Measuring Information Presentation in a Physics Class

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February 20, 2013 Physics & Astronomy Colloquium

Texas A&M University - Commerce

Primary: DUE-0535928
Prior:DUE-9455732
& PHY-0108787

ABSTRACT

At some level, the performance of students in a science class must depend on what is taught, the information content of the materials and assignments of the course. The introductory calculus-based electricity and magnetism class at the University of Arkansas is examined using a catalog of the basic reasoning steps involved in the solution of problems assigned in the class. These fundamental steps are used to quantify the distribution of informational content within the different elements of the course: laboratory, lecture, reading, and homework. This distribution of content is compared with the instructional outcomes measured by the Conceptual Survey of Electricity and Magnetism and by course exams to determine the relative efficacies of the various mechanism of presenting the information. Using this characterization technique, an exceptionally detailed picture of the information flow and the information structure of the class can be produced. Variation of the types and the amount of information presented is analyzed over multiple semesters.

Factors Affecting Instruction

- Information (what you teach)
- Pedagogy (how you teach)
- Class resources
- Class policy
- Student characteristics (who you teach)
- Staff characteristics (who teaches)

This talk investigates the information presented in an introductory physics course.

STRATEGY

- We would like to measure the active information flow in a physics class. To do this, a catalog of the fundamental (indivisible) reasoning steps presented in some form by the class is required.
- The text of the solutions to problems used in 20 semesters of a second-semester university physics class was examined and subdivided into indivisible steps, steps that could no longer be subdivided and retain meaning.
- We call these indivisible steps *Basic Steps*.
- Once identified, the set of basic steps was collected into sets representing similar reasoning. The groups will be called *Processes*.

Basic Step Decomposition

- After some experimentation a *Basic Step* identification protocol was developed that allowed sufficiently reproducible decomposition of solutions.
- The protocol was tested by three researchers on 30 problems and solutions drawn from three popular textbook. The decomposition protocol was applied by each of the three researchers and yielded a total of 159, 179, and 156 Basic Steps for an average of 165 Basic Steps.
- The overall decomposition error rate is then 100%·(179-156)/165=14% for the largest disagreement or 100%·(179-165)/165=8% for the average disagreement.
- The decomposition was more reproducible for problems the researchers judged to be well written.

Process Identification

After all solutions used in the class were decomposed, groups of Basic Steps were identified and formed into groups called *processes*. The identification of processes and the assignment of basic steps to processes was further refined by requiring:

1. A general model of the reasoning represented by each basic step was created. Each basic step has to represent a specialization of the general model.
2. A title was given each process that would be a good title for a section of a solution containing only the basic step.
3. A representative problem was written for each processes such that the model was the only reasoning required for solution of the problem.

Example Process

Title: Net Charge is on Outer Surface of a Conductor

General Reasoning Model: The charge on a solid conductor is confined to the outer surface. For a hollow conductor, if there is no charge inside the cavity of the conductor, the net charge of the surface of the cavity is zero and all charge is on the outer surface.

Example Question

Example: Net Charge on Conductor

Problem: A hollow metal conductor has inner radius R and outer radius $2R$. A charge Q is placed on the conductor. How much of this charge is on the inner surface of the conductor? There is no other net charge near the system.

Select One of the Following:

(a) 0 (b) Q (c) $-Q$ (d) $Q/2$ (e) $Q/4$

Solution

The charge on a solid conductor is confined to the outer surface; if there is no charge inside the cavity, the net charge of the surface of the cavity is zero.

The fundamental test that two processes are different is whether the two example questions would yield different results for some population of students.

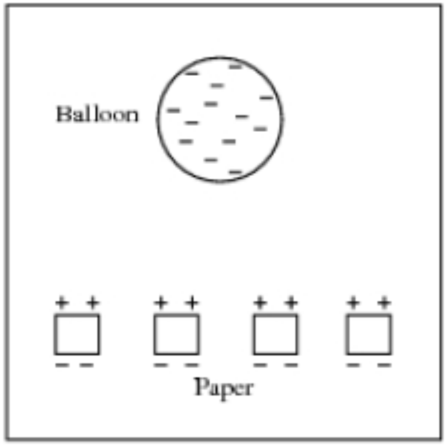
Example Problem

Example:Picking Up Paper with a Balloon

Problem: After rubbing a balloon in your hair, you can use it to lift small pieces of paper off a table. Explain.

Solution

When I rub a balloon in my hair, charge is transferred to/from the balloon from/to my hair and it acquires a net charge. The net charge on the balloon causes the charges in the atoms of the insulating paper pieces to polarize slightly leaving (assuming a negatively charged balloon) some excess negative charge farther from the balloon and some excess positive charge nearer to–as shown to the right. The electric force falls off with distance so that the positive charges nearer the balloon feel a larger attractive force than the repulsive force felt by the negative charges on the paper farther from the balloon, giving a net attractive force between the balloon and the pieces of paper.



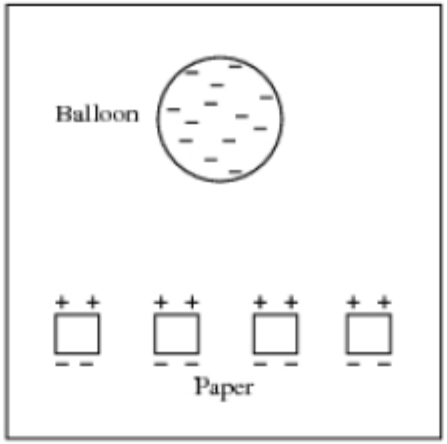
Example:Picking Up Paper with a Balloon

Problem: After rubbing a balloon in your hair, you can use it to lift small pieces of paper off a table. Explain.

Solution

(Composite) Attraction of Charged Object to Uncharged Object

- **Charging By Rubbing or Friction:** When I rub a balloon in my hair, charge is transferred to/from the balloon from/to my hair and it acquires a net charge.
- **Charged Object Causes Charge Separation or Polarization in An Uncharged Object:** The net charge on the balloon causes the charges in the atoms of the insulating paper pieces to polarize slightly leaving (assuming a negatively charged balloon) some excess negative charge farther from the balloon and some excess positive charge nearer to–as shown to the right.
- **Electric Force Falls Off with Increasing Distance:** The electric force falls off with distance so that the positive charges nearer the balloon feel a larger attractive force than the repulsive force felt by the negative charges on the paper farther from the balloon,
- **Net Force of Uncharged Object on Charged Object is Attractive:** giving a net attractive force between the balloon and the pieces of paper.



Statistics

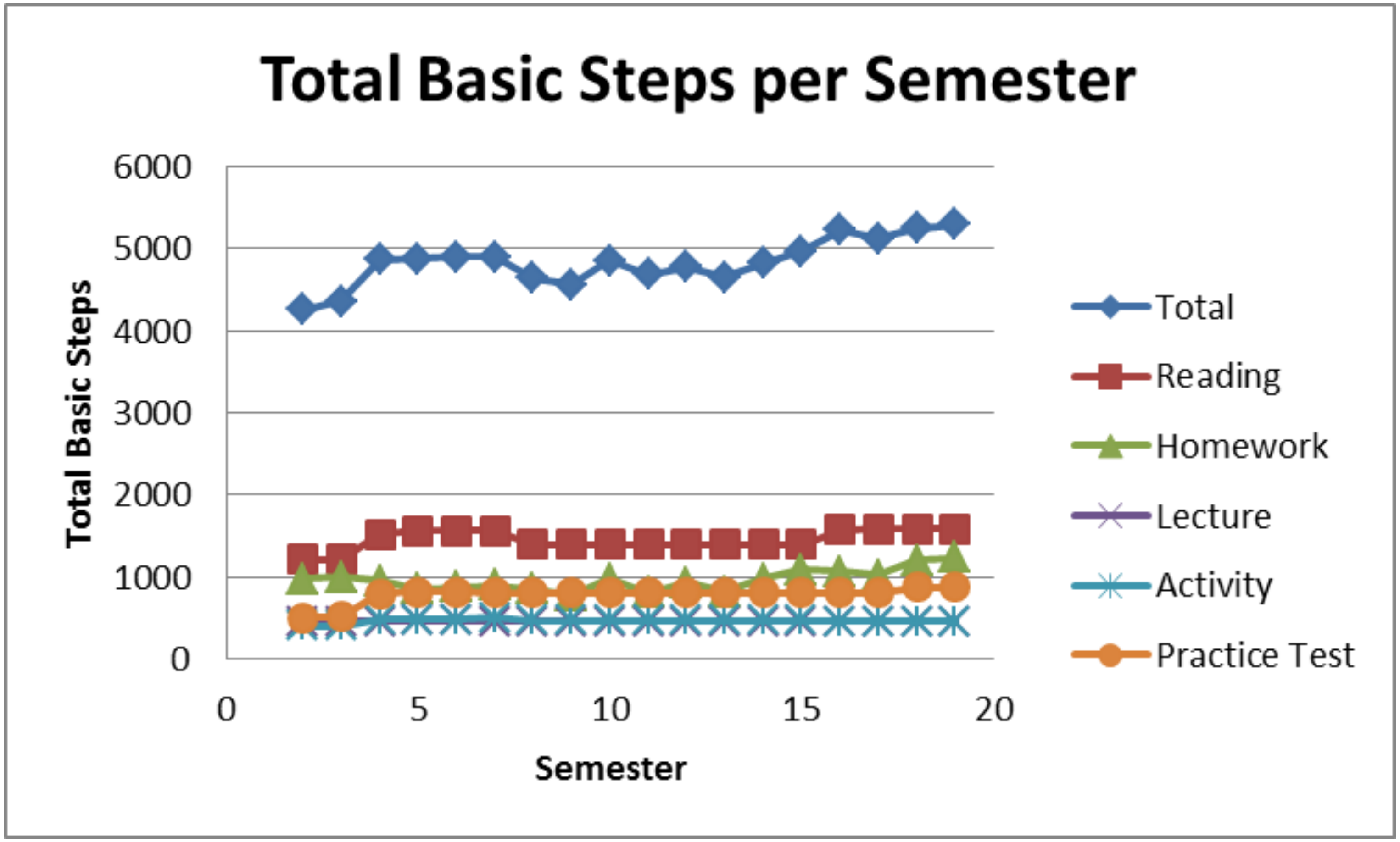
The process catalog and basic step decomposition allow one to study a physics class or physics materials using some new statistics.

- Basic Step Count – The total number of reasoning steps presented in the object.
- Process Count – The total number of independent reasoning steps in the object.
- Complexity – The basic step count per problem – How many reasoning steps are required to solve an average problem.
- Diversity – The process count per problem – How many independent reasoning steps are required to solve the average problem.
- Repetition – How often is a basic step representing a particular process repeated each semester.

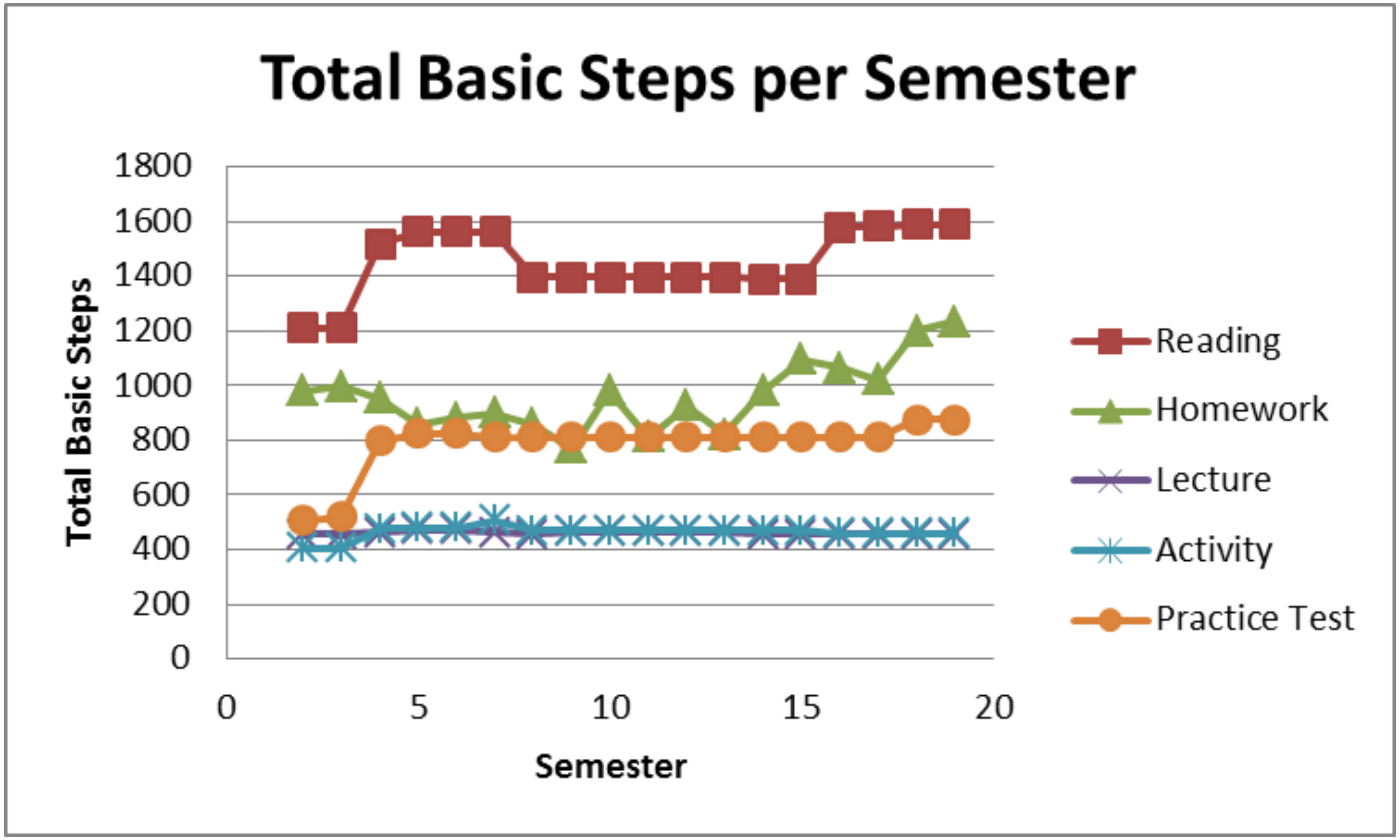
University Physics II (UPII)

- Second-semester introductory calculus-based electricity and magnetism class taken by scientists and engineers at the University of Arkansas.
- Initially developed under NSF CCD grant; used as a model for Arkansas' PhysTEC courses.
- One of the driving forces behind the dramatic growth in undergraduate physics majors.
- Two one-hour traditional lectures and two two-hour hands-on laboratories each week.
- Conceptual learning measured using the Conceptual Survey of Electricity and Magnetism (CSEM).

Basic Steps

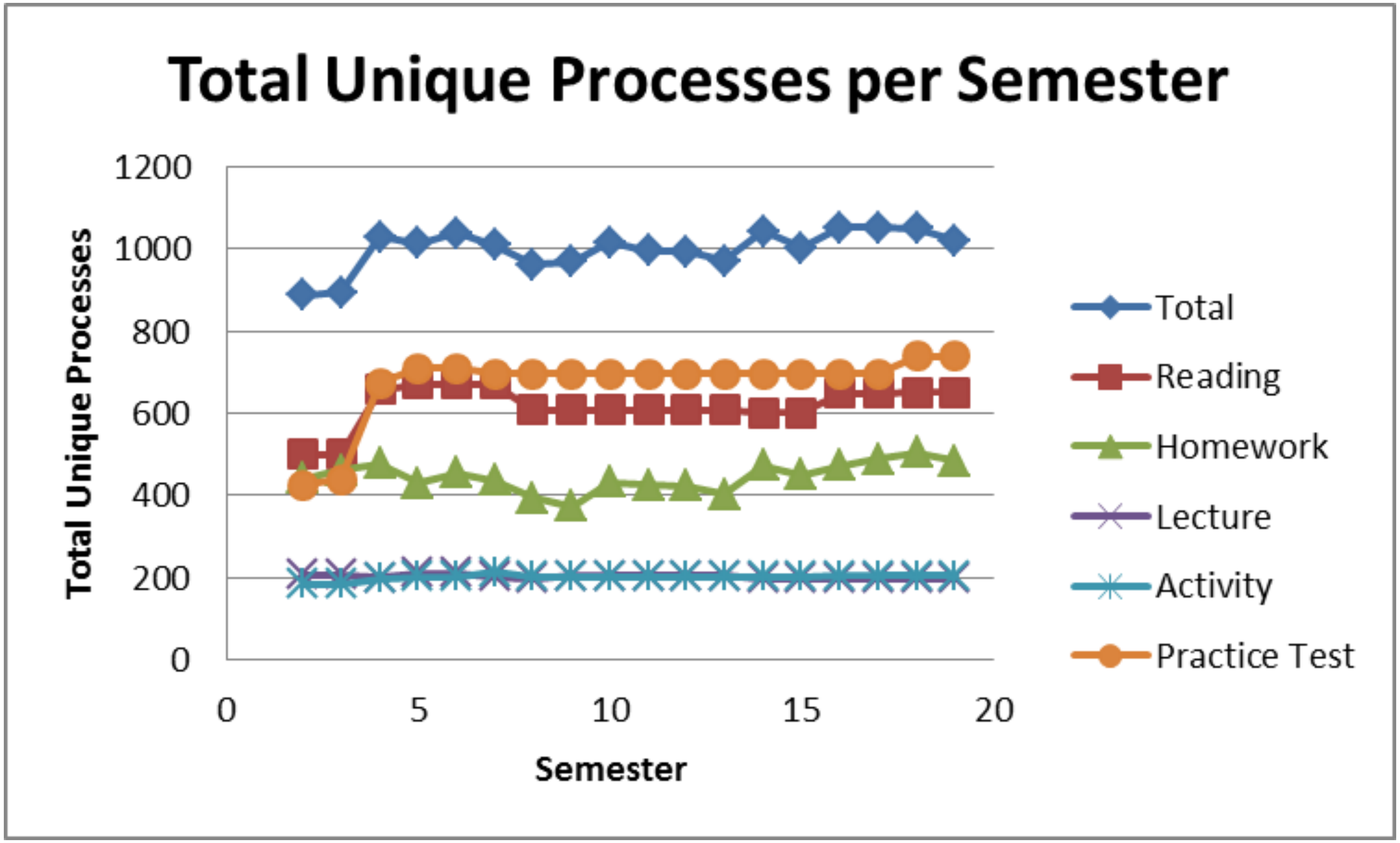

Total Basic Steps per Semester
6000
5000
4000
3000
2000
1000
0
Total Basic Steps
0
5
10
15
20
Semester
Total
Reading
Homework
Lecture
Activity
Practice Test

Basic Steps

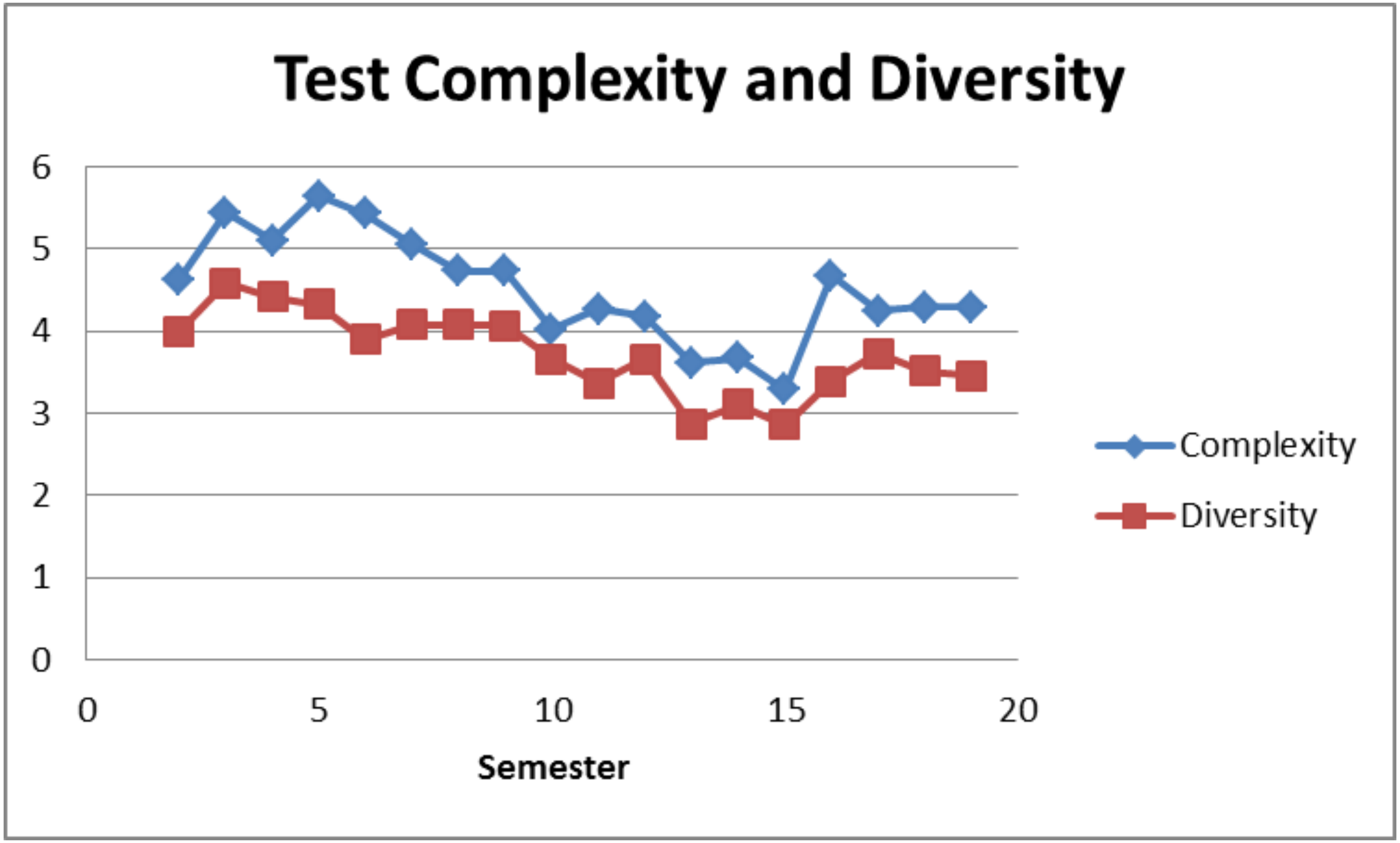


Total Basic Steps per Semester
1800
1600
1400
1200
1000
800
600
400
200
0
Total Basic Steps
0
5
10
15
20
Semester
Reading
Homework
Lecture
Activity
Practice Test

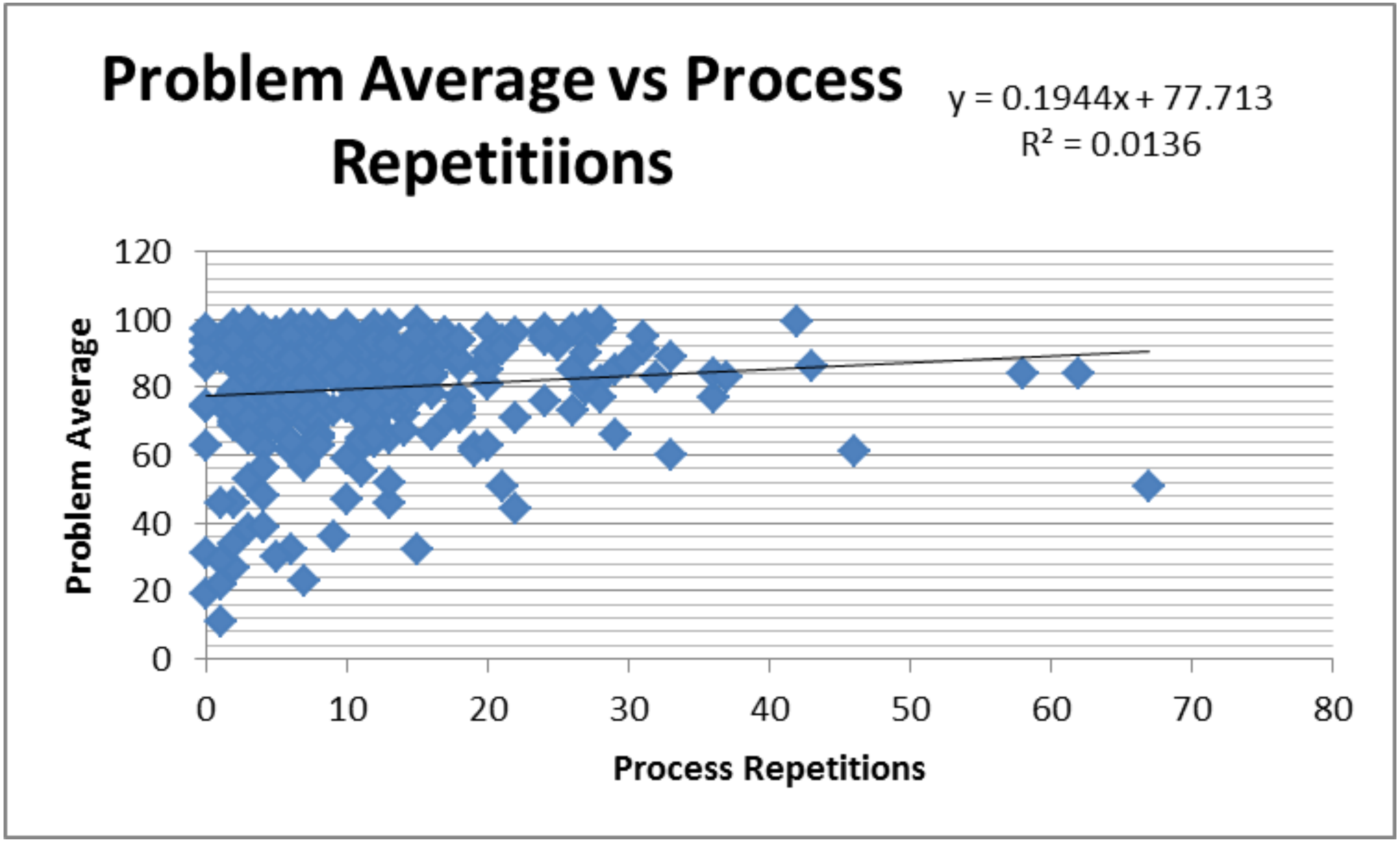
Unique Processes



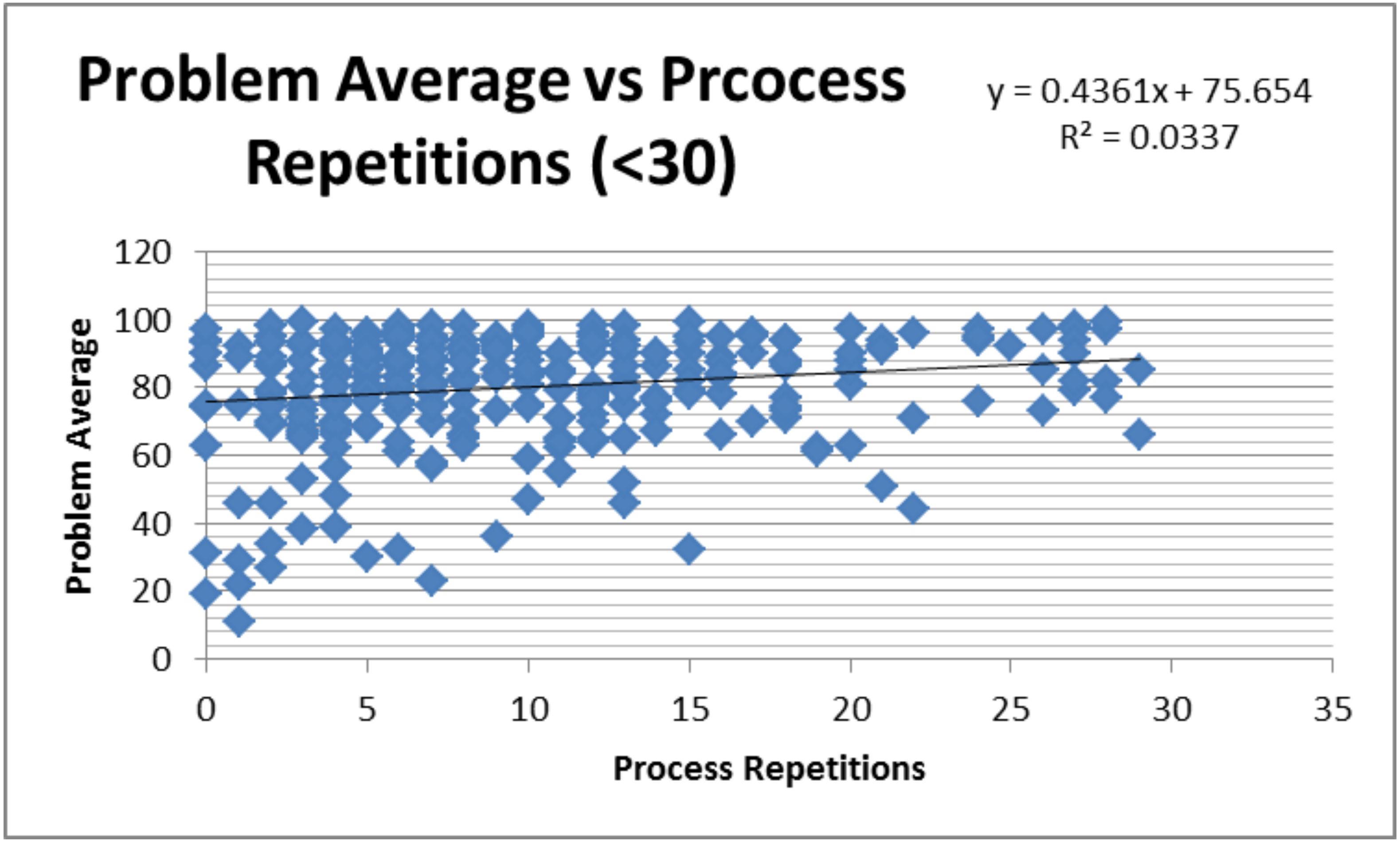
Complexity and Diversity



Effect of Repetition



Effect of Repetition



Effect on Test Problem Average if Process is Covered in Some Environment

Environment	Number of Problems with Included Process	Average if Included
All Problems	334	80
readings	178	84
activity	69	86
lecture	81	81
homework	205	83
practicetest	180	83
labquiz	43	82
Covered in Any Environment	270	82
Not Covered	64	69

Room for Improvement

The previous results do not take into account the number of times the process is repeated. Also not accounted for is the effect of diminishing returns where the 100th repetition does provide the same learning gains as the 1st repetition.

A better Model

$$\text{average} = \max - (\max - \min) \prod_{\text{environment}} e^{-\frac{R_i}{T_i}}$$

where min is the score before instruction, max is the score after an infinite amount of instruction, R_i is the number of times the process is repeated in environment i and T_i is a parameter that characterizes the efficacy of the environment; a larger T_i means the learning environment requires more repetitions for the same outcome.

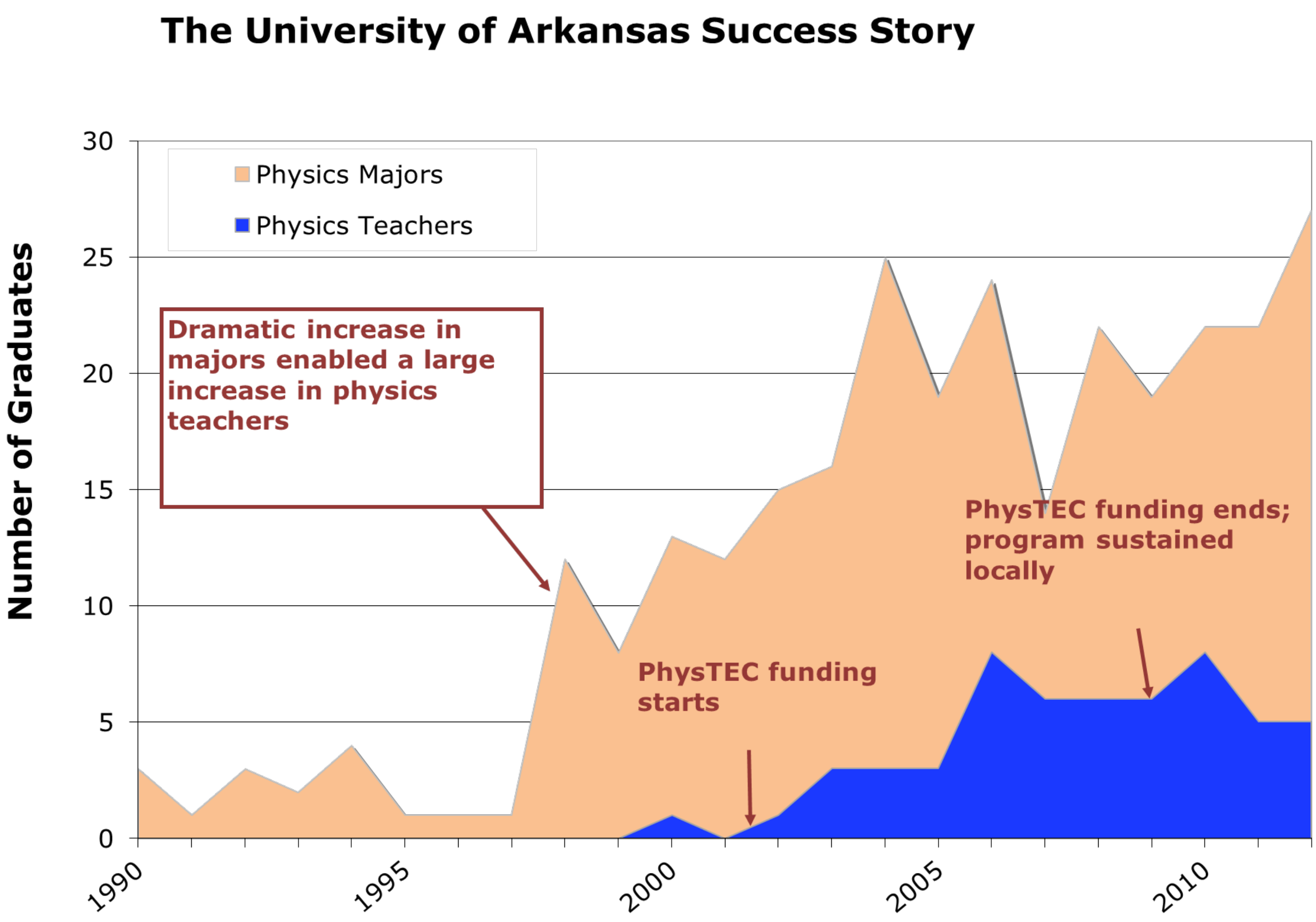
Non-Linear Fit

Parameter	Estimate
max	0.8634
min	0.6864
T-Reading	2.2843
T-Activity	0.4882
T-Homework	2.2256
T-Practice Test	1.0736
T-Lecture	76.8405

Conclusion

- Lecture was by far the most ineffective method of delivering information to students.
- The Activities which contain the inquiry-based learning experiences were the most effective means to produce increases in test performance.
- Homework and Reading were equally effective.

Results?



The University of Arkansas Success Story
Number of Graduates
30
25
20
15
10
5
0
1990
1995
2000
2005
2010
Physics Majors
Physics Teachers
Dramatic increase in majors enabled a large increase in physics teachers
PhysTEC funding starts
PhysTEC funding ends; program sustained locally

Of course, UPII wasn't the only change we made!

- The new class opened up a dialog with the engineering faculty.
- Our New BS Program-Multiple Tracks for Multiple Career Paths
- Track Record of Graduates
- Exceptional mentoring and advising

Contact Us

We can be reached by Googling, “Arkansas PhysTEC”.

Faculty Directors: John and Gay Stewart

Collaborators:

Masters Students – Jessica Clanton, Richard Campbell, John Wong, and Jennifer Campbell

Honors Students – Shawn Ballard and Christine Audo

Experimental Class Format:

- Students required to read material and attempt homework before class
- Large number of experiments, activities and demonstrations
- Lecture kept to a minimum, met three times/ week in lab, 2-80min, 1-110 min
- One instructor, one TA in each class
- Interactive discussion strongly encouraged
  - Now…

Calculus-based class format:

- Students required to read material and attempt homework before class, daily quizzes make sure.
- Large number of experiments, activities and demonstrations
- Lecture kept to a minimum, closely tied to activities. Lecture/lab twice a week
- Interactive discussion strongly encouraged

THE EFFECT OF MISSED ASSIGNMENTS ON PERFORMANCE

Missing	*Correlation with*	
	Test Average♦ *(77%)*	*Hake Gain*‡ *(51%)*
Homework	$R^2=0.118$	$R^2=0.033^*$
Lab	$R^2=0.115$	$R^2=0.038^*$
Lecture	$R^2=0.104$	$R^2=0.068$
Combined	$R^2=0.151$	$R^2=0.076$

♦*N=364 students* ‡*N=313 students*

*Significant at the $p = 0.05$ level

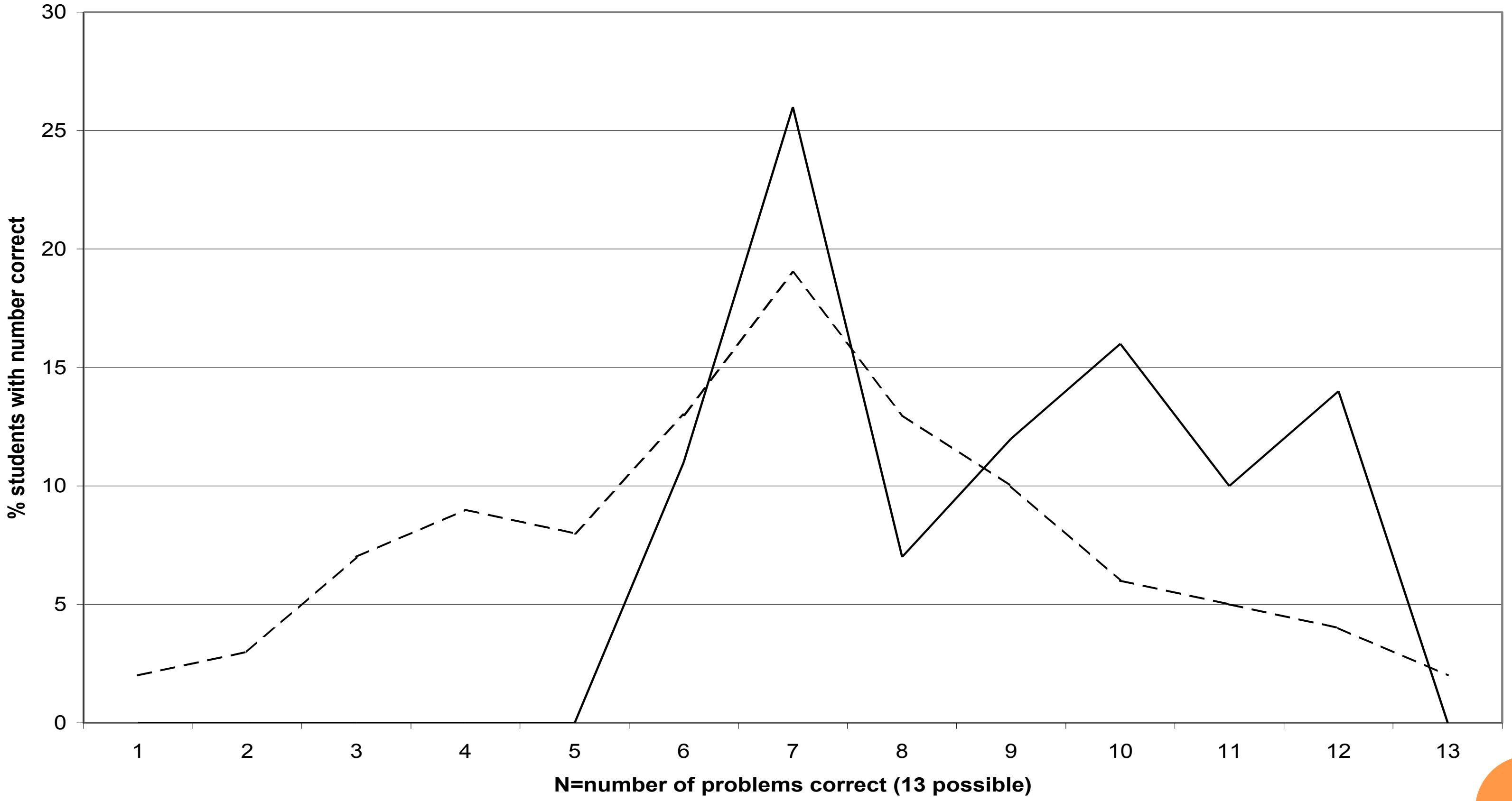
Remainder significant at the $p = 0.0001$ level

Phys. Rev. ST: PER 8, 010114 (2012) [14 pages] Using time-on-task measurements to understand student performance in a physics class: A four-year study

STUDENT PERFORMANCE MEASURES THE FACULTY RESPECT:

- Did better than previous UA classes on both problems and conceptual questions
  - Scored 10-18% higher on multiple choice conceptual questions given in previous version of course, even when not directly covered.
  - Compare results on a standard problem- solving test from a previous year

Results from a standard "problem-solving" exam



Popularity of Activities Using Everyday Materials – special impact on teachers

- Of 17 in-class activities, 2 experiments and 14 demonstrations, when asked for their favorite, NO off-the-shelf E&M was chosen!
- Three top activities and experiments:
  - Motor/generator construction 40%
  - Speaker/microphone const. 23%
  - Earth's Magnetic Field 8%
- Favorite Demos
  - rail gun
  - Leyden jar

Student Perceptions

In response to the question "What would you do to make the class better?"

- 77% of students said they liked the new format and learned more from it,
- 18% liked the format but wanted more lecture,
- 5% of the students preferred the old format.
- Faculty received higher teacher ratings than in old format, even in less effective sections.

Design Criteria for Activities

- No Cookbook!

  The activities were rewritten so that the directions did not encourage students to follow them like a cookbook.

- Flash

  Memorable, makes a strong impression, tactile construction

- Long-term reproducibility

  Memorable enough, simple enough and inexpensive enough that they could be expected to repeat it 10 years from now, and because of the flash would want to! We recruit younger siblings.

- Dependability

Dependability is a problem!

"If it is green it is biology, if it stinks it is chemistry, if it doesn't work it is physics.
--middle school science teacher

Transportability

The three-instructor class format provided an excellent laboratory for how easily material constructed by one person can be transferred to another.

- Best of Circumstances:
  - Developer immediately available
  - All activities done in same setting after developer has taught the first section to catch any bugs
  - Supportive, involved faculty
- Results:
  - Massive differences in student perceptions and performance depending on primary instructor

Analysis of Differences:

- Problems:
  - Instructor attitude toward materials
  - Integration of in-class activities in with reading, homework and lecture
  - Instructor comfort with unstructured environment

Solutions:

- Build the questions you want the students to ask into the activities.
- Target the activities to specific goals.
- Tie activities to lecture: have students derive relationships in labs.
- Tie activities to homework: have students make measurements of quantities calculated in homework.

Once you get them

- Upper division courses get better…a lot of excited, well-prepared students
- They get involved in research…many of our undergrads are published
- The whole place just "feels" better
- Other faculty get involved!

Teaching Assistants

- TA's come in with strong attitudes on teaching:

  "Physics is supposed to be hard."
- With adequate TA preparation, the setting becomes an opportunity for good student interaction:
  "I don't know if I can still teach it that way!"
- Higher attendance at office hours and student approval ratings carried over to teaching a traditional lab.

To make reform work…

When we embarked upon the first NSF-CCD project, it became clear that the first and greatest need for educational reform to be embraced and sustained was for our future faculty to be prepared to be as professional about their roles as educators as their roles as researchers.

Teaching

Outreach

(recruiting the next generation-long term solution)

Teaching Apprenticeships

- Some undergraduates wanted good preparation before going off to graduate school
- Even engineering counts it as a technical elective- "you really know it, on a whole different level, when you can teach it"
- Great experience for future teachers, mentored in a reformed course. College of Education counts it as a student teaching experience.

Teaching Apprenticeships: some details

Deep familiarity with content, then:

- Preparation for classroom presentations
- Testing and grading
- Addressing student alternative conceptions
- Effective use of classroom demonstrations
- Interactive classroom techniques

Course Structure and Grading Policy

- Four hours a week in an apprentice teacher role, 1 unplanned absence = 1/2 of a letter grade
- Week 1: 4 meetings on topics essential to classroom experience, 10-25 pages of reading per day.