Variation in Working Memory and the Optimal Design of STEM Labs
John M. Basey (Department of Ecology and Evolutionary Biology)

Summary. The proposed project has several purposes. 1) To examine a new inquiry-based lab design for the traditionally, guided, diversity-survey-lab in biology. 2) To seed STEM research into how student learning is influenced by individual variations in working memory and the potential overloading of the latter in inquiry-oriented lab designs. 3) To foster interdisciplinary collaboration between myself (Dr. John Basey, senior instructor, Department of Ecology and Evolutionary Biology, EEB), Dr. Akira Miyake (Department of Psychology and Neuroscience), the lecture professors of General Biology in EEB and hopefully other collaborators in science education.

This proposal is a component of a larger STEM research agenda resulting from recent collaboration between Dr. Miyake and myself. Our ultimate goal is to research how cognitive load imposed on students in the form of different designs of inquiry-oriented labs interacts with individual variations in working memory among students to influence learning. As a beginning step, I am re-designing the traditional and guided, diversity-survey-labs in biology (i.e. teacher-centered with guided procedures and a guided write-up) to mirror constructs advocated by science education reform (i.e. student-centered without guided procedures and an open-ended write-up). In addition, the new survey labs begin with “the learning cycle” and are more inquiry-oriented (hypothesis-driven). I am proposing to develop and finalize a working model of this new survey lab during summer 2010 and do a test-run in the classroom with an assessment in spring 2011.

This preliminary study will be integrated with our larger research agenda and help with two major NSF grants. The first (approximately $200,000) is due in May 2010 to the Transforming Undergraduate Education in Science Technology, Engineering and Mathematics (TUES) program. The second (approximately $1,000,000) is due in Nov 2010 to the Research and Evaluation on Education in Science and Engineering (REESE) program.

Receiving funding to help with STEM research is especially vital and inspiring, for me as a full-time instructor and with no contractual research component.

Background and Project. Recent reform in science education has called for teaching strategies emphasizing inquiry (1, 2) and this push has produced educational practices that improve student learning (3, 4). However, a recent model called Cognitive Load Theory (CLT) is challenging the open-inquiry-oriented (research-based) approach (5). CLT is based on the concept that (i) when working memory is overloaded, meaningful learning is diminished or ceases altogether, and that (ii) the non-guided, inquiry-oriented approach greatly enhances such cognitive overload.

Science labs are prone to producing a high cognitive load (6). Three components of inquiry-oriented labs that tend to increase cognitive load to varying degrees are: a student-centered (constructivist) vs. teacher-centered (expository) format, student-derived vs. teacher-derived procedures, and open-ended (unlimited freedom to explore and enhance) vs. guided (limited freedom to explore) write-ups. In addition, cognitive load is not evenly distributed throughout an inquiry-oriented lab and may be front-loaded (greater cognitive load due to lab design is placed prior to performance of the
investigation) or back-loaded (greater cognitive load due to lab design is placed subsequent to the performance of investigation or even data analysis). This proposed research is a preliminary stage of a larger research agenda to test the following hypothesis and predictions. Hypothesis -- Variations in students’ working memory capacity relative to cognitive load dictate the effectiveness of different designs of inquiry-oriented labs. Predictions -- Students with a high-functioning working memory will learn better from a student-centered (constructivist) approach with reduced to no procedural guidance and an open-ended write-up (unlimited freedom to explore and enhance without limitations). Students with a lower-functioning working memory will learn better from a lab designed to reduce cognitive load with various degrees of guidance at the onset from the teacher, during the procedures and in the final write-up. Furthermore, students with a lower-functioning working memory will learn less when labs are designed with a high front-loading to back-loading ratio and in highly front-loaded labs, will require extra processing time.

In this project, I will be revising the traditionally guided diversity-survey-labs in biology to a model based on science education reform, but this new model carries with it high cognitive load. (Note: this investigation is designed as a preliminary study to analyze learning outcomes between these two formats and to consolidate assessment methods prior to a full research agenda incorporating working memory.) “Traditional” survey labs are expository or verification style, are observation driven rather than hypothesis driven, have guided procedures, visualization is through drawing (looking through microscopes then drawing and labeling important features) and the write up is prompted (teacher-derived questions). My new lab strategy is inquiry-oriented utilizing the “learning cycle”, is hypothesis driven with student-derived procedures, visualization is through digital imaging (microscopes with digital cameras and images uploaded to computers) and the write-up is open-ended. I plan to examine three treatments: 1) traditional with drawing, 2) traditional with digital imaging, and 3) the new inquiry-oriented model with digital imaging. I will run a survey on student attitudes. I will examine lab reports from the treatments utilizing the Delphi method to derive and verify a rubric. Finally, I will have a pre/post cognitive assessment comparing the two treatments. The post cognitive assessment will be in the form of higher-order cognitive questions during a lab quiz and multiple choice exam questions planted in the exam for the lecture component of the class during the regular class exam and again on the final exam. Assessment questions will be carefully constructed and scrutinized by several collaborators to insure that they fairly represent potential learning outcomes from both treatments equally and do not favor one treatment over the other, but at the same time are representative of the targeted learning outcomes.

Impacts. This project will have numerous impacts. (1) The first impact is personal growth for me as the long-term coordinator of 24 Grad TAs and 800 or more undergraduates per semester in introductory biology labs at CU. By designing and carrying out this research, my understanding of underlying factors in STEM education especially lab design will expand. The interdisciplinary collaboration with Dr. Miyake, the DBER symposium, and interactions with other faculty working on STEM education research will broaden my perspectives on STEM education and provide a wide range of new insights and ideas. (2) The second impact is fostering interdisciplinary collaboration
at CU. In addition to enhancing my growth, this collaboration will have a synergistic impact on other collaborators (including the eight lecture faculty in introductory biology).

(3) This project will benefit STEM education. Minimally, I will present the diversity lab reform model and measured learning outcomes at the DBER symposium in late spring or fall 2011 and potentially the PTSP Conference on Teaching and Learning. I plan to publish in a journal such as the International Journal for Research in Science Teaching or through the Association for Biology Lab Educators (ABLE). The project will also be very visible to the EEB department. We currently have 9 faculty members on a General Biology committee, and faculty collaboration with lecture professors is a component of the assessment. We also meet once a month and this project will be the topic of the meetings and may act as a model for STEM research and reform associated with large lectures. The 24 graduate students (mostly from EEB) each semester involved in the proposed research will get direct hands-on experience with several different novel teaching strategies, and the new inquiry-based lab may improve learning for 800+ undergraduates per semester. (4) The requested graduate assistant specifically working on the assessment of this project will gain experience in education research. (5) This project will greatly enhance the chance of funding from the TUES and REESE programs.

**Literature Cited**


