Variation in Working Memory and the Optimal Design of STEM Labs
John M. Basey, Anastasia Maines and Clinton Francis

Summary: In the original proposal, I had collaborated with Dr. Akira Miyake and had submitted an NSF, TUES grant proposal in May 2010, to pair an investigation comparing student learning from different pedagogical approaches to plant biodiversity labs in introductory biology, and the load on working memory imposed by the pedagogical approaches relative to individual working memory capacity of students. I used funds from the Chancellor’s award to develop this investigation during summer 2010, prior to any NSF funding and to seed a second proposal to NSF, REESE on a related study. When the NSF proposals were not funded, I examined student learning from the following pedagogical approaches to plant biodiversity labs in Spring 2011: (1) lab styles (the learning cycle with a problem-based application phase vs. a modified expository with back-loaded opportunities for reflection, argumentation and induction) and (2) visualization methods used during lab activities (digital photography vs. hand drawing). However, I did not team up with Dr. Miyake to evaluate variations in individual working memory capacity. In spring 2011, I worked with Anastasia Maines, a graduate student in education at the time, to start preliminary evaluations of the research. In May 2011, I again collaborated with Dr. Miyake to revise and submit a second TUES proposal using preliminary results from the investigation. In summer 2011, Anastasia Maines extensively coded assessments. The revised TUES grant was not funded. We have recently completed the statistical analysis by collaborating with Dr. Clinton Francis from The National Evolution Synthesis Center. With collaboration from Miss Maines and Dr. Francis, I am currently planning on writing up the research over the summer and into the fall of 2012 and submitting for publication. I am also planning on presenting the research in a DBER seminar in the fall of 2012 and the ISTEM poster session in May 2013.

Background: One characteristic of inquiry-oriented lab design is lab style (Domin, 1999). Domin (1999) proposed four styles of hands-on, inquiry-oriented labs: expository, problem-based, discovery, and open-inquiry. Even though labs can take on a continuous range of styles, the lab style framework of Domin (1999) is good to use because it is an overarching theoretical framework based on whether the lab takes on an inductive (discovery and open-inquiry) or deductive (expository and problem-based) approach, whether procedures are provided (discovery and expository) or student generated (problem-based and open-inquiry), and whether outcomes are predetermined (discovery, expository and problem-based) or undetermined (open-inquiry).

An expository style is often called verification because the teacher provides explicit information at the beginning and students verify with teacher-derived procedures for a hands-on lab (Domin, 1999). The “traditional” lab style commonly referred to in research often takes on an expository style, even though the expository style is variable and can range from the “cookbook” format focusing on lower-order knowledge and comprehension (Anders et al., 2003; Jackman et al., 1987) to an inquiry-oriented style focusing on higher-order thinking (Domin, 2007; Hohenshell & Hand, 2006).

The learning cycle is a specific type of discovery lab (Domin, 1999). It starts with a guided hands-on procedure designed to engage students and get them to use inductive reasoning to derive explanatory hypotheses. This is followed with a teacher-centered instructional phase that explicitly goes over the theory. It ends in an application phase,
which students apply what they have learned utilizing varying formats. One potential application phase is the problem-based style, in which students are provided with a problem/hypothesis first, design their own tests of the problem/hypothesis, and generate their own conclusions.

Most research comparing the expository style and the learning cycle (or the expository style and the problem-based style) has produced results in favor of the non-expository style (Anders et al., 2003; Hand et al., 2004; Holcomb, 1971; Johnson & Lawson, 1998; Luckie et al., 2004; Toh & Woolnough, 1993).

In this study, we used modified lab styles that follow Domin’s (1999) categorization. (1) A modified expository lab style that included a 4-week, hands-on, pre-lab assignment, hands-on lab experimentation (inquiry), and a post-lab write-up including opportunities for reflection, argumentation, deductive reasoning, and inductive reasoning. (2) The learning cycle lab that included the same 4-week, hands-on, pre-lab assignment leading into the discovery phase, an instructional phase, and a problem-based application phase.

**Visualization Techniques.** Visualization can be an important factor in biology lab design. Plant biodiversity labs commonly have students draw and label important comparative features needed in the scaffolding process. Current technology, however, has provided an alternative to the draw-and-label through digital photography and efficient computer software. Digital photography has been especially successfully implemented in biology labs (Bell et al., 2004; Kelley et al., 2008; Mills et al. 2001).

**Methods:**

**Treatments:** (1) Expository plant biodiversity lab with drawing, (2) Expository plant biodiversity lab with digital imaging, (3) Learning cycle plant biodiversity lab with drawing, (4) Learning cycle plant biodiversity lab with digital imaging.

**Expository format.** The expository framework for the plant-biodiversity labs began with a lecture explaining content for the day. Students worked through a hands-on, guided set of procedures and then answered at the end a set of questions ranging from lower-order (knowledge, conceptualization, application) to higher-order thinking (analysis/synthesis; Hand & Keys, 1999). The following is a brief example:

**Learning cycle format.** We used the well-supported 3-phase learning cycle (Lawson, 1995). The three phases are: exploration, concept introduction, and concept application (Karplus, 1977). The key difference between a discovery style (such as the learning cycle) and an expository style is that the learning cycle begins with a hands-on investigation and inductive reasoning prior to concept introduction (Domin, 1999). The intent of having the exploratory stage prior to concept introduction is three fold: to initially engage students and get their attention, to have the students process information at a higher-level prior to concept introduction, and to provide students experience with inductive reasoning—an important part of the process of science. Instead of a teacher-centered lecture, concept introduction in this model was through a student-centered discussion that was facilitated by the teacher and gently guided students toward two unifying hypotheses: (1) that life originated in aquatic environments and then radiated to terrestrial habitats; and (2) that evolution through natural selection with adaptive radiation is an overarching theoretical framework that explains the current diversity of living organisms. The final stage of the learning cycle, concept application, was problem-based (Domin, 1999). Students were given the two hypotheses above and, in small
groups, they used deductive reasoning to derive predictions. Then they derived the observations they needed to test the hypotheses and ended with a hands-on investigation.

Implementation Design: Twenty four TAs taught 2 sections of 18-students, in four separate rooms. Each TA was assigned 2 of the 4 treatments and taught one lab in the style of each assigned treatment. We had specific paired comparisons: expository/drawing & digitizing vs. expository/digital photography, expository/drawing & digitizing vs. learning-cycle/drawing & digitizing, learning cycle/drawing & digitizing vs. learning cycle/digital photography, and expository/digital photography vs. learning-cycle/digital photography), we did not have any TAs teach comparisons 5 and 6 (expository/drawing & digitizing vs. learning-cycle/digital photography treatments and expository/digital photography vs. learning cycle drawing & digitizing). TAs were assigned randomly to the treatment pair. Thus, 6 TAs taught utilizing each desired pair of treatments (i.e. comparison 1, comparison 2, comparison 3, or comparison 4) with 216 students per comparison, and 12 TAs taught utilizing each treatment (1, 2, 3, or 4).

Assessments: (1) Formative Assessment -- lab write-ups from each treatment were collected and evaluated with a rubric. (2) Cognitive learning was assessed in two ways: (i) a practical exam in the lab and (ii) multiple choice questions in the lecture. (3) Attitudes were assessed with a survey addressing attitudes towards the lab specifically – lab rating, how much lab helped with lecture, how time efficient learning experience was, how exciting lab experience was, and how difficult lab experience was.

Assessments were coded in the spring and summer of 2011 by two researchers (myself and Anastasia Maines, a graduate student and one of the TAs). Both researchers coded the plant diversity quiz while Anastasia Maines coded the lab write-ups.

Observations of Teaching: To verify proper implementation of the treatments, TAs were observed by myself and Anastasia Maines. We utilized a checklist to quantify methods of teaching. If TAs did not follow the teaching protocols for the given lab style, they were removed from the study.

Results: We used generalized linear mixed models to determine the effect of lab-style (guided vs. learning cycle) and visualization (drawing vs. imaging) on the response variables of lower order (LO) and higher order (HO) questions on the plant diversity quiz in lab (quiz) and the plant diversity multiple-choice exam in lecture (exam). We treated lab-style and visualization as fixed effects and TA as a random effect. Response variable scores were arcsine square root transformed to meet assumptions about normality and homogeneity of variance prior to analysis. We standardized parameters that were considered in the models because they were on different scales (e.g., factors in two categories vs. lab report scores). This was achieved by centralizing predictor variables to a mean of zero and a standard deviation of 0.5, which places continuous variables and binary variable on a common scale.

For model selection, we used an information-theoretic approach to evaluate support for competing candidate models (Burnham and Anderson 2002) with Akaike’s Information Criterion corrected for small sample sizes (AICc) to determine the most parsimonious model that best explained overall lab rating. We ranked models based on differences in AICc scores (ΔAICc). Models with ΔAICc scores within two of the best models were considered to have strong support. For all candidate models within two ΔAICc of the best model, we calculated Akaike weights (wi) to quantify the degree of support for each. When more than one model had strong support (ΔAICc < 2), we used
Akaike weights to calculate model-averaged variable coefficients, unconditional standard errors (SE), and 95% confidence intervals (95% CIs). We concluded that there was little evidence for the effect of a fixed effect on overall lab rating when the 95% CIs included or overlapped zero.

**Does lab style and visualization influence the lab reports produced by students?** Lab reports from students were influenced by both lab style and visualization. Specifically, the learning cycle (relative to guided) and imaging (relative to drawing) both had independent negative influences on lower order-cognition in the lab report, but there was no indication that the effect was more severe in combination (interaction). In contrast, the learning cycle had a small positive effect on higher-order cognition in the lab report relative to the guided format.

**Is the transfer/retention of information from lab report to quiz for lower order and higher order cognition different for the different lab styles/visualizations?** Learning cycle lab reports were open ended and guided lab reports were prompted. Thus, guided lab reports fairly consistently related to the quiz whereas learning cycle lab reports were more variable. To see transfer of learning from lab report to quiz, we examined the components of the lab reports that associated directly with the quiz. Thus, components of lab reports that directly related to quiz questions were assessed for percent completeness for guided and learning cycle styles. Transfer from lab report to quiz was quantified by taking the % score on the quiz and subtracting it from the lab report. (Note: lab report questions were different than on the quiz questions, so a relative comparison at best can only be made.) Positive scores indicated better transfer/retention and negative scores indicated worse transfer/retention. Results indicated that visualization and lab style did not appear to influence transfer of higher order cognition from the lab report to the quiz, but learning cycle (relative to guided) and imaging (relative to drawing) both had a positive effect on lower-order transfer from the lab report to the quiz.

**Does the combination of classroom activities and the lab report influence learning by students in the different treatments as assessed by the quiz and exam?** Results indicate that visualization (drawing vs. imaging) failed to have a strong effect on any response variable (i.e. lower order and higher order quiz scores and exam scores). For lab style, the learning cycle had a negative effect on quiz lower order scores relative to the guided style.

**What were students’ attitudes towards the different treatments?** There is no evidence that the student populations exposed to the different treatments were different. In this case, the null deltaAICc = 0.66, giving it strong support from the data. Imaging (relative to drawing) had a strong negative influence on students perceptions of the overall rating for the lab, how exciting the lab was, how time efficient the lab was and how much the lab helped lecture; but imaging had no influence on student’s perception of lab difficulty. The learning cycle (relative to guided) had a strong negative effect on the overall rating and lack of difficulty (i.e. they thought the learning cycle was more difficult), but not on any other variables. Overall rating was positively influenced by lack of difficulty, excitement, help, and time efficiency. An interaction between time efficiency and imaging also had a positive influence on overall rating, while the interaction between imaging and excitement had a negative influence.

**Discussion.** Results of this study indicate that the learning cycle treatment
relative to the guided treatment did not improve learning nor did it improve student attitudes towards lab; rather it had a negative impact on lower-order cognition and overall attitudes towards lab. Imaging also did not result in improved learning relative to drawing nor improved attitudes towards lab. This study indicated that attitudes were worse towards labs with imaging. This study implies that the model for the learning cycle used in the plant diversity labs was not as good as the guided model and the value of imaging is questionable.

One question that arises is – Why did the learning cycle produce worse results than the guided when literature supports the learning cycle? These results are not necessarily inconsistent with our original conceptual framework. In our original framework, we wanted to measure individual working memory capacity of students and use it as a factor for the analysis. Consistent with our original ideas, it is possible that the level of difficulty of the learning cycle was higher than with the guided as also indicated by student perceptions. A theoretical framework for learning is called cognitive load theory (Kirschner et al. 2006). The premise is that if a learning situation allows the working memory of students to be surpassed, student learning is greatly reduced. Since the learning cycle is inductive and the plant diversity lab in itself is heavily laden with novel terminology, the poor results compared to guided in this specific instance may be due to cognitive overload of individual students. For this case, the engagement was inductive and students were supposed to be drawn by the discovery of a novel organism. The guided group, on the other hand, was learning important novel terminology associated with plant life cycles while the learning cycle group was discovering. In this situation, due to the novelty of the scaffolding, the inductive engagement phase may have overloaded some of the students working memory capacity; and thus, reduced learning for those students. Further research on working memory capacity in relation to lab style is still warranted.

An interesting result stems from the idea that the learning cycle treatment should have been more exciting to the students if the engagement phase worked. The attitude assessment indicated that students did not think the learning cycle and guided styles differed in excitement. Basey et al. 2008 found excitement to be the most important of the four factors examined in this study in determining student overall attitudes towards lab. Basey et al. 2011 showed that in a guided inquiry vs. a problem based lab students did not differ in their view of how exciting the lab was but did differ in the other three factors examined (difficulty, time efficiency and lecture help). Basey et al. 2011 concluded that lab style may not be a driving force that changes excitement, rather other factors such as the subject matter and material addressed could be more important in changing excitement. These data are consistent with that contention.

**Use of Funds:** $2,015 to Anastasia Maines one month grad assistant position from June 1 to August 1, 2011. 5,575 to Dr. John Basey for 1.5 summer months in 2010 and 2,410 for summer 2011. In summer 2010, I prepared the REESE NSF grant proposal that we submitted in November 2011. I also did the IRB protocol. I also designed the four treatments for the implementation of the experiment, and designed the assessments. In May 2011, I assessed the quizzes and gathered preliminary data for a TUES NSF grant submitted May 20 2011. During summer 2011, I revised labs based on information for Spring 2011 and supervised the work of Anastasia Maines. Summer 2012 I plan on writing the study up for publication and preparing a DBER seminar.
Literature Cited.