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THE TROUBLE WITH TRANSFER

by  
Kathryn J. Groneman

A thesis submitted to the faculty of  
Brigham Young University  
in partial fulfillment of the requirements for the degree of  
Master of Science

Department of Biology  
Brigham Young University  
August 2009

BRIGHAM YOUNG UNIVERSITY  
GRADUATE COMMITTEE APPROVAL

of a thesis submitted by

Kathryn J. Groneman

This thesis has been read by each member of the following graduate committee and by majority vote has been found to be satisfactory.

\_\_\_\_\_  
Date

\_\_\_\_\_  
William S. Bradshaw, Chair

\_\_\_\_\_  
Date

\_\_\_\_\_  
C. Riley Nelson

\_\_\_\_\_  
Date

\_\_\_\_\_  
John D. Bell

BRIGHAM YOUNG UNIVERSITY

As chair of the candidate's graduate committee, I have read the thesis of Kathryn J. Groneman in its final form and have found that (1) its format, citations, and bibliographical style are consistent and acceptable and fulfill university and department style requirements; (2) its illustrative materials including figures, tables, and charts are in place; and (3) the final manuscript is satisfactory to the graduate committee and is ready for submission to the university library.

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Date

---

William S. Bradshaw  
Chair, Graduate Committee

Accepted for the  
Department

---

Russell B. Rader  
Graduate Coordinator

Accepted for the  
College

---

Rodney J. Brown  
Dean, College of Life Science

## ABSTRACT

### THE TROUBLE WITH TRANSFER

Kathryn J. Groneman

Department of Biology

Master of Science

It is hoped that the scientific reasoning skills taught in our biology courses will carry over to be applied in novel settings: to new concepts, future courses, other disciplines, and non-academic pursuits. This is the educational concept of transfer. Efforts over many years in the Cell Biology course at BYU to design effective assessment questions that measure competence in both deep understanding of conceptual principles and the ability to draw valid conclusions from experimental data have had at least one disquieting result. The transfer performance of many otherwise capable students is not very satisfactory.

In order to explain this unsatisfactory performance, we assumed that the prompts for our transfer problems might be at fault. Consequently, we experimented with multiple versions that differed in wording or the biological setting in which the concept was placed. Performance on the various versions did not change significantly. We are led to investigate two potential underlying causes for this problem. First, like any other important scholastic trait, the ability to transfer requires directed practice through multiple iterations, a feature absent from most courses. Second, perhaps there is

something innate about an individual's learning style that is contrary to performing well at transfer tasks. Students sometimes see exams as tests of gamesmanship; "Teachers are trying to outsmart me with trick questions." Post-exam conversations can be very litigious: "But it's not clear what you wanted!" We recommend the pedagogical use of transfer problems which place on the learner the responsibility to define the appropriate scope for inquiry and improve one's ability to acquire the kind of precise and comprehensive understanding that makes transfer possible.

In this study, we analyze the effects of directed practice and learning style on transfer abilities. Implications for teaching are discussed and include promoting meta-cognitive practices, carefully selecting lecture and textual materials to reduce the "spotlighting effect" (selective focus on only a subset of ideas), and encouraging students to consciously use multiple learning strategies to help them succeed on various tasks. It is important to note that these skills are likely to take a significant amount of time for both students and teachers to master.

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CHAPTER 1

Parable of the 10

(Actually 14)

Versions

Every teacher understands the difficulty of constructing a “good” test question. A question that is consistent with course objectives and challenges students intellectually, but gives them the opportunity to demonstrate deep understanding of a concept, is hard to design. The instructors and teaching assistants of the cell biology course at BYU (Bio 360) have made an intense effort over the last 15 years to improve teaching and learning, including designing more effective assessments, both formative and summative. We have found this to be very demanding work. Our experience is that the first draft of a good exam problem frequently takes at least an hour of intensive effort to construct, and hence becomes a very valuable intellectual property. We become quite possessive of an item that has been “field tested” in a real exam and then passes through subsequent iterations of refinement.

In the semesters of Biology 360 up to and including fall 1999, midterm and final exams consisted solely of multiple choice items. The task in each problem was almost exclusively data analysis. Experimental scenarios that included figures and tables were presented to the students, and they were asked to choose from a list of possibilities those conclusions that were best supported by the data. Discussions among the teachers of the course then resulted in changing the test format. The former multiple choice questions (selected response format) were replaced by short essay questions (constructed response format). The justification for this change was that by requiring writing, it would be possible to distinguish those students who, when prompted, could select a correct response written by someone else (sometimes randomly) from those who could author their own conclusions because they really knew the science and had developed the requisite analytical ability. We hoped to test recollection rather than familiarity as

described by Yonelinas (2002). Familiarity is faster than recollection – we recognize that something is familiar (an answer to a multiple choice question for example) faster than we recollect why it is relevant. Familiarity is more superficial and automatic, where recollection involves conscious thought. We judged the latter skill to be a more advanced measure of genuine proficiency and one with more long-term benefits to our students (Clariana, 2003; Berg & Smith, 1994; McDaniel & Mason, 1985).

At the same time that we switched to a constructed response format, we also introduced conceptual problems into the exams. The development of data analysis skills and improving scientific reasoning continued to be primary course objectives, but we also began to formally assess mastery of conceptual information. The midterms consisted of three “conceptual problems” (for which students created diagrams, and described in detail key concepts that had been introduced in the course), and three “data analysis” problems (for which students were required to draw conclusions from data presented in the form of tables, electrophoresis gels, and other types of figures produced in experiments they had not encountered before). For the latter type of questions the task was uniformly to “Write in one sentence each the conclusions supported by these data.”

The initial design of the conceptual problems used in the exams was based, in part, on ease and uniformity of grading. Usually the tasks were spelled out in the stem of the question in very specific terms in order to avoid ambiguity. Problems were written according to many of the recommendations for writing constructed response questions offered by Hogan and Murphy (2007). Namely, problems were related to instructional objectives, a rubric was constructed as an example of the ideal answer, complex processes were assessed, the questions were reviewed by multiple professors and teachers

assistants, and the task was defined clearly (or so we thought). Examples of six of these problems are presented in Figure 1. The rubrics used to assess student responses were straight forward, many of them involving lists of elements considered necessary for a complete answer, each of which was awarded a small number of points. In a given semester a single rater graded the complete set of all student responses to a particular problem. As indicated in the figure, the mean scores for most of these conceptual problems assessed over at least nine semesters ranged from about 10-12 (66-80%) of a total possible 15 points. We attribute the statistically significant differences between these scores, made evident by the large number of students in the data sets, to scoring differences between raters and to intrinsic differences in the degree of difficulty of the various concepts or differences in emphasis placed on them during class instruction. The magnitude of the variance due to these sources was expected and appears to be reasonable.

Initially we thought that all of the conceptual problems were focused on the same intellectual level, primarily requiring recall and some degree of application. Interestingly, this has proven not to be the case. We report here an analysis of exam performance on two conceptual items appearing on the third of the four midterm examinations. The subject matter content assessed by Exam 3 was regulation of transcription. We have attempted to explain why performance on these items was low, and to proceed to a more general exploration of the relationship between student performance, the design of prompts for exam problems, and pre-exam preparation by students. The data are restricted to scores obtained from fall and winter semesters. Performance in the summer

term may be atypical, both because of the condensed time frame and a somewhat unrepresentative clientele.

#### Analysis of Transfer Problem Attributes

The two questions deal with transcriptional regulation, one featuring the *histidine* operon in E. coli (representing coverage of prokaryotic control mechanisms, Figure 2A) and one featuring cardiac actin and insulin gene expression in a heart cell (representing eukaryotic mechanisms, Figure 3). Students were asked to diagram or discuss the mechanisms of positive and negative transcriptional control relevant to each situation. These questions were somewhat distinctive because they attempted to measure the students' ability to apply what they knew about transcriptional control in novel situations (transfer). Because they were not simple recall questions, and different in this regard from conceptual items contained in the first two exams, we assumed that they would be considered difficult by our students.

Table 1 shows the results of the initial trials with exams in the new format. The data consist of the mean percent composite scores on conceptual and data analysis questions contained in four midterm exams administered over three semesters (winter 2000, fall 2000, and winter 2002). Performance on the set of data analysis problems was remarkably constant (about 62.7%) across all exams. In addition, on midterms 1, 2 and 4 students earned more points on the conceptual problems than on the data analysis problems. We expected this to be the case, since data analysis is a difficult, non-intuitive task for most students. However, performance on exam 3 was atypical. The conceptual scores from exam 3, containing the *his* operon and heart transcription transfer problems, dropped by 14.5% compared to average scores on exams 1 and 2.

Why? What were the attributes of these two problems that proved to be so challenging?

Both questions were set in unfamiliar biological settings, but called for the application of principles taught earlier. For prokaryotic mechanisms, course instruction focused on the lactose (*lac*) and *tryptophan* (*trp*) operons (reading assignments and diagrams were taken from Alberts, et al., 2002 and Lodish, et al., 2003). Though the *histidine* (*his*) operon featured in the exam problem functions almost identically to the *trp* operon, students did not encounter the *his* operon before the exam. For this reason, the exam prompt included clues about the similarities between *his* and *trp* operons, such as their anabolic function (as opposed to the catabolic *lac* operon) and the existence of a series of *his* codons early in the operon's leader sequence, a sign that attenuation is likely to play a role in its regulation. The course curriculum covers eukaryotic transcriptional control in detail (four class sessions), with some reference to the cell specific expression of the insulin and chymotrypsin genes in the pancreas and of  $\beta$ -globin expression in the fetal liver. No mention was specifically made in class of transcriptional regulation in the heart, or of cardiac actin. Students were expected to transfer general concepts about transcriptional control learned in class over the previous 3-4 week period of time to the novel scenarios encountered on the exam.

Careful reading of the answers to the two questions as originally administered, suggested that two distinct skills were involved in generating successful responses. First, students needed to perform one or more transfer tasks by recognizing the applicability of the principles studied in class to a related but unfamiliar situation presented in the exam. Second, students had to recall the set of facts about the mechanisms relevant to

transcriptional regulation that would allow them to correctly model each system.

To further investigate the respective influence of these two skills on student performance, we first categorized the reasoning skills necessary for a complete response into three cognitive “layers.” Thinking in terms of layers can be helpful when contemplating complex tasks. Creating subsystems within the greater system can make it easier to handle the information, and then eventually synthesize it into the larger picture (Mislevy & Riconscente, 2005). For the *his* operon question, three cognitive layers were defined: first, the students must make the determination that the system is prokaryotic; second, they must recognize the similarities between the *trp* and *his* operons; and third they must complete the problem by modeling the system. Similar layers were in operation for the heart problem: first, students must recognize that a heart cell is eukaryotic, and prokaryotic mechanisms do not apply; they must make the distinction that the cardiac actin gene is transcribed in the heart cell, and the insulin gene is not; and third they must actually execute the modeling task in detail.

Table 2A shows the results of a “layer” analysis of the *his* operon problem presented fall semester 2002. Of the 96 students, 89 (92.7%) completed the layer 1 task, and 71 (74.0%) were able to successfully complete the transfer tasks inherent in both layers 1 and 2. Thirty percent of students were also able to adequately model the system (layer 3). Our tentative explanation for why 26% of the students could not transfer their knowledge to a new situation is that they lacked prior deep content knowledge due to a superficial preparation in the study of this concept.

Table 2B displays the results of a similar analysis for the original heart question. As shown, 55% of 96 students were able to pass the transfer tasks (layers 1 and 2), but

only 10% successfully executed all aspects of the required tasks (layer 3). An observation relative to the transcription repression component of the problem may be relevant. Some students simply labeled the insulin gene on this problem as repressed or “turned off,” without diagramming the details of nucleosome architecture, histone deacetylation, or DNA methylation. This left us unable to assess whether these people understood these mechanisms and simply accepted them as implicit, or were actually lacking this content knowledge. The statistics as tabulated, however, suggest that a significant percentage of students were limited in both the transfer and the content knowledge tasks.

## Methods

### What’s Wrong with the Prompt?

We considered the possibility that decreased performance on these two problems may have been due to the wording of the prompt. Perhaps the way in which the problem was written was unintentionally diverting students in an unforeseen direction, or narrowing the scope or boundaries in which they conceived the concept to be nested; if it were worded differently, perhaps students would be able to perform more satisfactorily. In an analogy to architecture, Fulcher and Davidson (2009) would describe our exam modifications as retrofitting. Test design and test purpose need to be closely interrelated, and if data show that they are not (as ours did), a test architecture retrofit is called for. To test our hypothesis that the structure of the prompt was the problem for students, we created a modified version of the *his* operon problem (Figure 2B), and multiple versions of the heart problem (Table 3). Because neither the conceptual principles being tested nor the manner of instruction changed during this trial, we were able to use the same scoring

keys as in previous semesters. We will consider the analysis and results for the *his* and heart problems separately.

## Results

### Performance on Alternative Versions of the *His* Problem

Two versions of the prokaryotic operon question were administered together in a random distribution in both winter 2003 and fall 2003. Version 1, the “transfer” version (Figure 2A), was the original question, used on previous exams. The first part of the question asked students to model the mechanisms regulating the *his* operon (9 points). Part B asked students to compare their model with how a *galactose* operon might work in the same organism (3 points). In the final portion, students were asked to identify specific ways in which these mechanisms differed from eukaryotic transcriptional regulation (3 points). The first part in version 2, the “capture” or recall version (Figure 2B), asked students simply to model transcriptional control in the *trp* operon, which had been discussed extensively in one entire class session. Part B asked them to compare it to the regulation of the *lac* operon, to which another class period had been devoted. The third part was the same for both versions. This modified version was meant to eliminate all aspects of transfer and test students entirely on their recall of the course material. Figure 4 displays the results of a statistical analysis of the total mean scores and the scores for each of the three parts of the problem. The average total score on the capture, *trp* version was significantly higher than for the transfer, *his* version of the problem ( $p < 0.01$ ). This was also true for subsections a and b (Figure 2), but not c, which was identical in both versions.

Performance on the *trp* capture version (68%, 10.14 of 15 total possible points)

demonstrates that our students were generally capable of memorizing and reporting the details about the prokaryotic regulatory concepts that had been presented in class. This included assimilating a lot of new vocabulary (e.g., What enzymes are encoded by Lac Z, and Lac I? What is the difference between the function of an operator and that of an inducer? How does tryptophan function as a co-repressor?) and coming to grips with complex molecular mechanisms (e.g., What hairpin loops form under what circumstances during attenuation?). However, transferring that knowledge and applying it to a new setting proved to be significantly more difficult. Why? Is it possible that transcriptional regulation of prokaryotic operons is an example of an academic task that is so rich in novel detail that some students spend all their efforts in grappling with the minutia but fail to see the larger picture of the logic upon which control is based? This explanation for the lower scores on the *his* problem is based on the premise that genuine comprehension requires both knowledge of the details and understanding of the conceptual logic; without mastery at both levels, transfer is unlikely. Alternatively, comprehending factually complex information may not be the limiting factor. Instead, the explanation may be that students have not been provided (or engaged themselves in) enough practice in expressing that knowledge: integrating, constructing, and then articulating a model of their understanding outside of the framework in which they originally learned the concepts.

#### Performance on Alternative Versions of the *Heart* Problem

For the heart problem, we accumulated student performance data for 12 semesters during the interval from winter 2000 to fall 2007, ultimately authoring 14 different versions of the prompt (Table 3). The primary objective of the problem remained the

same throughout, while each variant was tested for its ability to elicit a more comprehensive response. There were three categories of modifications: minor changes in visual presentation, cues to the full range of regulatory mechanisms to be addressed, and different transfer scenarios in which the cell-specific nature of gene expression could be explained. For example, there were mechanical changes with the formatting, including bold or italicized fonts of various sizes (Versions 1B, 12), and the inclusion of a drawing of a newly synthesized cell-specific gene product (Version 7). The possible existence of different cognitive “layers” of understanding (see p. 5 above) was probed with Versions 2-5. Phrases like “both positive and negative control mechanisms” and “some genes are activated, some remain repressed” were added in the hope that students would be cued to include more of the negative regulatory elements that had been missing in the answers of students in previous semesters.

In one trial (Version 13), the students were required to first answer some preliminary objective questions (Figure 5) that might jog their memories about the range of elements that were likely to be part of a good answer (i.e., properties of the eukaryotic RNA polymerase, histone acetylase or deacetylase, DNA methylase, cell-specific protein content). Those receiving this version were not told that their answers to these items (correct or incorrect) were not tabulated as part of the score they would receive. Finally, for the purpose of assessing transfer, the prompt was placed in various physiological settings including a differentiated heart cell (Versions 1-5, 7), a differentiated pancreas cell (Versions 6, 12-13), the developing embryo (Version 8), cell types of the student’s choice (Version 11), and a “bare bones” version (9-10) that did not specify any cellular context.

Statistical analysis of the scores from these 14 versions failed to demonstrate a significant improvement due to wording of the prompt (Figure 6). It seemed that no matter how we worded the prompt, many students still failed to construct and explicate a complete picture of eukaryotic transcriptional mechanisms. Although one-way ANOVA demonstrates significant differences between the versions ( $p < 0.0001$ ), there were no significant gains in performance. Compared to Version 1, students presented with Versions 2 and 6 actually performed significantly worse. We conclude that our changes to the problem did not prompt students to be more thorough and accurate in their diagrams.

We observed that most students included positive regulatory elements in their models (enhancers, 88%; transactivating proteins, 88%; or TBP, 83%). Even though an entire class period was devoted to negative mechanisms and the required reading from the text (Alberts et al, 2002) provided sufficient coverage, few students included these repression elements in their answers (silencer base sequences, 41%). Moreover, chromatin remodeling elements (HAT, 30%) were significantly underrepresented, even though these concepts also received considerable emphasis in the text and in class. In general, students tended to “spotlight” certain aspects of transcriptional regulation and either completely excluded other components, or treated them minimally. This unsettling result persisted independent of what alternative version of the prompt was presented.

One result from a two-semester data set ( $n = 233$ ) comparing Version 12 (no prior objective questions) and 13 (answering prior objective questions) is informative. The objective items prompted some persons to include what we determined to be transfer elements (silencer, repressor, nucleosomes, HAT, DHAT, and DNA methylase, about

which they were knowledgeable) that they would otherwise have left out ( $p < 0.04$ , see Chapter 2, Table 4 for more details).

## Discussion

Recognizing that there are individual differences in the academic performance of a class of students over which an instructor has little control (there is a range in intrinsic intellectual capacity, and the ability of any individual to perform optimally is subject to a variety of personal idiosyncratic circumstances), we would still like to be able to identify those aspects of course design and instructional practice that are rate-limiting, and which, if correctly modified would lead to improvement.

Consider the following ideal learning sequence (Figure 7) presented in the form of a “Castle Top” Diagram (after Fink, 2003). Student-directed activities are indicated in bold type; teacher-directed activities are indicated in italics.

Figure 7. Ideal Learning Sequence for Acquiring Conceptual Understanding

In-Class		<i>2. Retrieve and apply facts and concepts through active learning exercises.</i>		<i>4. Test for mastery with formative assessments.</i> <b>Design plan for closing gaps in understanding.</b>	
Out-Of-Class	<b>1. Acquire foundational information through reading the text.</b>		<b>3. Reiterate retrieval of facts and concepts through Elaborative Questioning with classmates.</b>	<i>5. Author summative assessment problems.</i>	<b>6. Write solutions to summative assessment problems.</b>

Elaborative Questioning (EQ, Step 3) is an after class study technique conducted among two or three classmates (Keller et al., 2008). Each person is required to articulate and explain, to make

one's understanding of the relevant principles transparent to him or her and to others in the group. Questions are asked and answered. It is explained by King (1992):

Elaboration can take the form of adding details to the information, clarifying an idea, explaining the relationship between two or more of the new concepts, making inferences, visualizing an image of some aspect of the material, applying an analogy relating the new ideas to familiar things, or in some other way associating the new material with information already known or with past experience. Such elaborative activity makes the new material more meaningful to the learner and therefore easier to understand and remember.

Questions about specific details of information may be necessary, but are less useful than those that begin with "How?" or "Why?" Each member of the group must take an active part as a questioner and then a responder.

Our presumption in experimenting with alternative versions of conceptual exam problems was that the variation in performance we were observing might have been instituted at Step 5 in this sequence; the particular language and phrasing used in constructing the prompts were responsible for skewing the distribution. Redesigning the prompt, we reasoned, would produce higher scores by allowing students to more accurately express the understanding they had acquired earlier.

Without discounting the need for a well written question, our data suggest that the prompt is not the seat of the difficulty; it lies elsewhere in the learning sequence. The "transfer" versions of the conceptual problems are better questions than their "capture" counterparts: they are more compelling measures of deep conceptual understanding, a primary objective of the course. We propose, then, that modifications in Steps 3 and 4 of

this sequence are more likely to have a salutary impact. Our conclusion is that the pre-exam preparation that many students are making for conceptual understanding tends to be inadequate.

The basic problem may be the failure of many students to move from a perception of themselves as academic “consumers” to the more effective vision of themselves as academic “producers.” It is the learner who must assume the responsibility for himself or herself to construct as complete a model as possible of the concept under consideration. When students see their tasks narrowly as memorizing what is set in front of them instead of creating an independent understanding for which they can claim ownership, they will probably write an answer to a conceptual problem on an exam that is incomplete or inaccurate, and they will be less likely to successfully transfer their understanding if the task is presented in a novel circumstance. Our data demonstrate that by providing directed hints during testing it is possible to elicit from peoples’ minds components of a satisfactory conceptual model that they might otherwise leave out, but that something is preventing those elements from emerging spontaneously. When asked in a post-exam interview why he failed to include elements of chromatin remodeling in his eukaryotic transcription regulation diagram (Version 12), one cell biology student replied, “But that’s in a separate figure in the text.” Rather than being merely a silly rationalization, this comment may reveal an important insight: students who persist with poor study strategies will tend to artificially compartmentalize and fail to make the links needed in order to develop an expansive and inclusive model.

How can we help facilitate the transfer of responsibility for learning from the teacher to the student? How can we get them to be “Producers” instead of “Consumers”?

Some already established ideas may prove useful in the “gradual release of responsibility” from teacher to student (Fisher & Frey, 2008). Teachers can establish learning objectives to help students focus on the essentials. We can model the kind of thinking required to be successful at a task – we should demonstrate to novices how the expert thinks. Students should be encouraged to work collaboratively in such a way that each contributes to the discussion or project.

When students follow a traditional study routine that lacks rigorous formative assessment, they tend to be unaware of the superficiality of their understanding. The following side note was written as part of a student’s answer to the eukaryotic pancreas problem in a recent semester (Version 13, winter 2007; this person’s score was 5 of 15 total points). “I really don’t know what you want drawn here. I know transcription and can draw it, but I’m completely lost here.” This person neither knows transcription nor is able to draw it, but is unaware of those deficiencies. In this circumstance the task of transferring in a novel setting became both daunting and frustrating. We have frequently come to similar conclusions during personal post-exam interviews with students who are perplexed by their low scores. A brief oral exam quickly reveals the gap between what they thought they understood and what they really do comprehend.

The solution to this problem may be as deceptively simple as to provide more practice. Teachers can apply at least two remedies. First, make the study problem transparent. Explain this tendency for students to compartmentalize, resist the common request for “lists” (of “things we should know” or “what might be covered on the exam”), and place the responsibility for conceptual understanding squarely where it belongs – “It is in your EQ sessions (Step 3) that you should mutually help one another to put together

a complete story, your own comprehensive model of transcriptional regulation.” Second, continually include examples of more rigorous conceptual problems during formative assessment (Step 4; Kitchen et al., 2006). This would also include explanations, during debriefing, of why some answers were excellent and others were poor.

As a general rule, constructing effective assessment problems does not receive the attention it deserves. Having established what the objectives of a course should be, it seems somehow natural to then figure out how best to teach those objectives in the classroom. The principle of “Backward Design” turns this intuitive sequence around by suggesting that the correct order of operations is: 1) formulate objectives; 2) design assessments (decide how to tell if the objectives have been met); and 3) plan appropriate teaching and learning activities (Wiggins & McTighe, 1998). We subscribe strongly to the Backward Design principle, but add the following corollary. The nature of the assessments should never come as a surprise, because they will have been introduced at the outset, and our students will have had multiple opportunities to practice responding to them before exam time.

Even a cursory examination of any of the contemporary texts for the subspecialties of biology will confirm that it is an information-rich discipline – extraordinarily so. A serious consequence of this is that there is a tension, even conflict, between learning the core conceptual principles that lies at the heart of biology, the sine qua non of the subject, and the voluminous detail (vocabulary, acronyms, examples, visual images, diagrams, etc.) that accompany these central ideas. Writing exam questions about the detail is relatively straight forward, and such questions abound. Writing exam problems that reveal genuine understanding of the central concepts is

difficult, and such problems tend to be rare. Unfortunately, it is frequently true that students who are ignorant of or have misconceptions about the basics can correctly answer questions of the former type about the superficialities. We are suggesting here that deep understanding that permits transfer is best acquired through a learning sequence in which students construct comprehensive models about fundamental principles and articulate them frequently. Teachers can best assist in this effort by being highly selective about what the syllabus requires (subjects covered, mandatory pages and figures from the text to be digested), and promoting out-of-class study strategies that include techniques like EQ.

Consider the potential benefits to an undergraduate whose study regimen includes wrestling with a “fuzzy problem,” one that is somewhat imprecise, whose context is implied but not stated directly, one which leaves to the problem solver the responsibility of determining what the boundaries of the task ought to be. If such an item appears unexpectedly on an exam it will be uniformly hated and generate a long line of disgruntled grade grubbers pleading for justice. “I know this stuff, but I couldn’t figure out what you were looking for,” will be the plaintive protest. Rather than succumb to these litigious pressures, we recommend that teachers serve up a regular diet of “fuzzy problems” during in-class and homework exercises. These are the kinds of learning experiences most likely to stimulate an exploration of the depths of the biology under scrutiny and test the accuracy of the learner’s comprehension of those realms.

### Summary

An assessment of students’ understanding of biological concepts should focus on fundamentals, not peripheral details. Problems that require transfer of genuine

comprehension to previously unseen circumstances are better than those that only require rehearsal of text or classroom presentations. Well-written prompts for exam problems are necessary, but attempts to write more effective prompts will fail to generate better performance if the actual deficit lies in inadequate pre-exam study. Students tend to compartmentalize and fail to make necessary linkages if their study is limited to memorizing the words of others. Responding to “fuzzy problems” during EQ and formative assessment sessions can lead to improved conceptual understanding.

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Table 1. Comparative Performance on Conceptual and Data Analysis Examination Problems

Exam	Conceptual* (%)	Data Analysis (%)
Midterm 1	67.4	63.4
Midterm 2	70.8	62.0
Midterm 3	54.6	62.7
Midterm 4	74.7	64.3

\* $p < 0.0001$  one-way ANOVA

Mean percent scores from midterm examinations administered in three semesters (fall 2000, winter 2000, and winter 2002). Three conceptual and three data analysis problems were included in each examination. All were constructed response items, requiring labeled drawings or tables (conceptual problems) or individual sentences containing valid conclusion statements (data analysis problems). Bonferroni post-test demonstrates that the average for each conceptual problem is different from every other average ( $p < 0.01$ ). There was no significant difference among the four data analysis mean scores ( $p > 0.10$ ).

Table 2. Layer analysis of the *His* Operon and Heart Problems

A. “*His* operon” problem: analysis of examination performance by cognitive “layer”

	Number Passed	95% CI	Percent
Layer 1	89	± 0.05	92.7%
Layer 2 (of students who passed Layer 1)	71	± 0.08	79.8%*
Layer 3 (of students who passed Layers 1 and 2); score of >7/9	29	± 0.12	40.8%

n = 96; Error represents 95% confidence interval; \* 71/89 = 79.8%

Analysis of 96 examination scores for student enrolled in the fall semester 2002. Points were tallied separately for three different levels of conceptual understanding: layer 1, correctly distinguishing a prokaryotic system; layer 2, recognition that the *his* operon is regulated negatively by a co-repressor in a manner analogous to regulation in the *trp* operon; layer 3, generating a comprehensive diagram including molecular details like attenuation.

B. “Heart” Problem: Examination of Student Performance by Cognitive “Layer”

	Number Passed	95% CI	Percent
Layer 1	67	± 0.09	69.8%
Layer 2 (of students who passed Layer 1)	53	± 0.10	79.1%*
Layer 3 (of students who passed Layers 1 and 2); score of >12/15	10	± 0.11	18.9%

n = 96; Error represents 95% confidence interval; \* 53/67 = 79.1%

Analysis of 96 examination scores for student enrolled in the fall semester 2002. Points were tallied separately for three different levels of conceptual understanding: layer 1, correctly distinguishing a eukaryotic system; layer 2, recognition that the cardiac actin gene is transcribed in a heart cell and the insulin gene remains repressed; layer 3, generating a comprehensive model including positive and negative regulation mechanisms that will result in a unique set of genes being expressed in the differentiated cell.

Table 3. Performance Scores for Variants of the Eukaryotic Transcription Regulation Conceptual Problem

<b>Version</b>	<b>Description.....</b>	<b>Semesters</b>	<b>Students</b>	<b>Mean Score</b>	<b>SD</b>
1	This diagram, entitled <u>Transcriptional Regulation In A Heart Cell</u> , is incomplete. Your task is to add clearly labeled representations of all the missing molecular components, and the events in which they participate. When finished, you will have a picture of the control mechanisms that lead to a cell with a unique content of specific proteins. CA = cardiac actin; I = insulin, N = nucleus; C = cytoplasm.	6	513	9.06	± 3.78
1B	This diagram, entitled <i>Transcriptional Regulation In A Heart Cell</i> , is incomplete.	(2)			
2*	When finished, you will have a picture of the <i>positive and negative</i> control mechanisms that lead to a cell with a unique content of specific proteins.	2	120	7.69	± 3.62
3	This diagram, entitled <u>Transcriptional Regulation In A Eukaryotic Cell</u> , is incomplete. <i>The example is from the heart.</i>	2	89	8.00	± 3.96
4	This diagram, entitled <u>Transcriptional Regulation In A Eukaryotic Cell</u> , is incomplete. <i>The example is from the heart...</i> When finished, you will have a picture of the <i>positive and negative</i> control mechanisms ( <i>some genes are activated, some remain repressed</i> ) that lead to a cell with a unique content of specific proteins.	2	88	9.11	± 3.98

5	When finished, you will have a picture of the <i>positive and negative</i> control mechanisms ( <i>some genes are activated, some remain repressed</i> ) that lead to a cell with a unique content of specific proteins.	1	23	9.17	± 3.79
6*	This diagram, entitled <u>Transcriptional Regulation In A Pancreatic Islet(Endocrine) Cell</u> , is incomplete... When finished, you will have a picture of the <i>positive and negative</i> control mechanisms that lead...	3	464	6.96	± 3.91
7	This diagram, entitled <b>Transcriptional Regulation In A Eukaryotic Cell</b> , is incomplete. <i>The example is from the heart...</i> When finished, you will have a picture of the <i>positive and negative</i> control mechanisms ( <i>some genes are activated, some remain repressed</i> ) that lead to a cell with a unique content of specific proteins. ( <i>Drawing of cardiac actin placed in cytoplasm.</i> )	1	68	8.40	± 4.09
8	<i>The human embryo undergoes developmental processes that result, at birth, in a number of differentiated cell types, each with a unique structure and specialized function. Your task is to draw a clearly labeled diagram that explains, in as much molecular detail as you can, how activation and repression of transcription contribute to differential gene expression.</i>	2	95	8.28	± 3.40
8B	<i>The human embryo undergoes developmental processes that result, at birth, in a number of differentiated cell types, each with a unique structure and specialized function. This is primarily the</i>	(1)			

*result of mechanisms that regulate transcription. Your task is to draw a clearly labeled diagram that explains, in as much molecular detail as you can, how activation and repression of transcription contribute to differential gene expression*

9	<i>Draw a clearly labeled diagram that explains, in as much molecular detail as you can, the mechanisms that regulate transcription in a eukaryotic cell.</i>	1	29	9.58	± 2.63
10	<i>Draw a clearly labeled diagram that outline the details of how transcription is achieved. Illustrate the mechanisms that operate at the molecular level in eukaryotic, but not in prokaryotic, cells. Include both activation and repression processes.</i>	1	29	8.55	± 3.07
11	<i>Draw a clearly labeled diagram that outlines the details of how regulation of transcription is achieved in any eukaryotic cell type of your choice. Include in your drawing at least two genes, chosen to illustrate both positive and negative mechanisms that are involved.</i>	1	30	7.51	± 3.62
12	<i>Assume that this diagram, entitled <b>Transcriptional Regulation In A Pancreatic Endocrine (Islet) Cell</b>, is part of a chapter in a text whose subject is “Physiological And Developmental Regulation Of Gene Expression.” The figure, however, is incomplete. Your task is to add clearly labeled representations of all the missing molecular components, and the events in which they participate. When finished, you will have a picture of the spectrum of control mechanisms that lead to a cell</i>	2	117	8.28	± 3.16

with a unique content of specific proteins. N = nucleus, C = cytoplasm, I = insulin, CA = cardiac actin.

13	<i>(Same as #12, but with preliminary questions. See Table 3B)</i>	2	117	8.90	± 4.15
14	In this problem you need to “think like a differentiated eukaryotic cell,” In this case a pancreatic endocrine (islet) cell. Islet cells are capable of synthesizing insulin depending on blood glucose levels. Draw two pictures of the gene regulation that takes place, 1) after a meal, and 2) before a meal. These figures (on the front and back of this page), however, are incomplete. Your task is to add clearly labeled representations of the <b>insulin gene</b> and all the missing molecular components and events involved in its regulation. When finished, you will have a picture of the spectrum of eukaryotic gene regulation representations of the <b>insulin gene</b> and all the missing molecular components and events involved in its regulation. When finished, you will have a picture of the spectrum of eukaryotic gene regulation mechanisms. <b>Condition 1: Going From Low to High Blood Glucose levels –After a Meal</b> (we’ve drawn the nucleus really large so that you’d have room to draw everything. <b>Hint:</b> Focus on the events occurring in the nucleus. <b>Condition 2: Going from High to Low Blood Glucose Levels – Before a Meal</b>	1	57	8.26	± 4.23

\* Compared to Version 1, Versions 2 and 6 are statistically different using Dunnett’s or Bonferroni’s post-test ( $p < 0.05$ ). However, the anticipated effect of changing the prompt was to promote improvement; students actually did worse on Versions 2 and 6. Overall one-way ANOVA ( $p < 0.0001$ ).

## Figure Captions

Figure 1. Conceptual Examination Problems.

The numerical designation for each prompt indicates its exam and item number (2-1 = midterm exam #2, item #1, etc.) Numbers in bold are mean raw and percent scores ( $\pm$  standard deviation) across 9 semesters (n = 1218 students)

Figure 2. (A) Transfer and (B) Recall Versions of the Conceptual Problem Assessing Understanding of Transcriptional Regulation in Prokaryotic Cells.

Figure 3. Original Transfer Version of the *Heart* Conceptual Problem Assessing Understanding of Transcriptional Regulation in Eukaryotic Cells.

Figure 4. Analysis of Student Performance on the Transfer vs. Capture Versions of the *His* Operon Problem. Total scores are reported as well as scores for subsections a, b, and c (see Figure 2). Data for winter 2003 and fall 2003 semesters (transfer version n = 145, capture version n = 142). Analysis was an unpaired, two-tailed t-test. Error bars indicate mean  $\pm$  SEM.

Figure 5. Preliminary Objective Questions Included in Version 13

Figure 6. Heart Variant Averages. One-way ANOVA failed to demonstrate significant improvement compared to Version 1. Error bars indicate mean  $\pm$  SEM.

Figure 7. Ideal Learning Sequence for Acquiring Conceptual Understanding

## Figure 1

### 2-1 Microtubules/Microfilaments

**Avg = 9.81 (65.4%) ± 0.997**

Construct a table that compares and contrasts microtubules and microfilaments. Your table should include elements that compare structure, function, and the mechanisms involved in polymerization and depolymerization. Be sure your table is neat and readable.

### 2-2 Mitochondria/Chloroplasts

**Avg = 11.0 (73.3%) ± 1.11**

Draw a simple diagram that illustrates the following concepts: generation of ATP in the mitochondria, generation of ATP in the chloroplast and synthesis of sugars in the chloroplast. Your diagram should identify the general principles involved without giving the details and specific names of the many individual proteins and other organic molecules involved. However, it must divulge the specific roles of water and the roles and names of the relevant gases, subatomic particles, and nucleotides.

### 2-3 Secretory Pathway

**Avg = 11.0 (73.3 %) ± 1.06**

Draw a diagram that illustrates the steps involved in synthesizing a secretory protein. Your diagram should include the roles of the various organelles involved as well as the various protein and RNA complexes. The details of translation per se are not to be included.

### 3-3 Cell Cycle

**Avg = 8.14 (54.3%) ± 1.20**

Draw a clearly-labeled diagram that illustrates regulation of the cell cycle at the molecular level. Focus specifically on entrance and exit from M Phase, adding any general concepts that may apply at other phases as well. If you choose, you may augment your diagram with short sentences that describe relevant principles more easily stated than drawn.

### 4-1 Signal Transduction/Cross Talk

**Avg = 12.3 (82.0%) ± 0.936**

Work from a certain laboratory studied cross talk between G-protein-coupled hormone pathways that lead to the activation of protein kinase C with those that lead to production of cAMP. Specifically, activation of protein kinase C directly enhances the ability of hormones to stimulate cAMP production. Draw a diagram that illustrates the two pathways and proposes three ways by which this cross talk could occur.

### 4-3 RTK Signal Transduction

**Avg = 11.7 (78.0%) ± 1.14**

Draw a diagram that illustrates a mitogenic (one that promotes cell division) signaling pathway that is mediated through a RTK. Include all the relevant molecules and regulatory events involved. Add to your diagram the role of GAP, and explain the phenotype of a cell line that was homozygous for a non-functional mutation of GAP.

Figure 2

A. Original prokaryotic problem (*his* transfer version)

- a) Histidine is synthesized from ATP and 5-phosphoribosyl 1-pyrophosphate in a pathway requiring 10 enzymes. The genes encoding these proteins are linked in the *E. coli* genome. Analysis of the polycistronic mRNA generated from these genes shows 7 tandem *his* codons very early in the coding sequence. Based on this minimum amount of information, describe the likely mechanisms by which transcription of these genes are regulated. Include both a written description and a clearly labeled set of diagrams.
- b) Which elements of the model you have described above do you expect to be different from the genetic system in *E. coli* that regulated utilization of galactose?
- c) Which elements of the model you have described above do you expect to be different from those found in a mammalian cell?

B. Modified prokaryotic problem (*trp* recall version)

- a) Describe the mechanisms by which transcription of the genes of the *trp* operon in *E. coli* are regulated. Include both a written description and a clearly labeled set of diagrams.
- b) Which elements of the model you have described above do you expect to be different from the genetic system in *E. coli* that regulated utilization of lactose?
- c) Which elements of the model you have described above do you expect to be different from those found in a mammalian cell?

Figure 3

This diagram representing Transcriptional Regulation In A Heart Cell is incomplete. Your task is to add clearly labeled representations of all the missing molecular components, and the events in which they participate. When finished, you will have a picture of the control mechanisms that lead to a cell with a unique content of specific proteins. CA = cardiac actin; I = insulin, N = nucleus; C = cytoplasm.

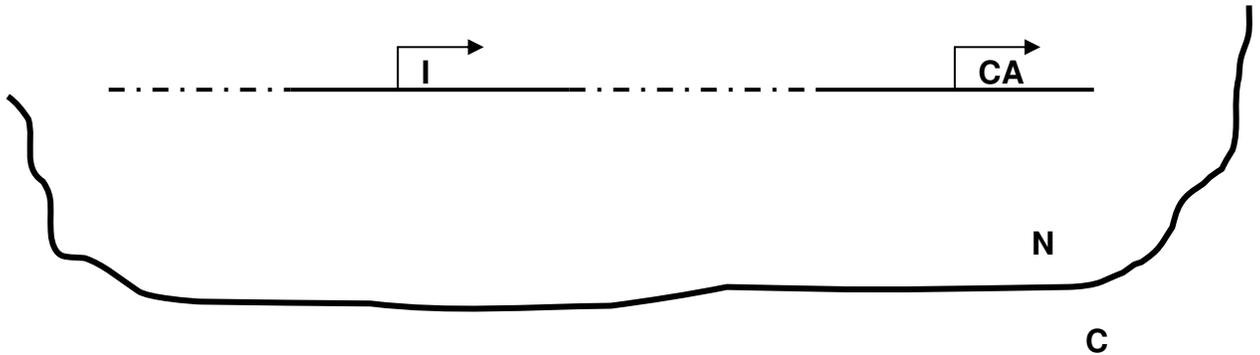


Figure 4

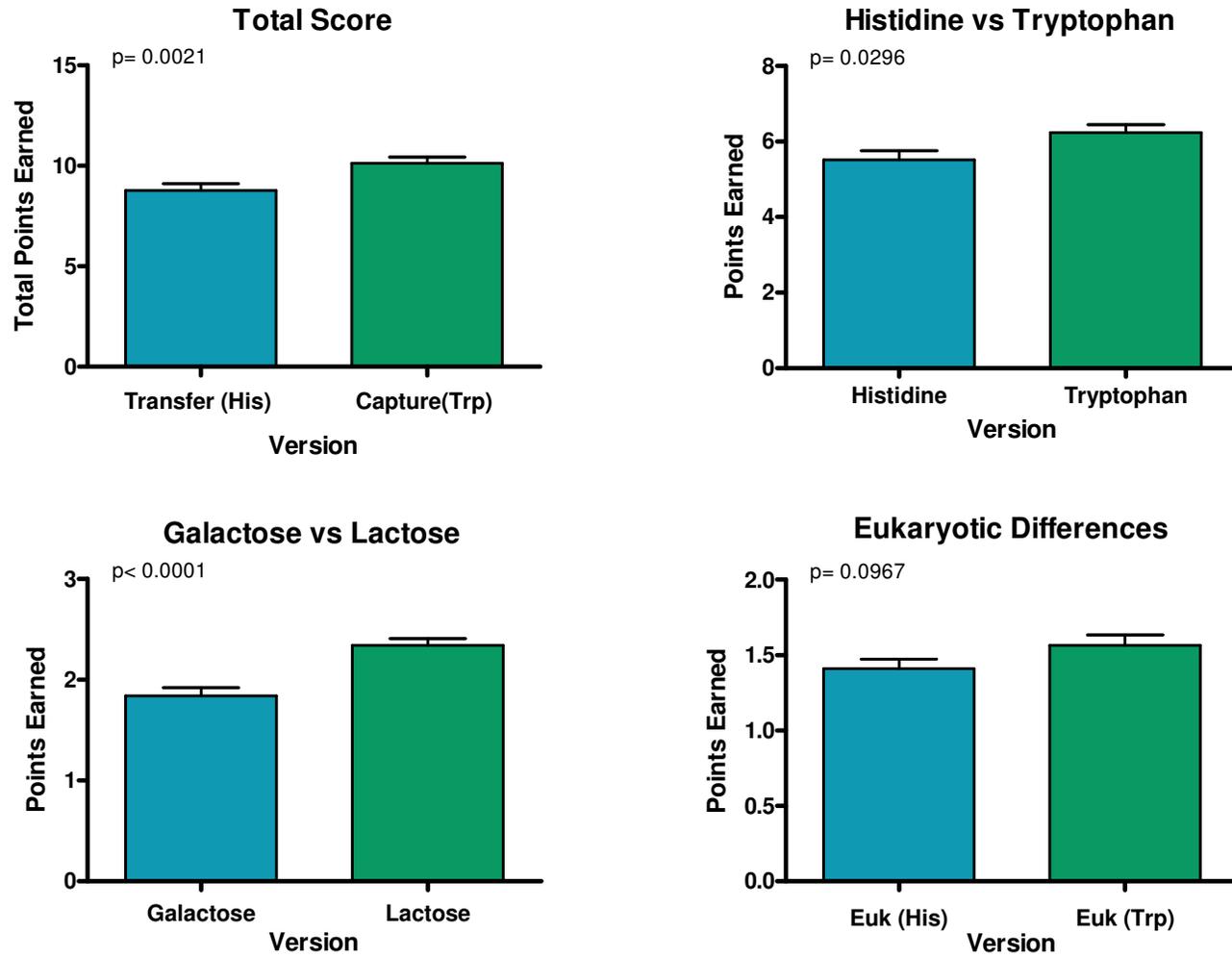


Figure 5

1. \_\_\_\_\_ True or False. Control of transcription of eukaryotic genes is commonly achieved through the binding of repressor proteins to operator sequences located within upstream promoters.
2. \_\_\_\_\_ True or False. Transactivating nuclear proteins that bind specifically to enhancer elements succeed in initiating RNA synthesis. They accomplish this by recruiting enzymatic proteins that remodel nucleosome core particles as a prerequisite to making promoter sites accessible to RNA polymerase.
3. \_\_\_\_\_ True or False. RNA polymerase II initiates transcription only at designated start sites through recognition of specific nucleotide sequences at its active site.
4. Which of the following proteins is most likely to be associated with chromatin in the promoter region of the tryptophan oxygenase gene following treatment of a rat with hydrocortisone? Circle one.
  - A. transactivating protein (Gal4)
  - B. catabolite activating protein (CAP)
  - C. cytosine methyl transferase
  - D. histone acetyl transferase
  - E. histone deacetylase
5. Which of the following proteins is most likely to be associated with chromatin in the promoter region of the  $\beta$ -globin gene in a brain cell of a fetal mouse? Circle one.
  - A. TFIID
  - B. Mediator
  - C. protein kinase A
  - D. histone acetyl transferase
  - E. cytosine methyl transferase
6. (Circle all that apply.) By binding to the TATA Box, TBP:
  - A. distorts nucleosome architecture by altering the interactions between histones and DNA
  - B. distorts the helix (kinks occur leading to a bending of the helix)
  - C. facilitates binding of other components of the basic complex (TFII A and B)
  - D. facilitates the binding of transactivating proteins to response elements in enhancers
  - E. phosphorylates the C-terminal domain of RNA polymerase at multiple sites

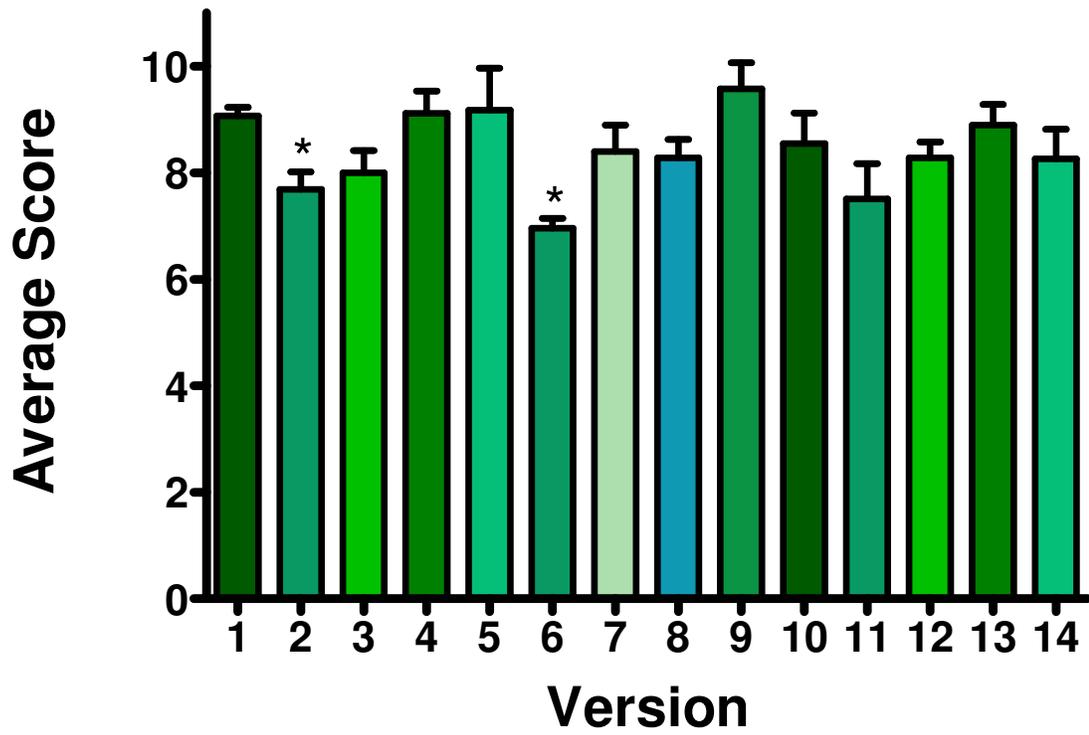
7. (Circle all that apply.) The mechanisms through which eukaryotic repressor proteins are known to act include

- A. competing with activator proteins for DNA binding sites
- B. masking the activation domain of transactivating proteins
- C. interacting from silencer elements with general transcription factors
- D. recruiting repressive chromatin remodeling complexes
- E. recruiting enzymes that condense chromatin through biochemical modifications of histones

8. \_\_\_\_\_ Provide the name of one specific histone acetyl transferase.

9. \_\_\_\_\_ Name the type of DNA sequence elements that may limit the boundaries of gene expression to a given domain or act to buffer from effects outside that domain.

Figure 6



Overall  $p < 0.0001$

\* Compared to Version 1  $p < 0.05$

Figure 7

In-Class

*2. Retrieve and apply facts and concepts through active learning exercises.*

*4. Test for mastery with formative assessments.*  
**Design plan for closing gaps in understanding.**

Out-Of-Class

**1. Acquire foundational information through reading the text.**

**3. Reiterate retrieval of facts and concepts through Elaborative Questioning with classmates.**

*5. Author summative assessment problems.*

**6. Write solutions to summative assessment problems.**

CHAPTER 2  
Practicing Transfer

Previous experience has demonstrated that the ability to transfer is not trivial. Because multiple changes to the prompt for the heart problem did not improve performance, we hypothesized that perhaps students needed more “deliberate practice” in order to produce sufficient gains. Some may think that performance in any task is limited by certain genetic constraints. However, in their review, Ericsson, Krampe, and Tesch-Romer discussed how “the maximal level of performance for individuals in a given domain is not attained automatically as function of extended experience... stable levels of performance after extended experiences are not rigidly limited by unmodifiable, possibly innate, factors, but can be further increased by deliberate efforts” (1993).

We used the Biology 360 course taught in the summer term 2008 to experimentally test the effect of extended practice on transfer performance. While there was still a focus on data analysis, specific attention was made to emphasize construction of conceptual ideas. Students were given many more opportunities to practice their transfer skills on conceptual problems added to each formative assessment. Individualized instruction would be the ideal process for guiding student to specific ways to improve their transfer performance. Realistically, this cannot be done in most classrooms from elementary school to the university level. Instead, teachers must create practice activities that engage students both during and between scheduled class meetings. “We call these practice activities *deliberate practice* and distinguish them from other activities, such as playful interaction, paid work, and observation of others” (Ericsson, Krampe, & Tesch-Romer, 1993).

For the summer term, these opportunities came in the form of in-class practice problems and advanced elaborative questioning scenarios. Transfer problems were included as an integral feature of the formative assessments held regularly each week. In past semesters, the formative assessment problems consisted of one general conceptual problem and one data analysis problem. During the summer term, in order to give students more practice in transferring “big idea” concepts, the format for the assessment changed to two conceptual problems and one data analysis problem. The first conceptual problem usually asked the students to diagram specific facts or processes presented in class. This was considered a “C grade-level” problem, only requiring students to use memorization and recall skills to retrieve information. The second conceptual problem was written in a “transfer” format – the prompt presented a novel scenario from which the students were to demonstrate their understanding and application of a core concept learned earlier. These problems were considered “A grade-level” since they required a transfer of understanding acquired in one setting to a new system. Our hypothesis was that if given enough opportunities to practice and hone transfer skills, the summer-term students would perform better on the *his* and Pancreas problems compared to that achieved in prior semesters.

### *His* Problem Results

We administered the *his* problem on a formative assessment exactly halfway through the term. The students had been introduced to prokaryotic gene regulation two days before. Unfortunately, their scores did not significantly improve despite the

increased emphasis we placed on transfer in conceptual problems (Table 1). Twice as many (57.3%) focused their answer on the attenuation mode of regulation (compared to previous semesters, 28.8%), but only half as many responded in complete fashion by including both the repressor and attenuation features (18.4% cf. 39.2%). Improvement in this transfer skill may take longer than the few weeks allotted to our summer-term students.

During the class period immediately after the assessment, students participated in an anonymous survey to explain their performance on the *his* problem (Table 2). A minority (16%) expressed confidence in their transfer ability and about one-fourth had no explanation for weakness in this task. Only 6% perceived that their score was related to the new context. Instead the majority of students, 34%, stated that they were over analyzing the prompt, searching for some clue as to what “the teacher wanted” instead of allowing the prompt to get them on the right track for demonstrating their understanding. This may be a common residual problem many educators face. Unfortunately, many students’ previous academic experiences imprint upon them the belief that tests and grades are based on each student’s ability to “out guess” the teacher. Instead of focusing on skills that could make them better thinkers overall, students resort to tactics that will help them get the grade they want without expending the effort needed to construct long-lasting conceptual frameworks.

After analyzing why they may not have performed as they had hoped, the students were also asked to provide a corrective action plan for improved success in the future. A diversity of responses was generated. These were grouped into the seven categories

summarized in Table 3. Our overall impression from these comments is that many students do not have a useful explanation for their inadequate performance, and some of these suggestions would actually be counter-productive. For example, the solution proposed by 19 students was to include everything they knew on future conceptual problems. This unfortunate “shotgun” approach to an improved score does not, of course, address the real problem – an inability to discriminate critical from trivial attributes. We hope to persuade students to abandon such a strategy. Having once looked at the key to a conceptual problem, many students complained that they “knew the information,” but didn’t know that it needed to be included for a correct answer. Completeness and thoroughness were heavily emphasized during the feedback phase of each of the assessment sessions in an attempt to help students construct comprehensive models of the biology they were studying.

When asked how to improve, students frequently say they will “try harder.” For some this probably means better focus or concentration while reading a textbook, or paying attention in class. The sense is that “I need to be more conscientious.” For most, however, “trying harder” at the same unsuccessful routine is not likely to help; a different kind of preparation is called for. Psychological studies on sports performance shows that while many individuals can excel in their domain, many reach a plateau where increased speed or accuracy seems impossible. However, these studies also show that there must be a change in the structure of the training to get beyond these leveling-off points (Ericsson, Krampe, & Tesch-Romer, 1993). The same could be said of a variety of skills where practice is involved, including scholastic transfer. By the late 19<sup>th</sup> century Bryan and

Harter (1899) demonstrated that simple repetition produced less than maximal performance. Indeed, continued improvement required purposeful “reorganization” of how to practice and perform the skill. These students who wish to “try harder” might be better served by determining to “try differently.”

We refer again to the fact that a large number of the students were unable to offer an explanation for why they didn’t include in their answers conceptual elements that they thought they understood. What does this mean about the student? What does this mean about how we teach mastery of the biology and the development of the complex skills needed to succeed with this kind of thinking? Helping students to be meta-cognitive (to think about their own thinking) needs to be a major objective for science courses intent on improving student learning and acquisition of transfer skills. These data show that many students don’t know where they went wrong, and most probably stopped thinking about it after the assessment was completed.

Recently there have been specific studies about how meta-cognition can improve academic performance. Kramarski and Zoldan experimented with different meta-cognitive approaches on a group of 9<sup>th</sup> grade Israeli students in mathematics classes (2008). There were 4 groups of students. The first were taught to think meta-cognitively by analyzing and diagnosing errors in students’ responses. A second group was taught to use a series of generic questions that they needed to answer to be successful. These questions had directed their thinking about how to connect a problem to prior knowledge, determining how, when, and why to use a specific mathematical strategy, and finally to reflect. The third group was taught both of the methods described above, and finally the

fourth, control group was not instructed in either meta-cognitive strategy. The researchers collected performance data on several different types of problems on several occasions, and found that those who were taught both meta-cognitive processes had improved performance over those only taught one or the other, and that they all performed better than the control group (Kramarski & Zoldan, 2008). These results should not be unique to 9<sup>th</sup> grade mathematics. University professors too must encourage a thoughtful analysis of performance on transfer skills if students are to make improvements. Of course, when a teacher chooses to include meta-cognitive analysis as a formal course objective, it will be probably be necessary to reduce the breadth of subject matter coverage.

#### Heart Problem Results

At the end of the semester we administered the Pancreas problem as a part of the final exam. The data in Table 4 demonstrate that performance did not improve. None of the performance percentages (43-83%) for the basic elements rose to the level of those achieved in the two semesters of the previous year. With respect to the transfer elements, we found that far more students (76%) included the chromatin remodelling HAT element in their diagrams than in previous semesters. However, most of the other elements were not well represented (4-42%). This attention to specific details, we have termed “spotlighting”, in analogy to those occasions when only one small portion of the theatre stage is illuminated. Students seem to focus on one portion of a concept, leaving other important elements in the shadows. We determined that this spotlighting effect may be

introduced on one or more of the following occasions: during the lecture, while reading from the textbook, or in a student's personal study alone or with peers.

Harp and Mayer (1998) discussed the spotlighting effect in their article about the cognitive damage of "seductive details". They remarked that "readers typically remember interesting adjuncts included in a passage rather than structurally important ideas." In the article they review a basic outline for how learning takes place. There must be *selection* of the relevant ideas, *organization* of those ideas, and finally an *integration* of those ideas with connections to prior knowledge. They performed experiments to test in which of these three stages seductive ideas damages proper learning of major principles about lightning formation. Perhaps seductive details "distract" learners from paying attention to the important information. Alternatively, seductive details "disrupt" the organizational process of important ideas, making them harder to recall. And finally, it could be that depending on where the seductive details are placed in a text, readers build their knowledge around the wrong framework, in other words, they are "diverted" from the right set of concepts.

Preliminary data suggest that it is in the last step, *integration* where seductive details do the most harm. Harp and Mayer (1998) found that if college students read interesting tidbits about where lightning strikes before reading about how a lightning flash is actually formed, they could not recall the foundationally essential elements of lightning formation. If the text was reversed with the seductive details coming at the end of the passage on lightning formation, students performed significantly better on recall and problem-solving questions. The authors acknowledge the following limitations to the

study: only a single text was used, there was a time limit for reading the material, and student selection was based on the amount of prior knowledge the college students self-reported on a questionnaire. The researchers also felt that interference of seductive details may not have been demonstrated in the other stages of learning, namely *selection* and *organization*, because the text was short, basic, and relatively organized.

Indeed, more recent research has provided data supporting the hypothesis that seductive details might interfere at multiple levels. Leham, Schraw, McCrudden, and Hartley (2007) wanted to expand on Harp and Mayer's research and to clarify the stages of learning while demonstrating that they are not mutually exclusive. These researchers tested the effects of seductive details on three learning processes, *attention*, *text coherence*, and *schematic activation*, which parallel Harp and Mayer's stages, *selection*, *organization*, and *integration*. The lightning formation text from Harp and Mayer's experiment was adapted and students were asked to read the passage without a time limit. The college students then rated the interest and importance of each sentence on a 4-point Likert-type scale. The highly interesting, but unimportant sentences identified by the students (22% of the sentences in the passage) were classified as seductive details. In all subsequent experiments student reading times were measured by a computer program that displayed one sentence of the text at a time, and proceeded at the discretion of the participant. The researchers also measured recall – students wrote down everything they could remember from the text and were graded according to a strict rubric for both major principles and seductive details. Each participant's holistic understanding was assessed by an essay requiring deep conceptual understanding of lightning formation for success.

Leham et al. (2007) found that students given text passages containing seductive details read the major principle sentences faster than students reading text containing just major principles. This was interpreted as support for the hypothesis that seductive details pull a reader's attention away from the main ideas. Additionally, students reading seductive details remembered fewer base ideas about lightning formation on the recall test, perhaps because they skimmed too rapidly through the more relevant text. Students who read the passage with seductive details also had fewer legitimate claims (conclusions) in their essays, suggesting that these students had a less holistic grasp of the material. This result might be due to a decreased ability to arrange the text coherently because of the interspersed seductive detail sentences, and/or that the seductive details activated an inappropriate schema around which the information was built. This newer research suggests that all three processes are interactive and may work in conjunction. "For example, disruption due to coherence breaks may distract a reader's attention away from main ideas, or distraction while reading seductive details may lead readers to construct a schema based on seductive details rather than main ideas" (Lehman et al., 2007)

What are the implications of these data in the college classroom? We may need to be more careful and selective about when and how we teach the most relevant information both in reading assignments and in lecture, and when and how to teach some of the interesting details that may actually be damaging to students' learning. Another part of the solution for how to combat this spotlighting problem probably lies in making students explicitly aware of this tendency and provoking them to construct the most

comprehensive model of a concept during their individual and group study. Determining how to overcome the “spotlighting effect” is especially relevant in cell biology, a subject that is inherently information-rich.

Practice is intuitively a good thing. Although we did not see measurable performance gains with either transfer problem, we feel that directed practice is needed, especially in large science classrooms. We plan to continue the inclusion of transfer problems in formative assessment in the future. Students will need to be continually prompted to think meta-cognitively about how they approach transfer problems and how to improve their individual performance.

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Table 1. Summer 2008 *his* problem results compared to fall and winter 2007

Semester	N	Version	Regulatory Mechanisms Included (%)			
			Repressor Only	Attenuation Only	Both	Blank*
Avg. †	674	<i>his</i>	13.8	28.8	39.2	18.2
Avg. ‡	142	<i>trp</i> §	10.6	23.4	59.6	6.4
S 2008 ¶	103	<i>his</i> §	8.7	57.3	18.4	15.5

\* no or erroneous answer

† weighted average of 6 semesters by number of students

‡ weighted average of 2 semesters by number of students

§  $p < 0.01$ , cf. original administration of *his* version (chi square analysis)

¶ included 3 pre-exam weekly formative practice exercises

Table 2. *His* Problem Survey Results

<u>Option</u>	<u>Option Content</u>	<u>Responses</u>	<u>Percent</u>
A	I was not really prepared.	10	10%
B	The scenario presented in the problem was completely foreign; I couldn't relate it to anything I had studied or understood in another context.	6	6%
C	I did not really understand parts of the concept even though I tried hard to prepare.	9	9%
D	I believe I understand how to approach these problems and I was able to demonstrate that on the assessment.	16	16%
E	My strategy was to search the problem for specific clues as to what you wanted rather than use the prompt to allow me to demonstrate my understanding.	34	34%
F	I really don't know why I left important elements out that I thought I understood.	24	24%
	Total	99	100%

Table 3. Proposed Action Plans

	<u>Action Plan</u>	<u>Responses</u>
1.	“Try harder” (talk more in class, better pre-class study, try harder in AEQ, better class notes, go to homework sessions)	14
2.	“Be more deliberate” (read text or assessment prompt more carefully)	15
3.	“Put down everything I know” (Cover all the bases. I won’t be graded down for excess explanations. The prompt led me astray.)	19
4.	“Focus better on concepts initially” (More thorough in capturing details, terms, concepts. Pay closer attention.)	11
5.	“Try for ‘Big Picture’” (Let details go; apply concepts presented earlier in course.)	12
6.	“Write assessment response as a teacher; don’t second guess the prompt.”	15
7.	Miscellaneous	13

Table 4. Summer 2008 Pancreas problem results compared to fall and winter 2007

	% of Students Who Included the Element in Their Drawing		
	Version Without Objective Questions (A)*	Version With Objective Questions (B)†	Summer 2008 (A)*‡
<u>Basic Elements</u>			
Enhancer	92 (± 5)	85 (± 6)	67 (± 8)
Transactivator	90 (± 5)	80 (± 7)	78 (± 7)
TATA	92 (± 5)	93 (± 5)	43 (± 9)
TBP	82 (± 7)	87 (± 6)	43 (± 9)
TFIIA, etc.	71 (± 8)	72 (± 8)	61 (± 9)
RNA Polymerase II	85 (± 6)	87 (± 6)	83 (± 7)
<u>Transfer Elements†</u>			
Silencer	41 (± 9)	42 (± 9)	30 (± 8)
Repressor	36 (± 9)	46 (± 9)	40 (± 9)
Nucleosomes	23 (± 8)	27 (± 8)	42 (± 9)
HAT	21 (± 7)	36 (± 9)	<b>76 (± 8)</b>
DHAT	11 (± 6)	18 (± 7)	4 (± 4)
DNA Methylase	25 (± 8)	35 (± 9)	19 (± 7)

Error margins indicate 95% confidence intervals (note the bolded number demonstrates a significant difference).

\* Pancreatic problem without cues (winter 2007, n = 119 and fall 2007, n=119; summer 2008, n=122).

† Pancreatic problem with selected response questions as cues (winter 2007, n = 119 and fall 2007, n=119). As an aggregate, the performances on the transfer elements were significantly different ( $p < 0.04$ ) cf. Version A and Version B by unpaired, two-tailed t-test. However, this difference was not due to emphasis from any one element.

‡ Bonferroni post-tests demonstrate a significant difference ( $p < 0.05$ ) between the summer 2008 term averages and Version B averages in both basic elements and transfer elements (one-way ANOVA).

CHAPTER 3

Learning Styles

&

Transfer Ability

A student's individual learning style may have a significant impact on his or her performance on problems that require academic transfer. Learning style would include both a philosophical component – one's view about education, its goals and processes, and practical elements – including study strategies and other scholastic procedures. It might appear obvious then, to find a match between the common learning styles of a group of students and the design and implementation of an academic course. However, in a critique of learning styles, Steven A. Stahl reviews many studies that fail to show that teaching and assessing students according to learning style produces measurable gains (1999). This may be because the inventories used to place student into categories may be biased, incomplete, and too general to be most useful. It is also impractical to expect teachers to be able to correctly categorize individuals and then make the perfect learning environment for each even in a small classroom, let alone a large cell biology course.

### Methods

While there may be a lack of empirical support for applying learning style information, having students think meta-cognitively about how they believe they best learn is likely to provide insights for both the students and the teacher. During the winter 2007 semester, students were asked to identify which one of ten possible learning styles was the closest personal fit for them (Figure 1). First, they selected the learning style category to which they felt they currently belonged. Then they were asked to select another learning style whose attributes they "wished" they possessed, one in which they might prefer to be categorized. These choices were explained in the context of a one page written essay which was a self-analysis describing how they think, study, and attempt to

learn. Instead of using these data to determine how to better teach and assess individuals (an effort whose usefulness Stahl questions in his review), we attempted to find a connection between learning style and transfer ability.

Seeing similarities between some of the 10 learning styles, we grouped them into 4 discrete categories: Implementers, Innovators, Strategists, and Miscellaneous based on common or overlapping traits. We defined Implementers as those students who were good at following rules, tended to focus on details, and were good at reproducing memorized material. Innovators are people who are creative and inventive; they seek connections between details in order to find patterns, and they work to understand the underlying principles or concepts. Students who classified themselves as Strategists could be described as being good at internalizing the expectations of teachers and managing their time and study in order to get the best grades. The Miscellaneous Group, which did not fit easily into the other three, was composed of the learning styles that focused on speed, accuracy, or took an evaluative stance on learning.

## Results

The difference between what students designated themselves to be at present and what they preferred to be was substantial ( $p < 0.01$ , Table 1). As to current status, a majority (36%) of the 187 responses were in the Implementers category. For the preferred status, however, 64% of the 189 responses were in the Innovators category. From these data we conclude that students perceive the advantages of learning styles that are less focused on going along and getting by (Implementers), and are more focused on genuine, long-lasting scholarship (Innovators).

Our deliberations over the results led us to hypothesize that students with the characteristics of the Innovators group would perform better at transfer tasks. To test this, we undertook a reexamination of student performance on the winter 2007 Heart/Pancreas problem. Recall that during winter 2007, three versions of the Heart/Pancreas problem were given to the students. The two of interest here are those with and without selected response cue questions to be answered before responding to the problem proposed. The rubric used to identify transfer elements of the Heart/Pancreas problem from the recall elements was used to re-grade the winter 2007 tests. The average scores on these two parts of the question, recall and transfer, were then correlated with learning style and version. The result of this analysis was that the recall task did not differentiate students by learning style for either version (performance levels varied from 4.6 to 5.8,  $p > 0.05$ , Figure 2). However, the transfer task did differentiate among learning styles on the original/basic version – the version without cues on the back ( $p < 0.001$  cf. Implementers and Innovators). The Innovators (1.4 average score) outscored the Implementers (0.7 average score). When the cues were present, however, this advantage disappeared. The data also show that the strategists tend to be the best performers overall.

## Discussion

Robert J. Sternberg (1999) conducted research with Elena Grigorenko which addressed the following question, “When abilities are taken into account, do styles still predict academic achievement? In other words, [they] were addressing directly the question... whether they account for significant variation in student performance over and beyond what is accounted for by abilities.” The two grouped 199 high school

students into separate groups for a four week AP psychology course. The separate groups were taught with different emphases on analytical, creative, memory, or practical skills. Students were also categorized as being legislative thinkers, executive thinkers, or judicial thinkers (Figure 1) by taking a learning style test (this classification did not determine into which of the four teaching groups the students were assigned). Finally, the students' analytical, creative, memory, and practical thinking skills were assessed (Grigorenko & Sternberg, 1997). The two researchers found that the legislative and judicial styles were positively correlated with all four skills assessed (correlations ranged from .15 to .23), meaning that students with legislative and judicial styles demonstrated analytical, creative, memory, and practical skills. Recall that in our study we categorized legislative students as Inventors. Students in the executive style category (Implementers) had negative correlations with analytical and creative thinking tasks on Grigorenko and Sternberg's assessment, -.15 and -.16 respectively. Although these correlations are modest, these data support our similar finding that Inventors outperform Implementers in analytical and creative tasks.

There is an ongoing debate about whether to match or purposely mismatch teaching and assessment styles in order to learning styles to increase student performance, with strongly conflicting views expressed. Our goal is not to diagnose students and then prescribe different tactics for teachers, but rather to increase students' understanding of their individual learning style in order to induce change. In a written lecture, Dr. David Robotham (1999) summarizes our hope for future student progress:

As an individual's proficiency increases, the use of systematic mismatches between instructional approach and learning style may encourage the

development of a wider learning style repertoire... It is theoretically possible that individuals can develop their learning capability to the point where they may consciously choose a learning style they find harder to learn through, as it is the most appropriate learning style, given the nature of a particular learning task.

The students in our winter 2007 semester recognized that adopting a different learning strategy, in the Innovator style, might help them be more successful with the difficult “analytical tasks” that we required them to complete (Table 1). Teachers must give students opportunities to develop this less intuitive learning style as a means to help increase their transfer skills.

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Table 1. Learning Style Self-Designation and Grouping

<u>Learning Style</u>	<u>Description</u>	<u>Self-Designation</u>	
		No. Current <sup>1</sup> (%)	No. Preferred <sup>2</sup> (%)
A	Executive: follow rules	37 (20)	7 (4)
B	Legislative: creative, inventive	8 (4)	33 (18)
C	Judicial: evaluate, give opinions	12 (6)	14 (7)
D	Impulsive: opt for speed	10 (5)	1 (1)
E	Reflective: opt for accuracy	15 (8)	14 (7)
F	Holistic: seek connections	23 (12)	30 (16)
G	Serialist: focus on details	11 (6)	13 (7)
H	Deep: seek patterns, principles	18 (10)	58 (31)
I	Surface: reproduce, memorize	20 (11)	1 (1)
J	Strategic: manage for grades	33 (18)	18 (10)
A, G, I	Implementers	68 (36)	21* (11)
B, F, H	Innovators	49 (26)	121* (64)
C, D, E	Miscellaneous	37 (20)	29* (15)
S	Strategists	33 (18)	18* (10)

Cell Biology, winter 2007. Students were given 10 descriptions of different academic learning styles. In an essay each person identified that style that best characterized his or her current state, and that style each would prefer to the current one. n =167 students (19 of whom made multiple entries); <sup>1</sup>187 current responses; <sup>2</sup>189 preferred responses.

\* p < 0.01, chi square analysis (distribution for the 4 Preferred consolidated categories compared to with Current values).

## Figure Captions

Figure 1. Learning Style Categories

Figure 2. Learning Style and Transfer Ability. Students' ability to perform on recall and transfer components of the heart problem dependant on learning style. Winter 2007 semester (n = 167). Error bars indicate mean  $\pm$  SEM.

Figure 1.

- I. Categories based on a model of different modes of self-government (after Sternberg, Thinking Styles, 1997).
  - A. *Executive* students carry out initiatives, follow rules, prefer prestructured problems, give talks based on other peoples' ideas, follow directions, and use the proper method to solve any problem. They are implementers, who take pride in getting things done. They dislike designing original projects or writing proposals, and tend not to be artists or investment bankers.
  - B. *Legislative* students like to come up with their own way of doing things, prefer problems that are not prestructured, enjoy writing creative papers, rely on their own ideas, enjoy inventing new things and deciding on what work to do. They dislike solving math problems in a book, memorizing poems, recounting past events, and remembering the individual events in existing stories.
  - C. *Judicial* students are evaluators. They prefer problems that require analysis, giving opinions, correcting other peoples' work, and considering the strategy of a competing sports' team. They dislike memorizing dates of wars, being assigned to help weaker colleagues, writing a story from scratch, or following directions without knowing the reasons why.
- II. The impulsivity-reflection continuum (Kagan, 1966)

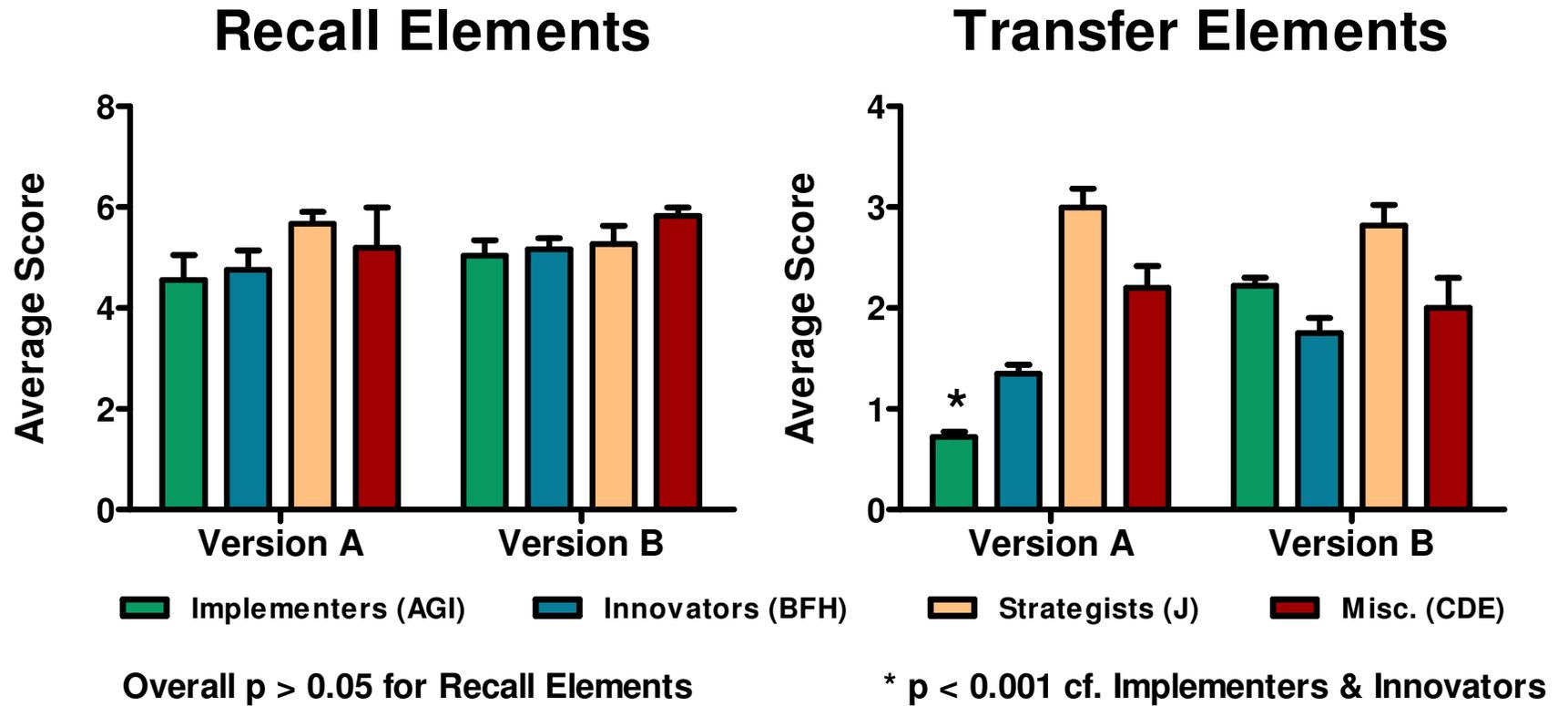
In grade school you faced many rows of arithmetic problems of the same type - solve them as fast as you can. In a keyboarding class it was a timed typing exercise. In these scenarios there was a choice: complete some of the task flawlessly, or complete as much as you can knowing that you will probably make mistakes.

  - D. The *impulsive* student chooses the latter, completes many problems, but with a high error rate - a trade off between accuracy and speed. This is usually not by conscious choice, but because it feels natural; there is a minimal anxiety over committing errors. Such people tend to make more errors in reading prose and are more likely to offer incorrect solutions on problems requiring inductive reasoning or visual discrimination.
  - E. The *reflective* student tends to make the opposite kind of choices: in the trade off between accuracy and speed, opt for accuracy.
- III. Holist (wholistic) and serialist strategies (Pask, 1988)
  - F. The *wholistic* student tries to build up his/her own overview of a topic; thrives on illustration, analogy, and anecdote; and actively seeks connections between ideas. Persons with this preference may be in danger of drawing premature conclusions or making unjustified generalizations.
  - G. The *serialist* student focuses on the topic in isolation; concentrates on details and evidence; and adopts a cautious logical stance, noting objections. Persons with this preference may have difficulty relating different elements to form a whole.

#### IV. Approaches to studying (Marton, 1976 and 1997)

- H. The intent of the student with the *deep approach* is to seek meaning. This person tries to relate ideas to previous knowledge or experience, look for patterns and underlying principles, monitor the development of understanding while learning, relate evidence to conclusions, and becomes actively interested in the course content.
- I. The intent of the student with the *surface approach* is to cope with the course requirements. The focus is on reproducing. This person treats the course as separate bits of knowledge, memorizes facts, carries out routine procedures, finds difficulty in making sense of new ideas, and feels undue pressure and worry about the work.
- J. The intent of the student with the *strategic approach* is achieve the highest possible grades. The focus is on putting consistent effort into studying, managing time wisely, finding the right conditions and materials for study, being alert to exam and assignment requirements, and figuring out the perceived preferences of teacher

Figure 2.



## CHAPTER 4

### Summary

The research results reported above raise several salient questions for teachers who are attempting to improve the quality of learning in their students.

Do our assessments overestimate the number of students who have acquired genuine (transferrable) understanding of fundamental principles?

The answer is probably yes. Teachers may assume, incorrectly, that students have deep understanding of an abstract concept due to their ability to accurately recall important bits of factual information. This is certainly not always true. In addition, students frequently experience a disconnect between the stated objectives (sometimes lofty expectations) of their courses and the actual tasks they are asked to perform on exams.

Transfer is a harder academic task than we originally thought it was going to be. A lot of effort was made to try to find the optimum prompt for a transfer problem, but this turned out not to be a quick fix. We are fighting something of an uphill battle, laboring against a model of education that students have lived with for more than a dozen years, a model based on “transfer” in the more traditional sense of a teacher conveying and passing along information and students copying and imitating. This is fundamentally different than asking a student to acquire an independent, personal, thorough understanding of the foundational principles of a discipline.

We were surprised to find that many of our students failed to address the fundamental concept being tested in the heart (pancreas) problem, that cells become uniquely differentiated because some genes are actively expressed and others are actively repressed. When first asked to answer the objective questions on the back of the problem page, many students were able to recognize the names of relevant proteins and even

appeared to understand their function since they got most of the questions correct.

However, many then failed to include those relevant proteins in their diagrams. In this case, providing the details we were encouraging students to include may have seduced them into skimming over the fundamental biological principle.

What can teachers do to encourage students to learn important details while at the same time not neglecting the main concept? We need to make a conscious effort to help students focus on the fundamental idea by repeatedly asking them to formulate “essential questions.” For the heart (pancreas) problem, the essential question is “What molecular mechanisms control the process through which cells become differentiated?” Everything we do in class, everything they read, every practice problem they attempt should have a connection to that essential question. We can teach the details, but they must be taught within the context of that core concept. Furthermore, our assessments should include problems that allow students to demonstrate their understanding of the fundamental concept. This focus may come at the expense of some of the details that teachers personally think are important, but it seems reasonable that without a firm conceptual basis, students are unlikely to remember the details anyway.

#### How much time or effort is required to obtain transferrable understanding?

We originally thought that practice would produce a measurable gain in performance. Although that did not occur during the seven weeks of the summer term, it is possible that this is too short a period for practice to have an impact. In addition, summer term is an intense academic experience; the entire course condensed into half the length of a regular semester. However, it may be that the absolute length of time spent in practice is not as significant as the number of iterations to which students are exposed.

We tried to maximize exposure by having weekly formative assessments (actually two assessments during each Friday's class time). These assessments were immediately followed by student-student, student-TA, and ultimately student-professor feedback.

What during a formative assessment does the post-test feedback accomplish?

An individual is able, after the fact, to confirm the validity of another person's analysis (the teacher or a classmate), but this is not the same as arriving at the same understanding spontaneously. Some other cognitive experience besides recognition of one's deficiency will have to occur or the next round of assessment feedback is likely to have the same outcome.

What teacher-directed learning strategies are most effective in promoting transfer?

In our summer 2008 formative assessment sessions the feedback consisted initially of providing ideal answers to the questions. Students then discussed them, and tried to determine what they did right in their responses and what they could improve for next time. While this is important feedback, it may be insufficient. After taking the *his* problem the summer 2008 students took a survey in which they attempted to verbalize why they may have performed unsatisfactorily. Approximately a quarter of the students replied that they did not know why they didn't answer completely and left out elements that they thought they understood. This is probably an important insight – novices are not adept at making a correct diagnosis. However, determining what the real cognitive limitations are is critically important. Surely there is some reason why they could not perform, but most students are not in the habit of meta-cognitive analysis.

What is it about practice that improves performance? Initially, becoming more familiar with the nature of the task is likely to help students to progress. Following that

initial familiarity, however, how does further experience develop expertise? These are difficult questions for teachers to answer, and there might not be an explicit answer. However, we believe students must be engaged in a meta-cognitive exercise. Novices invariably make mistakes as they learn a new skill, and continue to make new mistakes as time proceeds. The trick is in recognizing the flaws and then proactively finding a method which results in more success, more often in a very personal way. Students who are committed to finding this personalized method are likely to see gains, and to be encouraged to continue, even if those gains are small.

While we cannot force students to learn or to take our advice, teachers can promote meta-cognitive thinking that guides students to creating their own technique for solving difficult problems. This promotion must occur often. We may be tempted to have students think about thinking at the beginning of the year or semester, and then hope that they remember and act on that early admonition as time goes on. It would be more helpful to introduce the meta-cognition at the beginning of the year, and then reinforce it both before the practice task (have students actively remember what happened during the last assessment and form a plan for the current one) and during every feed-back discussion after the practice session (have students share new ideas with each other, write down what worked, and what they will consciously do differently next time). Teachers can share their own successful methods and encourage students who have found a successful routine to share them, but ultimately students must experiment to find their own style.

We have no doubt that practice is an essential element in developing transfer expertise. The best thing for teachers to do is provide specific feedback, promote meta-

cognitive thinking, and to accept that students must personally commit themselves to the task.

Can students adopt new learning styles that are more amenable to transfer?

The styles which students chose to characterize their approach to learning are probably not descriptions of an innate, fixed personality trait. While some preferences may be hard-wired, we feel that students can and should be taught how to learn and to apply knowledge more effectively in ways that may not seem “natural” to them. Recall that we consolidated the learning styles we surveyed into four groups: Implementers, Innovators, Strategists, and Miscellaneous groups. Because we are interested in transfer, we focused on those creative qualities of the Innovator group that seem to help them be successful at that task. This does not mean, however, that we think the skills of Implementers or Strategists are ineffective. Rather we feel that there is an imbalance within individuals. In our survey we found that most students placed themselves in the Implementer category but demonstrated a preference for the Innovator style. Thus, the students are already aware of their personal learning style limitations, and express an interest in becoming more creative. It would probably be most beneficial to our students if they were able to think in multiple ways and to develop new skills that will undoubtedly be useful in their future lives. Helping students be more adept at a variety of skills is every teacher’s goal.

Once students identify the learning style that helps them best at transferring conceptual knowledge from one context to another, will they be able to perform different transfer tasks faster and more accurately? To facilitate this level of mastery, we must first assist students to contemplate the satisfaction that comes from successfully completing a

transfer task. We may ask them, “How do you feel now that you’ve done well on the exercise? What methodology did you employ? Can you do it again, and recognize future success based on what just occurred?” The answers to these questions should be written down, discussed with teachers and more importantly with fellow classmates, and should be reviewed time and time again as they work transfer problems. In all of this, the teacher hopes to foster in the student an internal feedback system to complement, and ultimately replace, the external feedback provided from others during formative assessment.

Do both students and teachers underestimate the costs of achieving transferrable understanding?

The answer to this question is probably yes.

One of the conclusions that follows from the present study is that we have underestimated the cognitive complexity of the assessment instruments we have designed, including both the “data analysis” and “conceptual” types of problems. We have accumulated evidence that demonstrates that different data analysis problems rank order students differently, suggesting that the intellectual tasks they require are not unidimensional (Bradshaw, et al., manuscript in preparation). In addition to addressing different biological topics (transcriptional regulation or signal transduction, for example), these problems differ in regard to the experimental procedures used to generate the data (immunoprecipitation or gel mobility shift assays, for example), and the degree to which conclusions depend on prior mastery of the subject matter or can be derived independently due to general skill in interpreting figures and tables (“figure literacy”). These and other elements probably confer different degrees of abstraction on various problems rendering them more or less difficult.

Conceptual problems too exhibit subtle differences that should be recognized and defined. Moreover, while the general meaning of “transfer” in an educational setting is straight-forward, there are alternatives for measuring conceptual transfer operationally. We note that “transfer” is not listed in Bloom’s Taxonomy of educational objectives (although it is represented in part under the heading “Application”). In all of the A-level conceptual problems administered in the summer 2008 term, the transfer task was to draw a diagram that illustrated how the elements in the new biological scenario were operating. The assumption was that a student who could construct a picture containing all the relevant elements in their proper relationships had mastered the concept, and, in fact that assumption was probably valid for all or most of those problems. The data presented in Chapter I, however, demonstrate that that assumption did not hold for the heart (pancreas) problem: some students could score very well against a rubric that was a check-list of diagram elements, and still not correctly address the primary principle – showing the insulin gene activated and the cardiac actin gene repressed in a differentiated pancreas cell.

We have come to believe, then, that writing problems that accurately assess whatever intellectual tasks constitute “transfer” is not at all trivial. Each such problem may be so unique in some, perhaps subtle, element, that practice on one is never an exact formative preparation for the next problem presented a week or a month later. If so, then the instructor must accept the hope that extensive practice with a set of transfer problems of different complexity will help build generic “transfer” skills in students, including the self confidence to deal with a truly novel situation. This limiting feature of the formative

pedagogy using transfer problems should be explained to students, so that they share their teacher's perspective about what practice can realistically hope to achieve.

Meta-cognition and learning to learn needs to be embedded “across the curriculum.” Every course should have explicit, transparent objectives that include learning how to learn. The requirement for meta-cognition should be a constant. Our summer 2008 students were also asked to create an action plan to help them improve after they got the results of the *his* problem. But how many of them returned to that action plan once they wrote it down? How many of them actually changed their study habits? We are certain they had every intention of following through with their action plan, but as collegiate pressures mounted; they likely forgot to actively pursue their goal. Teachers can help provide a remedy. Students should be encouraged to not only make an action plan, but to review it often. Those who write what methods work for them should remind themselves, perhaps before every formative assessment, by actually reading their own writing. A continuous log showing the evolution of a student's thought processes as he or she develops transfer skills would be beneficial to the individual, the small group with whom he or she interacts, to the class as a whole, and to the teacher.

If students don't leave college with improved transfer skills, then has the time and money may not have been worth the effort. The benefit, certainly, is not going to be measured by how many facts they remember from their various courses. The half-life of that information is very short.