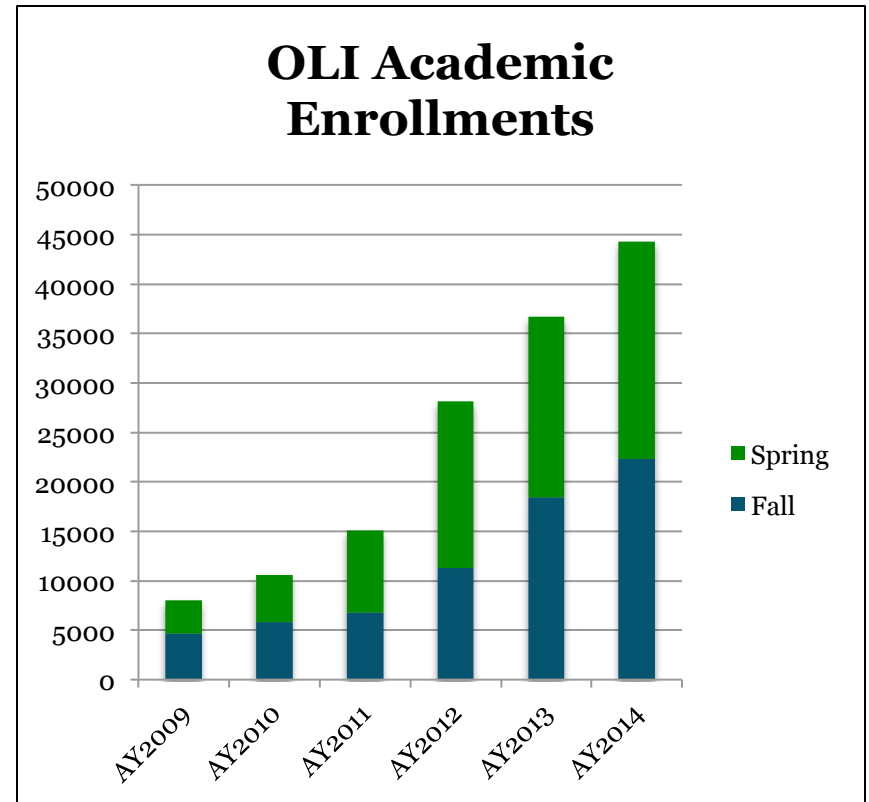
Since 2006

Course Use

- Used by 1809 Instructors in 1050 Institutions
- 1,245,807 Independent Learner Enrollments (Registered and Anonymous)

Development

- 44 Academic and 9 CMU service courses have been created.
- By 104 contributing Faculty from 55 Institutions



Current Work

Embedding data into design & improvement

IDEA Project

- NSF DIR Project
- Tools for supporting learning engineering
- Integration into workflow
- Existing and new analytic methods
- 3 Core components:
 - Model Checker
 - Performance Profiler

Reports

Performance | Usage | Feedback | Model Checker

Modern Biology v. 1.4 [Edit]

Unit 1 - Module 1: The Cell

SUMMARY

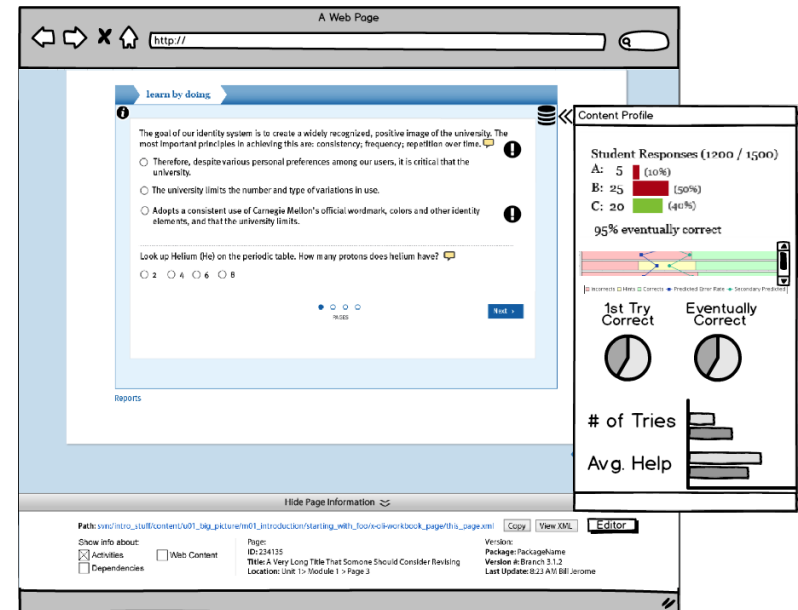
LOs: Opportunities: LO - No LBDs: LOs - No DIGT

12 50 5 3

Mapping: Learning Objectives to Skills

Show only unassigned

Unit	Learning Objective	Skills	LBDs	DIGTs	Checkpoints	Quizzes	Questions
1	1.1 List atoms (elements) found in biological systems that are most important to life.	A	1	1	0	1	1
2	1.1 Identify the more electronegative atom when comparing two atoms.	A	2	1	0	1	1
3	1.1 Define a hydrogen bond and draw possible hydrogen bonds between any two.	2	2	2	0	1	1
4	1.1 Identify the more electronegative atom when comparing two atoms.	A	2	1	0	1	1
5	1.1 List atoms (elements) found in biological systems that are most important to life.	3	1	1	0	1	1



New Approaches: ALMAP at UC Davis

FIGURE 1: (A) Weekly Practice Centered Training (PCT) vs. Traditional Discussion Sections and (B) Pre-Post Schedule.

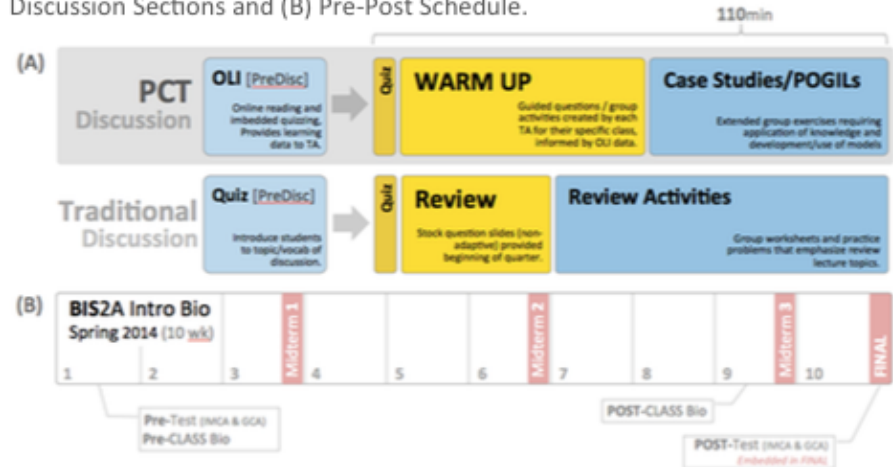


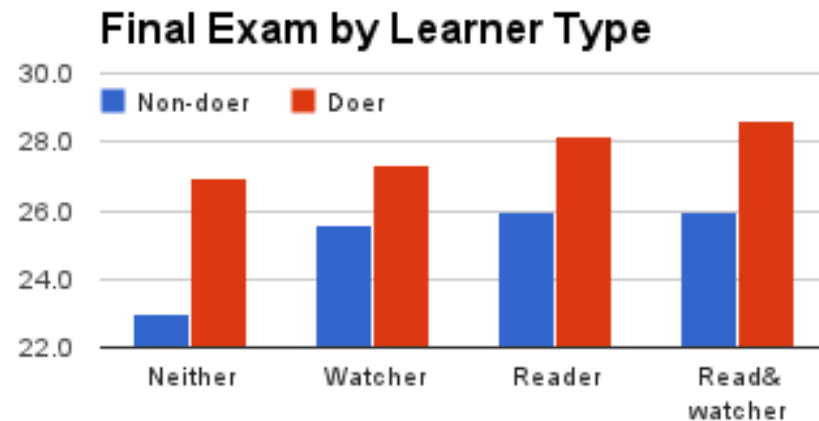
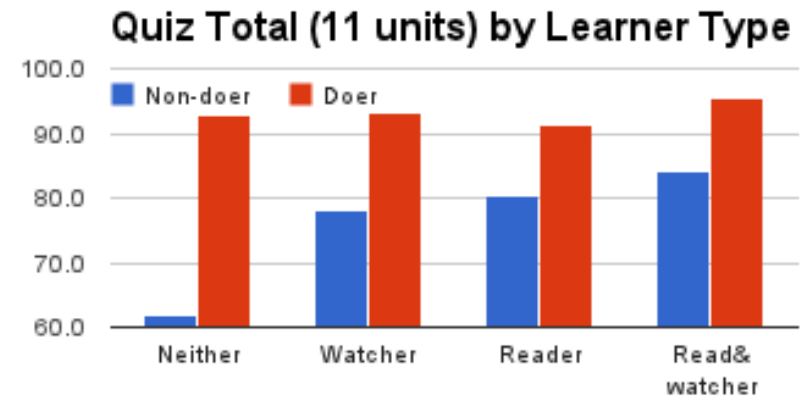
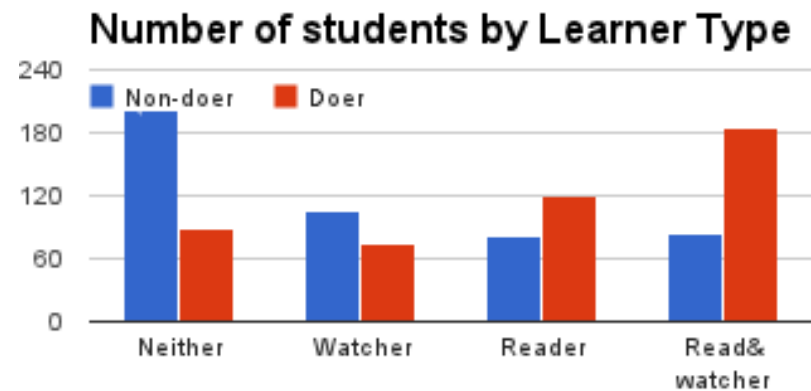
Figure 2: PCT emphasized (A) Data-driven instruction and (B) Instructional approaches that maximize engagement, student application of knowledge, and immediate feedback.



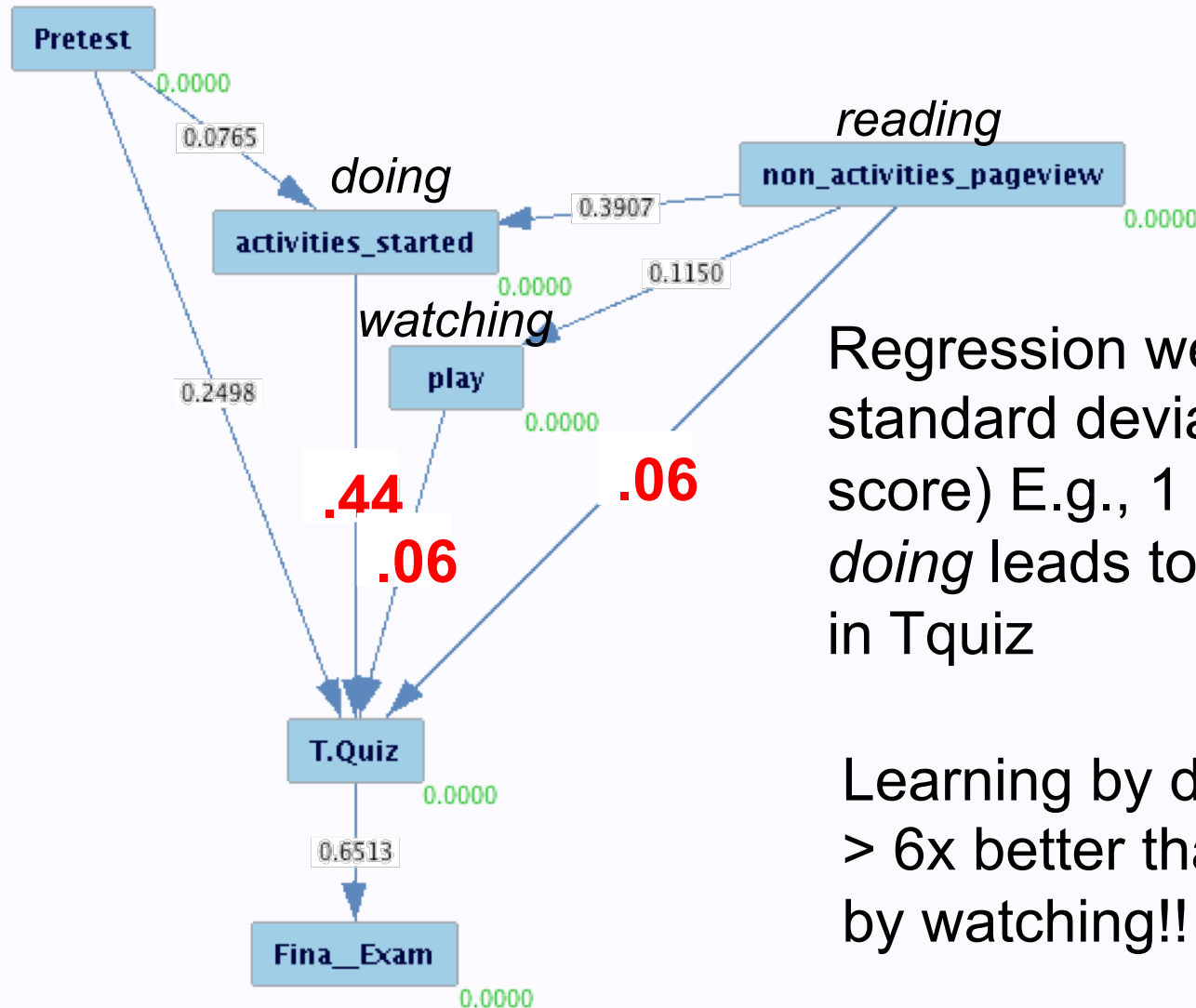
Learning is Not a Spectator Sport

Presented at L@S 2015

- Collaboration between GA Tech and Carnegie Mellon
- Psychology MOOC using OLI course
- Where does learning occur?
- Watching vs Reading vs Doing



Tetrad inference of causal relationships



Regression weights in standard deviation units (z-score) E.g., 1 sd increase of *doing* leads to .44 increase in Tquiz

Learning by doing
> 6x better than learning by watching!!

Looking ahead

CMU as a hub

CTAT Cognitive **Tutor** Authoring Tools

LearnLab
Pittsburgh Science of Learning Center

 **ETCglobal**
Carnegie Mellon.
PITTSBURGH

ChemCollective



• Human-
Computer
Interaction
Institute

DANCE
Discourse Affordances
for Natural Collaborative
Exchange

 **SimStudent**
A Computational Model of Learning

Integrative Design,
Arts and
Technology
Network

Pittsburgh Science of Learning Center
DATASHOP



**Open
Learning
Initiative**

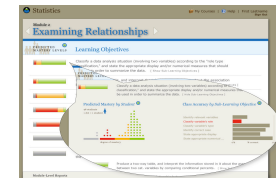
Carnegie Mellon University

Transforming higher education
through the science of learning.

Autolab

Eberly Center

Teaching Excellence & Educational Innovation

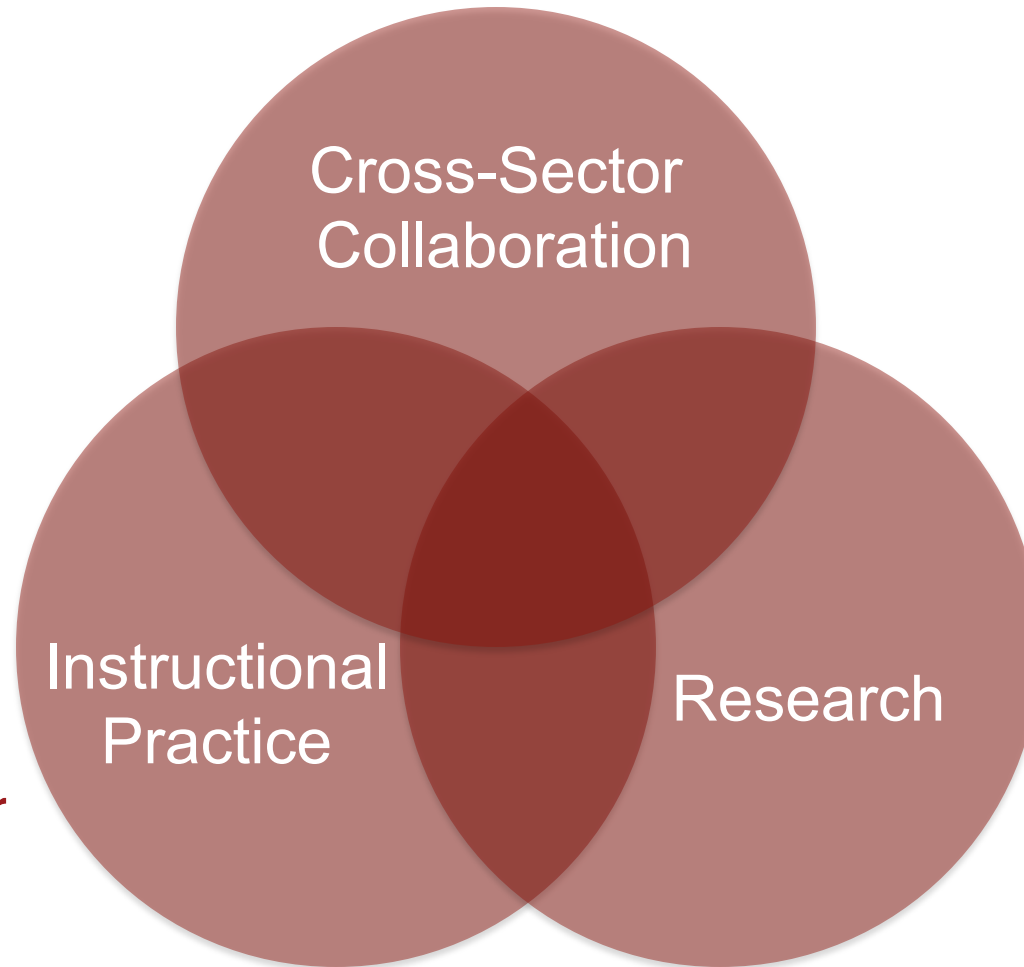


PIER@ Carnegie Mellon
PROGRAM IN INTERDISCIPLINARY EDUCATION RESEARCH

The Carnegie Mellon Genetics
Cognitive Tutor

Carnegie Mellon University

The Simon Initiative

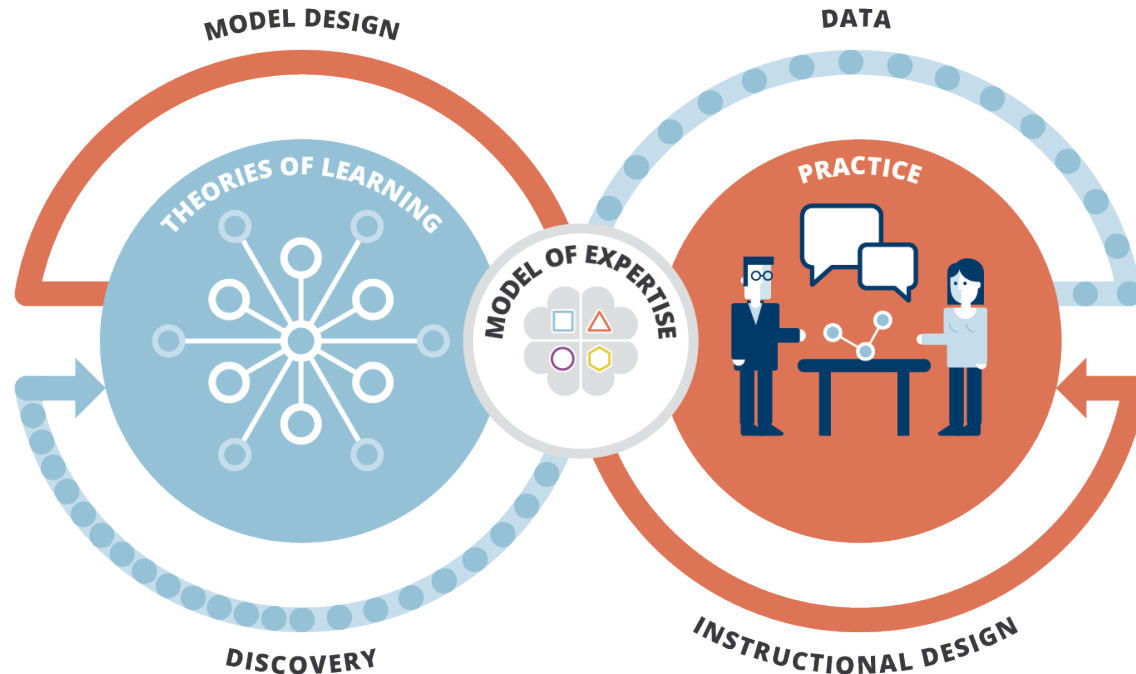


Eberly Center
Teaching Excellence & Educational Innovation



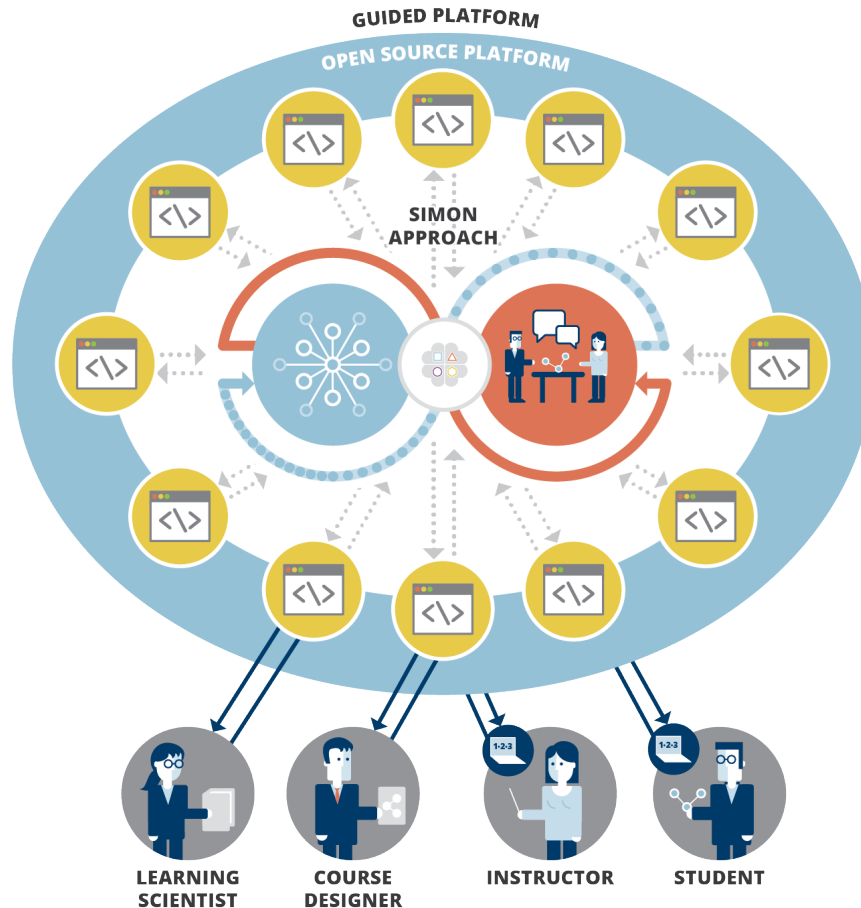
Carnegie Mellon University

The Simon Initiative



A data-driven virtuous cycle of learning science research and innovative educational practice causes demonstrably better learning outcomes for students from any background or place

The Simon Initiative



At CMU: To build a *learning engineering ecosystem* in which learning science research can feasibly and frequently be leveraged to demonstrably improve CMU education, and in which CMU education can provide data which can be leveraged to improve theories of learning

Globally: To provide accessible tools and methods with which any person or institution can adopt and improve upon CMU's approach to learning engineering

Questions?

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