Opening a faculty dialog on transforming chemistry instruction

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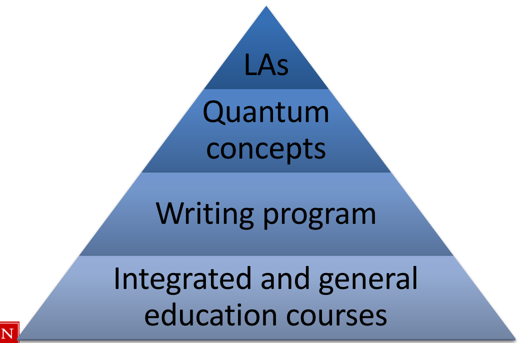
Research Presentation – 1/30/2017
California State University Northridge

"Education is ***improving the lives of others*** and for leaving your ***community*** and world better than you found it."

-- Marian Wright Edelman



Part 1: Department-level

Transforming how (undergraduate) students think about writing in chemistry

"When all the students in the class obtain the same results to an activity, and there is only one scientifically acceptable outcome, the learners quickly realize that they must somehow generate, copy, or paraphrase the knowledge claim that is desired by the teacher. Thus, writing in this genre can easily become a rote activity, especially when the students have no opportunity to determine the appropriate methods for the investigation, ways to display the data, or new meanings for the data."

--Carolyn Keys. "Revitalizing Instruction in Scientific Genres: Connecting Knowledge Production with Writing to Learn in Science." *Science Education* 83 (1999).

CH111/CH112 Course Structure

Honors-level first-year chemistry course sequence with analytical chemistry lab
- Lecture (3 hrs), discussion (1 hr), pre-lab lecture (1 hr), and lab (4 hrs)
- Students take first-year writing concurrent with CH111

Types of assignments in lab portion of the course
- Post-lab questions (5 in fall, 3 in spring)
- Scholarly papers (5 in fall, 3 in spring)
- Capstone project (team-based research project in spring semester)

Division of instructional labor
- Course Instructor: Full-time lecturer / instructor; Hiring, training, and content creation
- Teaching Assistants: Graduate students in Chemistry; Grade papers on technical merits
- Writing Assistants: Graduate students in science fields (CH and others); Confer with students; comment on, grade writing

Timeline of Development and Implementation

Year 0 – Baseline
- Formal lab reports for every other lab (5 per semester, including 1st)
- Students receive a five-page "Basic Guide to Writing Lab Reports"
- No explicit, in-class writing instruction
- ~**20** hours of writing, >**50** pages per student/semester

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Timeline of Development and Implementation

Year 0 – Baseline
- ~**20** hours of writing, >**50** pages per student/semester

Year 1 – No logic / Writing instruction as an afterthought
- In-class instruction and optional writing tutoring
- No change in work, No change in outcomes
- Changes for next year: handouts and schedule for revisions

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Timeline of Development and Implementation

Year 0 – Baseline
- ~**20** hours of writing, >**50** pages per student/semester

Year 1 – No logic / Writing instruction as an afterthought
- In-class instruction and optional writing tutoring

Year 2 – Rhetorical logic of Scientific Communication
- Writing assistant role is cemented. Handouts are provided.
- Instruction follows the sequence of the rhetoric discourse.
- Significant improvement in quality of form, voice of papers
- Student anxiety increases, but writing remains juvenile
- Changes for next year: direct instruction of craft skills (figures, literature, outlines)

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Timeline of Development and Implementation

Year 0 – Baseline
- ~**20** hours of writing, >**50** pages per student/semester

Year 1 – No logic / Writing instruction as an afterthought
- In-class instruction and optional writing tutoring

Year 2 – Rhetorical logic of Scientific Communication
- Writing assistant role is cemented. Handouts are provided.
- Instruction follows the sequence of the rhetoric discourse.

Year 3 – Craft logic of Scientific Practice and Communication
- Craft skills taught first: exhibits (figures/tables), outlines, and literature
- Remaining instruction follows the sequence of the rhetoric discourse
- Polished, shorter papers (looks polished); still juvenile (no change in critical thinking)
- Student anxiety maximum, despite decrease in page production (35 pgs)
- Changes for next year: rethink sequence of assignments, focus on "meaning"

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Timeline of Development and Implementation

Year 0 – Baseline
- ~**20** hours of writing, >**50** pages per student/semester

Year 1 – No logic / Writing instruction as an afterthought
- In-class instruction and optional writing tutoring

Year 2 – Rhetorical logic of Scientific Communication
- Writing assistant role is cemented. Handouts are provided.
- Instruction follows the sequence of the rhetoric discourse.

Year 3 – Craft logic of Scientific Practice and Communication
- Craft skills then IMRD sequence
- Polished, shorter papers (looks polished); still juvenile (no change in critical thinking)

Year 4 – Less-is-more, Just-in-time logics added (Multiple logics)
- New sequence: craft skills, RDC papers, Methods/Introduction when relevant
- Less juvenile (no irrelevant Introductions and Methods sections)
- Lowest anxiety level since baseline (decrease in time and pages: 15 hrs, 15 pgs)

➢ Overall argument in paper remains superficial and novice.
➢ Then, 2013 CCCC…

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Year 5 – Nature of science logic / Engaging with exhibits and sources as practitioners of science

- Continued with successful logics: craft logic, less is more, and just-in-time
- Scientists generate ***exhibits*** – science writing starts by engaging with them: What exhibits are useful? not useful? (Figures, tables)
- Results are not just the data/exhibits. Results must engage in an ***argument*** with the field. Are their results affirming? Disputing? Refining?
- Refocused on the use of the literature as practitioners of science
- Understanding and presenting results requires an understanding of the ***theory*** and ***methods*** of the chemistry
- This is how ***expert scientists*** think about their results – our job is to get these students to start seeing their work in the same way.
- Voice, tenses, conventions, and structure are a ***veneer*** on top of the science.

- Incredible result: student effort remains ~**20** hours
  output is concise (~**7** pgs final product, ~**20** pgs workflow)

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Developed Rubrics for Scholarly, Research-Based Writing

	(A) Critical thinking / Interpretation of results	(B) Research and Engagement
Novice (High School)	1) Raw data as "results"	1) Didn't understand the result
	2) Makes observation of data in prose	2) Used pre-lab, lab manual, lecture, and course text for background
	3) Any discussion of "correctness" of result (accuracy, etc…)	3) Looked for *any* result *anywhere* to match results
	4) Appropriate discussion of "correctness"	4) Found a reputable / primary source to match the results
Near-expert (Graduate Students)	5) Science behind the result is discussed (limits, applicability,…)	5) Surveyed the literature for appropriate source to contrast
	6) Links results to motivation and impacts	6) Researched to determine the reason for their result, not just a source that is similar
	7) True motivation, true impacts	

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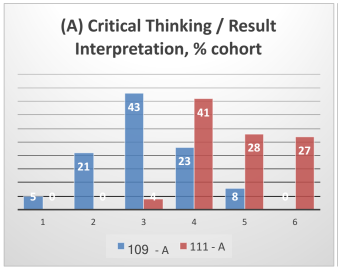
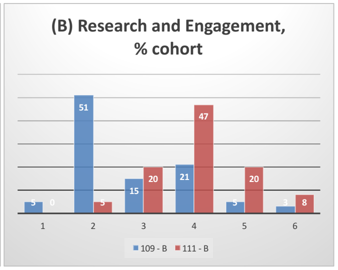
Major gains in rubric metrics

Cohort	(A) Critical thinking / Result Interpretation	(B) Research and Engagement
Incoming students	~ 2	~ 2
Post "Year 0" CH111	3 – 4	3
Post "Year 5" CH111	4.8 ± 0.9	4.0 ± 1.0
Post CH109 students	3.0 ± 1.0	2.8 ± 1.2





Significant shifts in students attitudes (LIKERT scale data: 1 = Strongly Disagree, 5 = Strongly Agree)

Attitude	Before CH111	After CH112
Understand importance of writing in science	3.0 ± 1.0	4.7 ± 0.5
Scientists write in complicated/obtuse way	4.0 ± 0.8	1.9 ± 0.8
Feel prepared to write science papers	2.1 ± 0.9	4.4 ± 0.5

Student feelings about program components

Question about program	Response
Despite being more work, do it again?	4.6 ± 0.7
Necessity of program documents	4.3 ± 0.7
Usefulness of writing assistant	4.3 ± 0.9

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Major Conclusions – What we believe

- No assumptions about "craft" abilities. ***Teach everything***.
- Do *not* waste time on ill-conceived work. ***Less is more, Just-in-time***
- Focus on ***nature of science*** and crafting ***strong arguments*** leads to writing in the sciences with maturity
- Writing must be ***preceded*** by instruction in ***critical thinking***
- Students must ***engage with sources*** only as part of the process of doing scientific inquiry.
- Structure and conventions should taught ***in context*** of preparating a strong ***argument***

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Major Outcomes in CH111/112

- ***Content Knowledge Gains*** achieved without explicit goals stated
- Major ***shift in attitudes*** about the nature of science and writing
- Increased rate of funded undergraduate research proposals
- ***ESL students thrive*** as well as native speakers in this program.

Major Outcomes beyond the courses

- Students in ***upper-division*** courses use these materials
- Transformed ***graduate student*** culture (***and writing***) in the department.
- BUCWP writing model is being adopted in ***other departments*** at BU
- Writing materials have been ***adopted by peers*** at ***other institutions*** (Providence College, The Hockaday School, Regis College)

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Part 2: Course-level

Transforming how we engage students outside of the class and how we teach quantum concepts at the introductory level

"Getting students engaged and guiding their thinking in the classroom is **just the beginning** of true learning, however**.** This classroom experience has to be followed up with extended "**effortful study**," where the student spends considerably more time than is possible in the classroom **developing expert-like thinking and skills.**"

-- Carl Wieman

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Students struggle to prepare for class

Students are unsuccessful at preparing for class because

- they "read", but like it's a story
- "do problems" if we make them, don't connect to course material
- poor metacognitive sense - gauge for what is expected of them
- afraid to seek help – they are afraid to make mistakes
- have (major) deficiencies in their pre-requisite skills

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Students struggle to prepare for class

Students are most able to succeed when

- they prepare for class
- they are given context for their work
- they are given explicit expectations (low or high)
- they are supported and given guidance
- they are challenged to find answers for themselves

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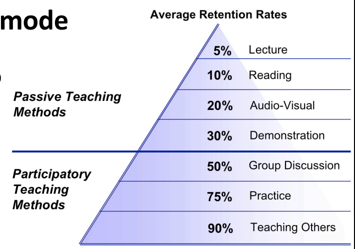
Our students crave the passive mode

- Many students are accustomed to working hard, but ineffectively
  - Highlighter
  - Flash cards
  - Rewriting notes
  - Looking at problem solutions



*Adapted from National Training Laboratories. Bethel, Maine

- They interpret a lack of specific assigned work as an invitation to do little or no active work
- Courses that penalize group success de-incentivize many important forms of active learning

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Why not completely "flip" the classroom?

What's good about flipping:

- Get students "working" outside of class (that's what we want!)
- Give support to students during problem-solving in-class

Why completely flipped classrooms aren't the solution:

- Students do not get as excited for the material (infectious instructors are necessary here)
- Students often miss the contextual parts (self-motivation)
- Students tend to learn material as "isolated fact nuggets" rather than developing understanding
- Overburdening students ("what is a credit?")

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A note about overburdening students

- Remediation of pre-requisite skills ***causes a large burden*** on students in introductory courses
- ***Increasing inhomogeneity*** in incoming classes requires thoughtful attention and planning
- Out-of-class "workshops***" did not remedy*** the situation

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Goals for a hybrid model

- Engage students in ***active preparation*** for class meetings
- Increase student ***excitement*** about subject material by providing ***context*** to the material
- Free-up lecture time for preconceptions, misconceptions, deeper investigations, and other ***active learning modes*** (clickers, group work)

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Hybrid model

1. Prime students in class:
   - Give context and guidance
   - Set explicit expectations for learning outcomes (make sure to …)
2. Students explore at home
   - Guided activities
   - Online tutoring with ALEKS
   - Pair with Piazza or discussion board for great results
3. Quiz students on their learning from explorations at home
4. Develop and extend during next class meeting
   - Use class time to address confusion
   - Extended concepts and discuss applications

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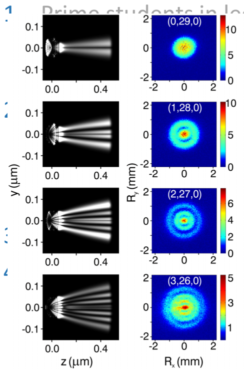
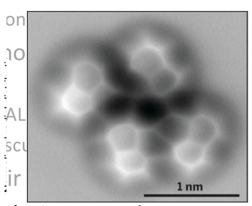
Hybrid model

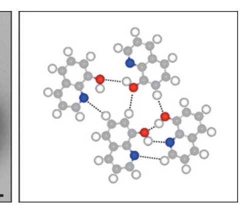
Prime students in lecture:



dance

on





during next class

ress confusion

nd discuss applications

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Different goals for activities

- Remediation of pre-requisite skills (ALEKS)
- Skill / confidence building (Textbook, blended HW solution)
- Investigating basic concepts (JUST Activities)
- Exploring relationships and making connections (JUST Activities)

Different types of activities

- Answer questions by doing research
- Sketching, drawing, making analogies
- Play with widget (Mathematica CDF) to learn relationships
- Watch a video to get answers
- Engage in a student debate in groups

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Teaching Quantum Concepts using JUST activities

- Summer CH101 course (< 50 students; small by BU standards)
- Workbook of 20 activities used to help the students work between classes to tackle the quantum aspects
- Pre- and post-instruction concept surveys given to the class
- Content Knowledge Gains and student attitudes were assessed after the course

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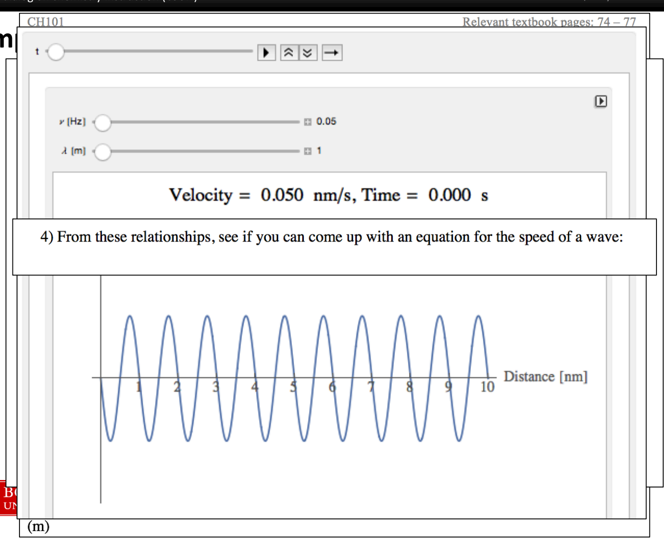
Sam



Results of JUST activities on quantum concept instruction

Engagement leads to content gains

- Positive correlation between completion of activities and
  - Content Knowledge Gains (pre- / post-surveys)
  - Course grade
- Students with lowest content gains showed least amount of out-of-class engagement with the activities (not accuracy, completion)
- Students with largest content gains learned to represent their understanding with ***multiple representations***

… but we saw something else really interesting …

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Part 3: College-level

Transforming how chemistry is taught to students outside of Chemistry departments

"Interdisciplinary/cross-curricular teaching provides a meaningful way in which students can use knowledge learned in one context as a knowledge base in other contexts"

-- Collins, Brown, and Newman

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Integrated Science Experience Courses

A two-course sequence:

- Freshmen year, 2nd semester (ISE1 – Gen Chem)
- Sophomore year, 1st semester (ISE2 – Organic)

Major goals and outcomes:

- Show how Chemistry is foundational in neuroscience and biology
- Reach and excite students who are traditionally quantitative-weak
- Retain existing skills; overlapping skills are extended
- Implement a research-type component into the labs
- No net change in contact hours – reorganization
- Extend concepts to attract more CH majors

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Integrated Science Experience Courses

Selected topics in ISE 1 – General Chemistry:

- pH and buffers
- Spectroscopy, calibration curves, and electronic structure
- Reaction kinetics and mechanism
- Biosensors

Selected topics in ISE 2 – Organic Chemistry:

- Extractions, Recrystallizations
- Chromatography (TLC, Flash)
- Synthesis
- NMR/UPLC-MS

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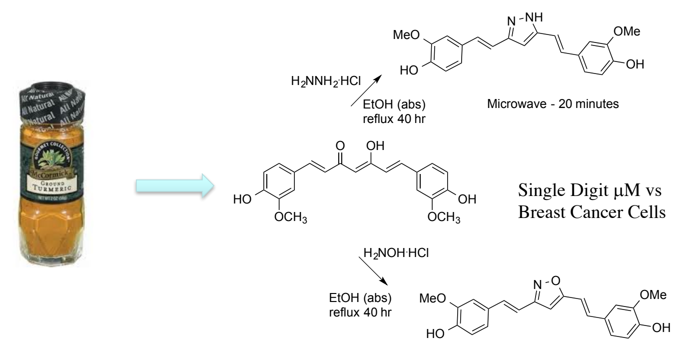
ISE2 – Organic – Curcumin Project



Amolins, A. W.; Peterson, L. B.; Blagg, B. S. J. *Bioorg. Med. Chem.* **2009**, *17*, 360-367

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Core Natural Sciences II – "Reality"

A general education course dealing in modern scientific concepts:

- Special relativity
- Atomic structure and theory
- Spectroscopy, IR, and global temperature change
- Quantum mechanics
- Neurobiology
- Perception and memory
- Virtual and artificial reality

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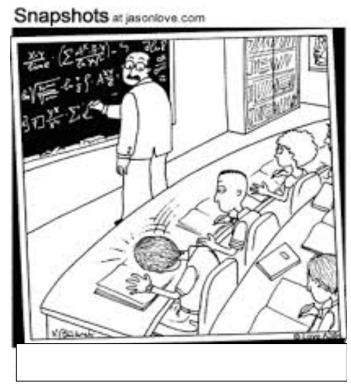
Old classrooms versus new classrooms



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Learning Assistant (LA) Program

Piloted in CH101 / CH102 (General Chemistry for non-majors)

- Non-majors, pre-meds, health sciences, biomedical engineering
- Students entering CH101 have ***very inhomogeneous*** level of preparation and ***are less likely to seek assistance out-of-class***
- Want to ***create active learners*** and improve ***metacognitive sense***

Who are the learning assistants?

- Previous students who ***know what it takes to succeed***
- Intelligent, sociable, enthusiastic, proactive, hard-working
- ***Approachable*** and willing to help peers.
- Equipped with a ***strong foundation in pedagogy*** and teaching practice (STEM Education Techniques and Skills)

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Learning Assistant (LA) Progra

LA Responsibilities Include:

- Facilitate student group work in
- Hold weekly office hours / ***tutor***
- Make mini subject presentation:
- Play a large role in our ***course cu***

Grade	% Students
D	3.7 ± 1.6
F	1.5 ± 0.7
W	9.1 ± 1.2
D/F/W	14.3% ± 2.3%

- Four levels of impact:
- The students: unique perspective, peer-plus mentors
- The course: near-instant feedback, invested partners
- The LA: strengthen concepts, boost confidence, great experience
- Beyond: work with other departments, alternative career paths

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Faculty dialog on chemistry instruction (CSUN)

Acknowledgments

BU Chemistry Writing Program

- Joseph Bizup
- Rebecca Kinraide
- Seann Mulcahy
- All of the writing assistants

Activities Project

- Emily Allen
- Peter Garik
- Dan Dill
- Neil Jain*
- Sammy Rubin*

Learning Assistant program

- Adam Moser, Nic Hammond
- Natalya Bassina
- Manher Jariwala (Physics)
- Kathryn Spilios (Biology)
- Morris Cohen*
- Brian Stankus*
- Andrew Klufas*

Integrated Courses

- Paul Lipton (Neuro)
- Kathyrn Spilos (Biology)
- Wayne Snyder (CS)
- Ami Katz (Physics)

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