Scaffolded Explicit Revision as a Practical Framework to Promote Effective Student Effort (in Content-Rich Courses)

Presented at the 2013 Celebration of Teaching & Learning
Hunter Moseley, PhD
Assistant Professor
Department of Chemistry, University of Louisville
hunter.moseley@louisville.edu

NB “When printing or referencing this information, you must include the full citation as ‘Reprinted with permission from Hunter Moseley (2013)”

SCAFFOLDED EXPLICIT REVISION AS A PRACTICAL FRAMEWORK TO PROMOTE EFFECTIVE STUDENT EFFORT (IN CONTENT-RICH COURSES)

An Example of Evidence-Based Learning

Hunter Moseley, Ph.D.
Department of Chemistry, University of Louisville
OVERVIEW

- Background (Key Concepts)
- CHEM 445 – Survey of Biochemistry
- Statistical Analysis and Results
- Caveats and Discussion
- Conclusions

KEY CONCEPTS

- Bloom’s Taxonomy of Educational Objectives
- Metacognition
- Self-regulated Learning
- Scaffolding
- Formative Assessment
- Explicit Revision
BLOOM’S TAXONOMY
Classification of Educational Objectives

- Remembering
- Understanding
- Applying
- Analyzing
- Evaluating
- Creating

Common Misconceptions
- Creating vs Applying
  - Creating new ideas.
  - Applying to different problems.
- Evaluating vs Analyzing
  - Evaluation – measure against a standard or compare against others.
  - Analysis – separate a whole into its constituent parts.

Why was “creating” switched for “evaluating” at the top of the taxonomy?

METACOGNITION & SELF-REGULATED LEARNING

- Metacognition – thinking about one’s thinking (in order to improve one’s thinking).
- Self-regulated learning – taking control and improving one’s own learning using metacognition, planning, and a desire to learn.

http://en.wikipedia.org/wiki/Metacognition
SCAFFOLDING

Two Definitions:

- Any learning aid used to enable a level of learning that is beyond a student’s immediate grasp.
- A set of learning instruments used together to help students obtain multiple levels of learning.


FORMATIVE ASSESSMENT

  - “Feedback is information about the gap between the actual level and the reference level of a system parameter which is used to alter the gap in some way.”
  - Emphasizes two parts:
    - Perceive the gap.
    - Take action to close the gap.
  - “Formative assessment is concerned with how judgments about the quality of student responses (performances, pieces, or works) can be used to shape and improve the student’s competence by short-circuiting the randomness and inefficiency of trial-and-error learning.”
  - Emphasizes student self-assessment as a key form of feedback.
  - “Practice in a classroom is formative to the extent that evidence about student achievement is elicited, interpreted, and used by teachers, learners, or their peers, to make decisions about the next steps in instruction [i.e., any activity that is intended to create learning] that are likely to be better or better founded, than the decisions they would have taken in the absence of the evidence that was elicited.”
  - Emphasizes that teachers, students, or their peers are all possible decision-makers.
  - “The vagueness of the constitutive and operational definitions directly contributes to the weaknesses found in the related research and dearth of empirical evidence identifying best practices related to formative assessment.”
  - Criticizes the definition as too broad to be useful.
EXPLICIT REVISION

- Definition: the requirement to amend or alter performance after assessment for the purpose of improvement.
  - Emphasizes use and prior creation of feedback from teacher-, peer-, and/or self-assessment as a necessary part of a revision process.
  - By definition, explicit revision is a form of formative assessment.

EXPLICIT REVISION VS FORMATIVE ASSESSMENT

- Explicit revision focuses on the use of feedback, which naturally leads to the generation of feedback, but with a specific use in mind as an end-goal of its generation.
- This subtle but important difference on the “required” interpretation and use of feedback has several advantages over classic formative assessment:
  - Promotes strong metacognition and self-regulation where students do not just stop at the point of reflection on past performance, but act upon this reflection in revision.
  - Leads to a revision mentality that develops self-assessment and critical thinking skills.
- Explicit revision may have a broader impact across the classroom than classic formative assessment, which tends to help low achievers more than high achievers.
  - Open-ended revision can directly encourage high achievers to extend their efforts and stretch their limits.

EXPLICIT REVISION AS A PRACTICAL FRAMEWORK IN COURSE DESIGN

- Useful for designing assessments and other learning instruments that integrate:
  - formative self-, peer-, and teacher-assessment.
  - self-regulation.
  - metacognition.
  - subject-domain-specific skills.
- Amenable to scaffolding for:
  - Aiding students to reach a new level of learning by repeated revision.
  - Devising complementary explicit revision instruments that promote learning across multiple levels.

OVERVIEW

- Background (Key Concepts)
- CHEM 445 – Survey of Biochemistry
- Statistical Analysis and Results
- Caveats and Discussion
- Conclusions
CHEM 445
SURVEY OF BIOCHEMISTRY
S2011

- 14-week undergraduate biochemistry course offered in the UofL Department of Chemistry.
  - Class meets twice a week for 75 minute.
  - Squeezes 2 semesters of material into 1.

- Learning objectives are:
  i. Students understand biological processes and concepts from the chemical perspective.
  ii. Students effectively find, learn, and apply relevant biochemical knowledge.
  iii. Students critique biochemical information from a variety of sources including peer-reviewed journal articles and determine the information's reliability, significance, and applicability to specific problems.

- Serves primarily biology and chemistry majors preparing for professional or graduate school.
  - The learning objectives target base biochemical skill sets needed for these programs and industrial research.

INTEGRATION OF TEACHING-LEARNING METHODS

- Use of a critical thinking model.
- Semi-Socratic method in lecture.
- Active and collaborative learning assignments.
- Explicit promotion of metacognition.
- Repetitive retrieval of information and spacing.
- Scaffolded explicit revision across assessments.
USE OF THE PAUL-ELDER CRITICAL THINKING MODEL

- Students are given the “blue book”.
  - A concise reference on critical thinking as a process.
- Teaching instruments use capitalized terminology from the PE model.
  - Emphasizes the critical thinking aspects in the given assignment or lecture.
  - Provides a basis for modeling critical thinking within the subject domain.


SEMI-SOCRATIC METHOD IN LECTURE

- Socratic method
  - Posing/drawing a series of questions to lead students to discover knowledge by encouraging debate between opposing viewpoints.
  - Not practical in the lecture of a content-rich area like biochemistry.
- Semi-Socratic method
  - Uses well-timed questions in lecture to emphasize a particular point or lead to deeper understanding on a particular topic.
  - Creates pauses that allow reflection on the presented material.
  - Questions are integrated into the lecture overheads and provided to students to direct their reading of the textbook.
Lecture Notes for Peptide Bond and Peptides

III. Peptide Bond and Peptides

- Now, amino acids are linked together to form peptides and proteins.
- They are linked together by a carbon-nitrogen bond between their amino and carboxyl groups called a peptide bond.
  - The two molecules are condensed into one by the collective removal of a water molecule and in the process an amido or amide functional group, highlighted in yellow, is created.
  - NP. Thus, this reaction is called a condensation reaction.
  - Its reverse on the other hand is called hydrolysis, which simplifies to hydrolysis or destruction by water.
  - NP. Which direction occurs spontaneously?
  - NP. Hydrolysis occurs spontaneously.
  - But the half-life of a peptide bond is about 7 years, under typical intracellular conditions.
  - SO. Which means chemically, it has a high what?
    - Activation barrier or delta G dagger, which can be lowered by an enzyme.
    - NP. And the type of enzymes that lower this activation barrier are called peptidases.
    - They belong to the hydrolases or enzyme commission number 3 category of enzymatic reactions.
  - As previously mentioned, amino acids are linked together by peptide bonds to form peptides and proteins.
    - Several conventions on exactly what is a peptide and what is a protein exists.
    - The book says that proteins have a mass over 10 kilodaltons and below this is a peptide.
  - NP. I believe that a more widely accepted cutoff is 5 kilodaltons or roughly 50 amino acids.
    - The weighted average of amino acid mass based on their observed occurrence in peptides and proteins is 110 Daltons, which many people round to 100 Daltons for making quick estimations.
  - NP. Here is a tetrapeptide linked together by 3 peptide bonds.
    - SO. What is this amino acid?
      - NP. NP. NP. NP. Alanine, glycine, glutamine, lysine.
  - NP. How many different tetrapeptides are possible?
    - From 20 amino acids, it is 20 to the 4 power or 100,000 different tetrapeptides.
    - NP. What is largest net positive and negative charge possible for this peptide?
      - NP. NP. NP. NP. NP. +2 and -2.
    - NP. We can use the pKa’s of individual amino acids to estimate the pKa’s of this peptide’s ionizable groups.
  - NP. How do we estimate the isoelectric point of this peptide?
    - NP. Order the pka and average the two around the isoelectric form.
    - NP. The estimated pI for this peptide is a pI of 5.61.
  - NP. Why is this type of estimate not as accurate for proteins?
    - Proteins have very precise conformation states i.e. native structure with ionizable groups that can be in a significantly different chemical context from free amino acids and peptides.

NP – new point in slide animation.
ACTIVE AND COLLABORATIVE LEARNING ASSIGNMENTS

- An umbrella of methods where students perform activities that directly involve learning.
- Promotes deeper learning of fewer concepts.
- Facilitates peer-modeling.
- Fosters the development of peer study groups.
- Methods used in CHEM 445 include:
  - Concept maps
  - Peer-reviewed journal articles.
  - Significance ranking.
  - Metacognitive questions.
  - SEE-I.
  - Peer critique (peer-assessment).
- In-class assignment design:
  - 15-minute target, leaving 60 minutes for lecture.
  - Breaks up a long lecture.
  - Revision allows the use of harder assignments.
  - Often involves groups of 2 to 4 students.
  - Grading is reduced for the instructor.
  - Individual revision forces individual compliance.

Example Homework Assignment

- Using the journal article La´szlo´ Patthy, Genes 238, 103-114 (1999), answer the following questions:
  a) What type of source is this handout?
  b) What key genetic variation method enabled the Cambrian Explosion (metazoan radiation)?
  c) How reliable is this information (hypothesis, theory, or law)? Explain.
  d) What other developments implemented or facilitated this key genetic variation method?
     - Rank these developments in order of Significance.
  e) How did this key genetic variation method enable the Cambrian Explosion?

Answers:
- Review article.
- The leading theory is the development of efficient exon shuffling via:
  - Evolution of larger and less compact genomes.
  - Increased number and size of spliceosomal introns in genes.
  - Development of efficient intronic recombination elements.
  - Development of modular functional protein domains packaged in exons.
- This allowed a much faster evolution of genes with new functions and a subsequent diversification of multicellular organisms.
Example In-Class Assignment

- Work in pairs.
  - Write your names on the blank sheet of paper.
  - Time limit: till the end of class.

a) Create a composite list of phenomena that affect protein structure and function from the lists created in the homework assignment.
b) Identify which phenomena are derived from the properties of water.
c) On one side of the paper have one person quickly create a concept map using the composite list of phenomena and the terms “protein structure” and “protein function” while the other watches.
  - Only use lines and do not use arrows.
  - Do not circle the terms in the beginning.
  - At the end, circle the most Significant phenomena with respect to their effect on protein structure and function.
  - With a squiggly circle, identify the “central organizing concept” in the concept map.
  - Rank these phenomena in order of Significance with respect to their effect on protein structure and function. Explain your ranking.
  - Have the second person create a quick concept map on the other side of the paper and do the above steps while the other watches.
    - Indicate by a number (1st or 2nd) the order in which the concept maps were created.
    - Put your name on the concept map.
d) Have the each person revised their concept map, underline the revisions and use double lines for new relationships. Use an X for deleted relationships.
  - Optionally, draw a new concept map and indicate it is a revision.

Quick Concept Map

- Work in pairs.
  - 10 minute time limit.

a) On one side of the paper have one person quickly create a concept map using the Standards from the PE model while the other watches.
  - Only use lines and do not use arrows.
  - Do not circle the terms in the beginning.
  - At the end, circle the most Significant Standard.
  - With a squiggly circle, identify the “central organizing concept” in the concept map.
  - Rank the Standards with respect to their Importance in critical thinking. Explain your ranking.
  - Have the second person create a quick concept map on the other side of the paper and do the above steps while the other watches.
    - Indicate by a number (1st or 2nd) the order in which the concept maps were created.
    - Put your name on the concept map.

b) Have the each person revised their concept map, underline the revisions and use double lines for new relationships. Use an X for deleted relationships.
  - Optionally, draw a new concept map and indicate it is a revision.
EXPLICIT PROMOTION OF METACOGNITION

- First in-class assignment requires students to self-assess the type of archetypical learner they are:
  - Visual
  - Aural
  - Reading/Writing
  - Kinesthetic

- First homework assignment includes taking the VARK questionnaire:

- The concept that "intelligence is malleable through effort" is emphasized to students.
- Study aids are provided on how to study and prepare for quizzes and exams.
  - Includes advice from former students on what was effective for them.
  - Indicates the type of learner that advice originated from.
- Students are asked to write about how they prepared for quizzes and exams.
  - Done near the end of the course.
  - Used to revamp study aids for the following year.


REPETITIVE RETRIEVAL OF INFORMATION AND SPACING

- Repetitive Retrieval vs Study.
  - Repetitive retrieval is more effective than study in long-term retention of knowledge.

- Temporal Spacing.
  - Increased frequency of testing improves performance, up to a frequency of once or twice a week.

- Concept Spacing.
  - Randomizing the order of what is tested improves long-term retention of knowledge and induction.
  - Students are not always able to perceive this effect.

CHEM 445 MASTERY QUIZZES (MQs)

- All or none tests requiring 13.5 out of 15 correct answers.
  - Limited to a single side of a sheet of paper.
  - Questions focus on basic knowledge and key concepts.
  - 10 different quizzes are introduced, one at a time, over the 14 weeks.
  - In-class testing provided once a week for 20 minutes.
  - Students can take as many MQs as they want and then self-assess.
  - Testing encouraged during office-hours or during other classes.
  - Allows individual optimal test-taking frequency without sacrificing class time.
  - Students are given one-point extra credit for passing MQs a 2nd time.
  - Provides additional repetitive retrieval and confidence in what they have learned.
  - Ability to take quizzes multiple times lowers the desire to cheat.
  - Students self-assess using a grading key, marking in red ink.
  - Emphasis put on “equivalent meaning” and not “verbatim” answers in comparison to the grading key.
  - Fractional grading encourages better and more rigorous self-assessment.
  - Instructor models and provides feedback on self-assessment.
  - Simplifies grading for the instructor.
  - Students are NOT allowed to keep the MQs nor the grading key.
  - Multiple MQs creates a metacognitive challenge for students to overcome.
  - Heavily encourages metacognition and self-regulation.
  - Takes 2 to 4 tries to pass any given MQ.
  - Focusing on one MQ at a time and taking others for exposure.
  - Remembering questions to study for later.

CHEN 445 Topic 1 Mastery Quiz

1-2) List the 6 major characteristics of life.

3) What are primary, secondary, and tertiary sources of scientific information?

4) List the 4 major types of biomolecules.

5) Define a chiral center.

6) Define thermodynamics.

7) Identify and briefly describe the leading theory on the chemical evolution of cellular life.

8) Define entropy.

9) Define gene.

10) Define (biological) evolution.

11) List the 4 major types of noncovalent interactions among biomolecules.

12) Write out the Henderson-Hasselbalch equation.

13) Define osmotic pressure.

14) Why does water evaporate at room temperature?

15) Why is it more convenient to describe buffers in the context of Brønsted-Lowry definitions of acids and bases rather than Lewis definitions?
1-2) High degree of chemical complexity.
   Systems for extracting and using energy.
   Can respond to stimuli.
   Self-replication.
   Can adapt and evolve over generations.
   Defined functions for components.
3) Primary – peer-reviewed journal articles.
   Secondary – review articles in peer-reviewed journals.
   Tertiary – non-peer-reviewed sources like textbooks.
4) Nucleic acids, proteins, lipids, saccharides.
5) Atoms tethered to a set of ligands in an arrangement that is not superimposable on its mirror image.
6) Study of the relationship and conversion of energy between its different forms.
7) RNA World Theory - cellular life based on DNA, RNA, and protein evolved from self-replicating RNA.
8) A measure of disorder of a system representing the number of random states that a system can occupy.
9) An inheritable piece of nucleic acid that encodes a protein or nucleic acid gene product.
10) Iterative process of adaptation via mutation, genetic recombination, and selection by which a population of organisms changes.
11) Hydrogen bonds, ionic or electrostatic interactions, hydrophobic interactions, and van der Waals interactions.
12) \[ \text{pH} = \text{pK}_a + \log \frac{[A]}{[HA]} \]
13) Pressure to resist water diffusing across a semipermeable membrane.
14) Because of the entropy gained by changing into a gas.
15) Brønsted-Lowry and buffer definitions both deal with hydrogen cations \( H^+ \) rather than electron pairs.

**Chem 445 Topic 1**

1) FWY
2) D,E,K,R, all have charged R groups.
3-4) Primary (1°) - amino acid sequence
Secondary (2°) - spatial arrangement of main-chain atoms within a polypeptide segment.
Tertiary (3°) - Spatial arrangement of amino acids not necessarily close with respect to the primary sequence.
Quaternary (4°) - Spatial arrangement of polypeptides in complexes.
5) Type I – P in position 2; Type II – G in position 3.
6-7) Homolog - proteins that belong to the same protein family & share common sequence, structure, & ancestry.
Paralog - homologs found in the same species.
Ortholog – homologs found in different species.
8) Sequence dictates structure which enables function.
9-10) ion-exchange – charge; size-exclusion – size;
   affinity – binding affinity; reverse-phase – polarity.
11-12) i) Electrostatic interactions of AA with helical dipoles.
   ii) Propensity of certain AAs to form α-helical conformation.
   iii) Interactions between close R groups.
   iv) Steric hindrance of close (adjacent) R groups.
   v) Occurrence and location of G and P residues.
13) Folding pattern (spatial arrangement) of 2 or more 2* structural elements. Tertiary structure (3°).
14) Proteins have an astronomical number of possible conformation to randomly search and yet can fold spontaneously within seconds.
15) The trans conformation is sterically favored. The cis conformation has more sidechain conformations that have repulsive clashes between the electron clouds of their atoms.

**SCAFFOLDED EXPLICIT REVISION ACROSS ASSESSMENTS**

- Promotes student learning across different levels of learning.
- Assessments (1000 points total).
  - 10 Mastery Quizzes (250 points).
    - Target Remembering to Understanding.
  - ~20 Assignments (200 points).
    - Target Understanding to Creating.
  - 3 Exams (550 points).
    - Target Applying to Creating.
    - Exam revision for the first 2 exams, as extra credit for these exams.
Example Exam1 Questions

Question: Which factors affect the bond dissociation energy (BDE) of hydrogen bonds and how? Identify which factors are related to the electrostatic and covalent nature of the hydrogen bond. Which factors play an important role in protein folding and why?

Answer: i) The geometry of the hydrogen bond where a linear arrangement of hydrogen donor, hydrogen, and hydrogen acceptor is stronger. The geometry is more related to the covalent nature of the bond. ii) The strength of dipoles which is somewhat dictated by the nuclei involved. The stronger the dipoles (the more electronegative the hydrogen donor and hydrogen acceptor), the stronger the bond. This is related more to the electrostatic nature of the bond. iii) Temperature is also a factor (but do not count off if they don’t list it.) iv) The dielectric constant (relative permittivity) of the environment, where a more nonpolar environment creates a stronger bond. This is related to the electrostatic nature of the bond. The geometry and dielectric constant play very important roles in protein folding by dictating geometric constraints that get stronger when formed in a protein’s hydrophobic core. (One could also argue that the geometric nature of the hydrogen bonds is an important characteristic that enables the hydrophobic effect.)

<table>
<thead>
<tr>
<th></th>
<th>A</th>
<th>B</th>
<th>C</th>
<th>D</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>100%</td>
<td>42%</td>
<td>30%</td>
<td>34%</td>
</tr>
<tr>
<td>B</td>
<td>100%</td>
<td>30%</td>
<td>36%</td>
<td></td>
</tr>
<tr>
<td>C</td>
<td>100%</td>
<td>30%</td>
<td>31%</td>
<td></td>
</tr>
<tr>
<td>D</td>
<td>100%</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Question: Consider the following: protein A and B are from Saccharomyces cerevisiae, protein C from Mus musculus, and protein D from Saccharomyces pastorianus. All have roughly 30 to 40% sequence identity to each other. With respect to A, what is each protein B, C, and D? What are the structural and functional implications between protein A and the other proteins? Now consider the following extra information: i) these proteins have 2 domains, each roughly half the size of the protein and ii) one of the domains binds NADH. What are the potential structural and functional implications now? What other information would make things clearer?

Answer: B is a paralog to A. C and D are orthologs to A. Structurally they will all be similar. There functional similarity with respect to A will be D > C > B. Considering the additional information, it is hard to tell what the functional relationships may be beyond the likely ability to bind NADH. Knowing if the sequence similarity between the proteins is spread evenly across the sequence or mostly sequestered to a given domain would be most helpful.
OVERVIEW

- Background (Key Concepts)
- CHEM 445 – Survey of Biochemistry
- Statistical Analysis and Results
- Caveats and Discussion
- Conclusions

STATISTICAL METHODOLOGY AND DESIGN

- Earlier assessments are correlated with later assessments using a series of multiple regression models.
- Forward variable selection methodology was used to determine the series.
  - The variable selection criterion was based on improving $\text{adj}R^2$.
  - $\text{adj}R^2 = 1 - N/(N-p)(1-R^2)$
    - Adjusted square of the coefficient of multiple correlation.
    - Calculated using the Smith formula correcting for small sample size.
    - $R^2$ – square of the coefficient of multiple correlation (coefficient of determination).
    - $N$ – sample size.
    - $p$ – number of variables (predictors) in multiple regression model.
- Prior exams were used as an indirect control for:
  - General aptitude.
  - Prior knowledge.
  - Prior effort.
- Effects of mastery quizzes, exam revision, and assignments were determined using the improvement in $\text{adj}R^2$.
  - Partial $F = (\text{adj}R^2_{AB} - \text{adj}R^2_A)/(1 - \text{adj}R^2_A)$
  - $\text{adj}R^2_A$ is the largest for the models with one less independent variable.
- Student feedback was used as an analytical cross-validation.

Maxwell, S. Psych Methods 5, 434 (2000).
CHEM 445 S2011 DATASET

Table 1 – List of Assessment Variables

<table>
<thead>
<tr>
<th>Assessment Variable</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Exam1</td>
<td>100 point first exam composed entirely of essay questions.</td>
</tr>
<tr>
<td>Exam1 EC Fraction</td>
<td>Fraction correct of 4 to 6 questions from Exam1 given to a student for revision. These questions were given as extra credit.</td>
</tr>
<tr>
<td>Exam1 MQ Count</td>
<td>Number of mastery quizzes passed by a student before taking Exam1.</td>
</tr>
<tr>
<td>Exam1 Assignment Count</td>
<td>Number of assignments performed by a student before taking Exam1.</td>
</tr>
<tr>
<td>Exam2</td>
<td>150 point cumulative second exam composed mostly of essay questions. Nonessay questions involve analysis of metabolic pathways including classification of specific enzymatic reactions.</td>
</tr>
<tr>
<td>Exam2 EC Fraction</td>
<td>Fraction correct of 4 to 6 questions from Exam2 given to a student for revision. These questions were given as extra credit.</td>
</tr>
<tr>
<td>Exam2 MQ Count</td>
<td>Number of mastery quizzes passed by a student before taking Exam2.</td>
</tr>
<tr>
<td>Exam2 Assignment Count</td>
<td>Number of assignments performed by a student before taking Exam2.</td>
</tr>
<tr>
<td>Final Exam</td>
<td>300 point cumulative final exam composed mostly of essay questions. Nonessay questions involve analysis of metabolic pathways including classification of specific enzymatic reactions.</td>
</tr>
<tr>
<td>Exams. EC Fraction</td>
<td>Average of Exam1 EC Fraction and Exam2 EC Fraction.</td>
</tr>
<tr>
<td>MQ Count</td>
<td>Number of mastery quizzes passed by the student in the course. No attempts allowed after the Final Exam.</td>
</tr>
<tr>
<td>Assignment Count</td>
<td>Number of assignments performed by a student. No assignments accepted after the Final Exam.</td>
</tr>
</tbody>
</table>

Only 5 students revised any assignments and no statistical effect could be detected.

REGRESSION OF EXAM2 TO EXAM1

Table 3 – Linear Regression of Exam2

<table>
<thead>
<tr>
<th>Regression Model</th>
<th>R²</th>
<th>adjR²</th>
<th>F-test</th>
<th>p-value</th>
<th>Power</th>
</tr>
</thead>
<tbody>
<tr>
<td>Exam2=Exam1</td>
<td>0.708</td>
<td>0.696</td>
<td>60.71</td>
<td>1.25</td>
<td>0.000</td>
</tr>
<tr>
<td>Exam2=Exam2 MQ Count</td>
<td>0.115</td>
<td>0.079</td>
<td>3.26</td>
<td>0.0832</td>
<td>0.0868</td>
</tr>
<tr>
<td>Exam2=Exam1 EC Fraction</td>
<td>0.0108</td>
<td>-0.0267</td>
<td>0.274</td>
<td>0.705</td>
<td>-</td>
</tr>
<tr>
<td>Exam2=Exam2 Assignment Count</td>
<td>0.00695</td>
<td>-0.0328</td>
<td>0.175</td>
<td>0.679</td>
<td>-</td>
</tr>
</tbody>
</table>

R² = square of the coefficient of multiple correlation (Pearson, 1914). *adjR² = 1 - (N/(N-p))*R²* from Smith version (Wherry, 1931; Yin & Fan, 2001).
F-test against model with regression coefficients equal to zero. The degrees of freedom are listed as numerator,denominator.

Exam1 EC Fraction provides a medium effect size of 0.192 over Exam1.

Table 4 – Multiple Regression Models of Exam2 to Exam1

| Regression Model       | R² | adjR² | F-test | p-value | Power | Partial F | Power | F-test 1-Simpler,Pr(>|F|) |
|------------------------|----|-------|--------|---------|-------|-----------|-------|--------------------------|
| Exam2=Exam1+Exam2 MQ Count | 0.958 | 0.946 | 5.38e-08 | 0.0001 | - | - | - |
| Exam2=Exam1+Exam2 Assignment Count | 0.888 | 0.879 | 3.76e-07 | 0.0007 | - | - | - |
| Exam2=Exam1+Exam2 Assignment Count | 0.864 | 0.853 | 2.92e-07 | 0.0053 | - | - | - |
| Exam2=Exam1+Exam2 Assignment Count | 0.855 | 0.842 | 2.70e-07 | 0.0092 | - | - | - |
| Exam2=Exam2 Assignment Count | 0.834 | 0.821 | 2.50e-07 | 0.0125 | - | - | - |

F-test against model with regression coefficients equal to zero. The degrees of freedom are listed as numerator,denominator.

Power = statistical power calculated using the pwr.f2.test method with α = 0.05 and the above R² (Champely & Champely, 2009; Cohen, 1988). *indicates R² = 0.
F-test 1-Simpler,Pr(>|F|) = F-test to simpler model by one independent variable.
**REGRESSION OF FINALEXAM TO EXAM2**

<table>
<thead>
<tr>
<th>Table 5 – Linear Regression of FinalExam</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Regression Model</strong></td>
</tr>
<tr>
<td>FinalExam-Exam1</td>
</tr>
<tr>
<td>FinalExam-Exam2</td>
</tr>
<tr>
<td>FinalExam-Exam1.ED.Fraction</td>
</tr>
<tr>
<td>FinalExam-Exam2.ED.Fraction</td>
</tr>
<tr>
<td>FinalExam-Exam3.ED.Fraction</td>
</tr>
<tr>
<td>FinalExam-MQCount</td>
</tr>
<tr>
<td>FinalExam-AssignmentCount</td>
</tr>
</tbody>
</table>

**R²** = square of the coefficient of multiple correlation (Pearson, 1921). "R" = 1 - R². **Power** calculated using the pwr.f2.test method with α = 0.05 and the above f² (Champely & Champely, 2009; Cohen, 1988). "-" indicates adjR² ≤ 0.

**REGRESSION OF FINALEXAM TO EXAM1**

<table>
<thead>
<tr>
<th>Table 6 – Multiple Regression of FinalExam to Exam1</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Regression Model</strong></td>
</tr>
<tr>
<td>FinalExam-Exam1+Exam2</td>
</tr>
<tr>
<td>FinalExam-Exam2+ED.Count</td>
</tr>
<tr>
<td>FinalExam-Exam3+ED.Fraction</td>
</tr>
<tr>
<td>FinalExam-AssignmentCount</td>
</tr>
</tbody>
</table>

**MCount+Exams.ED.Fraction provides a large effect size of 0.704 over Exam1.**

<table>
<thead>
<tr>
<th>Table 7 – Multiple Regression of FinalExam to Exam1</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Regression Model</strong></td>
</tr>
<tr>
<td>FinalExam-Exam1+MQCount</td>
</tr>
<tr>
<td>FinalExam-Exam2+MQCount</td>
</tr>
<tr>
<td>FinalExam-Exam3+MQCount</td>
</tr>
</tbody>
</table>

**MCount+Exams.ED.Fraction provides a large effect size of 0.704 over Exam1.**

**Note:** Power = statistical power calculated using the pwr.f2.test method with α = 0.05 and the above f² (Champely & Champely, 2009; Cohen, 1988). "-" indicates R² ≤ 0. **f²** = 0.02 ≤ f² < 0.15: small effect; 0.15 ≤ f² < 0.35: medium effect; f² ≥ 0.35: large effect. The degrees of freedom are listed as numerator, denominator.
**CONSISTENT PATTERN OF CORRELATION**

<table>
<thead>
<tr>
<th>Regression Model</th>
<th>partial $f^2$ to prior Exam</th>
<th>Power</th>
</tr>
</thead>
<tbody>
<tr>
<td>FinalExam=Exam1+Exam2+AssignmentCount</td>
<td>0.192</td>
<td>0.516</td>
</tr>
<tr>
<td>+MQCount</td>
<td>0.344</td>
<td>0.678</td>
</tr>
<tr>
<td>FinalExam=Exam1+MQCount</td>
<td>0.704</td>
<td>0.967</td>
</tr>
</tbody>
</table>

$R^2$ = square of the coefficient of multiple correlation (Pearson, 1914). \( adjR^2 = 1 - \frac{N}{N-p}(1-R^2) \) from Smith version (Wherry, 1931; Yin & Fan, 2001).

$F = \frac{R^2}{1-R^2}$, altered from original to use $R^2$ instead of $F$ to compensate for sample size statistical bias inherent in $F$ (Cohen, 1988; Huberty, 2002; Maxwell, 2000). $^\cdot$ indicates $R^2 = 0$. partial $f^2 = \frac{R^2}{1-R^2}$ where $R^2$ is the largest for the models with one less independent variable.

Traditionally, small effect is $0.02 \leq f^2 < 0.15$; medium effect is $0.15 \leq f^2 < 0.35$; large effect $f^2 \geq 0.35$ (Cohen, 1992).

Power – statistical power calculated using the pwr.f2.test method with $\alpha = 0.05$ and the above $f^2$ (Champely & Champely, 2009; Cohen, 1988). $^\cdot$ indicates $R^2 \leq 0$.

**STUDENT FEEDBACK**

<table>
<thead>
<tr>
<th>Teaching-Learning Method</th>
<th>Most Effective</th>
<th>Top 3 Most Effective</th>
<th>Disliked Most</th>
<th>Liked Mosted</th>
</tr>
</thead>
<tbody>
<tr>
<td>Exam Extra Credit</td>
<td>6</td>
<td>20</td>
<td>0</td>
<td>6</td>
</tr>
<tr>
<td>Mastery Quizzes</td>
<td>10</td>
<td>20</td>
<td>2</td>
<td>9</td>
</tr>
<tr>
<td>Assignments</td>
<td>3</td>
<td>11</td>
<td>5</td>
<td>2</td>
</tr>
<tr>
<td>Exam</td>
<td>1</td>
<td>6</td>
<td>3</td>
<td>0</td>
</tr>
<tr>
<td>Lecture</td>
<td>4</td>
<td>19</td>
<td>7</td>
<td>9</td>
</tr>
</tbody>
</table>

Only 25 students responded and not all questions were answered.

Disliked Most – tallied when student response was related to the method.

Liked Most – tallied when student response was related to the method.

Students also identified Exam Revision and Mastery Quizzes as the most effective teaching instruments!
CAVEATS

- Small sample size: 27 students.
  - 15 is the minimum acceptable sample size for a matched-pair design like this study.
  - Use of \( \text{adj} R^2 \) helps address the sample size statistical bias.
  - Residuals from none of the models tested as non-normal at the 0.01 confidence level.
- No direct control was used for comparison.
  - Prior exams provide an indirect control for general aptitude, prior knowledge, and prior effort.
  - Fortuitous lack of explicit revision in the assignments provides a second indirect control, allowing a direct comparison of learning instruments that do and don’t use explicit revision.
- Extraction of causation from a correlative analysis.
  - Only prior measured independent variables are correlated with future Exam performance.
  - Student feedback provides a cross-validation.

WHY IS SCAFFOLDED EXPLICIT REVISION SO EFFECTIVE?

- Explicit revision focuses the student’s attention on the weaknesses in his/her performance, while modeling self-corrective learning strategies and critical thinking.
- Utilized this way, explicit revision motivates students towards mastery goals over performance goals.
  - “extra credit” encourages students to apply effort in order to overcome prior gaps in performance.
  - Students internalize the concept that performance is malleable and improvable through effort.
- Additive effects arise from scaffolding created by the combined use of mastery quizzes and exam revision.
  - MQs targets Remembering to Understanding.
  - Exam Revision targets Applying to Creating.

CONCLUSIONS

- Explicit revision is a practical framework for designing class assessments that integrate:
  - Formative self-, peer-, and teacher-assessments.
  - Metacognition.
  - Self-regulation.
  - Subject-specific (critical thinking) skills.
- This is even true for content-rich science courses.
- Improvement in student performance and the effectiveness of their effort is demonstrated by:
  - Rigorous multiple regression analysis.
  - Cross-validation with student feedback.
- Scaffolding of explicit revision facilitates additive effects from multiple teaching instruments.

ACKNOWLEDGMENTS

- Dr. Cathy Bays
- Dr. Jennifer Brueckner-Collins
- Dr. Julia Chariker