Impacts of Digital Imaging versus Drawing on Student Learning in Undergraduate Biodiversity Labs

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Abstract: We examined the effects of documenting observations with digital imaging versus hand drawing in inquiry-based college biodiversity labs. Plant biodiversity labs were divided into two treatments, digital imaging (N = 221) and hand drawing (N = 238). Graduate-student teaching assistants (N = 24) taught one class in each treatment. Assessments revealed that imaging relative to drawing had a significant negative effect on the lower order content students included in their lab reports, student perceptions of the lab overall, the time efficiency of their learning experience and perceived excitement. Documentation style had no significant influence on lower-order or higher-order learning or attitudes towards biology as a discipline. Contrary to overall trends, observations indicated that a proportion of students were excited and motivated by digital imaging. A mixed model of allowing students the choice of documenting observations with digital imaging or drawing may be the best model.

INTRODUCTION

The United Nations Decade of Education for Sustainable Development (2005-2014) recognized biodiversity education as a worldwide priority (Lindemann-Methies et al., 2009). In the United States a great opportunity for biodiversity education exists in the hands-on lab component of college introductory biology classes. Although advocates for biodiversity education emphasize a need for engaging learning experiences that are grounded in evolution and go beyond rote memorization (Lindemann-Methies et al., 2009, Basey et al., 2014), commonplace undergraduate biodiversity labs take on the form of “marches through the phyla” that emphasize declarative knowledge (see Morgan and Carter 2009, Scully & Fisher 2009). The need for information on how to transform these biodiversity labs to engaging experiences grounded in science and emphasizing evolution-based higher-order reasoning is paramount.

Basey et al. (2014) argued that commonplace biodiversity labs are particularly difficult to transform because of the theoretical nature of evolution, the relatively large quantity of novel and highly interactive terminology required for evolution-based higher-order reasoning and limitations on working memory. Studies on the effects of transformative designs for biodiversity labs are rare. Smith and Cheruvelil (2009) reported a substantial loss in content understanding by their students when they used a transformed design for their biodiversity labs. Timmerman et al. (2008) reported substantially lower effect sizes for their transformed inquiry-oriented biodiversity segment in lab + lecture (0.6) than for their non-transformed non-biodiversity segments (plant anatomy = 2.1, animal anatomy = 1.8). However, neither study analyzed the effects of their transformed design on higher-order cognition learning (i.e. application, analysis and synthesis). Basey et al. (2014) successfully promoted both lower-order and higher-order learning in a transformed biodiversity lab by reducing overall lower-order content, increasing time allocation through time-efficient hands-on pre-labs, and including written post-labs emphasizing higher-order learning by having students use documented observations as evidence for evolution-based higher-order argumentation. In this study, we extended the model for biodiversity labs of Basey et al. (2014) by analyzing whether observation documentation through digital imaging or hand drawing impacted student learning and attitudes.

Biodiversity lab educators have contended that digital imaging can enhance documentation of hands-on lab observations (Mills et al. 2001, Thomassan 2002, Withers & Wallace 2007), can improve implementation of inquiry in the lab (Leonard 2003, Withers & Wallace 2007, Mcintosh & Richter 2007), and can improve student learning (Waegel 2004). In a case study approach to biodiversity, Travaille & Adams (2006) touted the use of digital imaging for an inquiry analysis of *Caenorhabditis elegans*, a model species for biology education, and Bowen & Bell (2004) hyped the use of digital cameras for the study of butterfly life cycles. Beyond biodiversity labs, Kelley et al. (2008) and Zinn et al. (2011) advocated for the incorporation of digital imaging and digital imaging analyses as an important component of the biology undergraduate curriculum because of its rising importance in the job market.

Even with all the arguments for implementation of digital imaging in biology labs, studies examining impacts of digital imaging on student learning and/or attitudes are rare. Tatar & Robinson (2003) found no difference in content learning in a high school biology lab between a class using digital photography and a class using no digital photography, but found that student's procedural knowledge was better for the class using digital photography. Kelley et al. (2008) had students quantitatively evaluate images and found that students improved in their ability to analyze scale, quantify and interpret images and characterize imaging methods, but they did not evaluate content cognition. More studies that address impacts of digital imaging on student learning and attitudes especially in relation to biodiversity labs are clearly needed.

The goal of this study was to evaluate the hypothesis that digital photography enhances learning and attitudes of students in biology labs over the traditional method of hand drawing. We specifically examined the relative impact of visualization style (digital photography versus hand drawing) on student formative lab reports, then on student learning outcomes and attitudes (i.e. Bloom's lower-order cognition, Bloom's higher-order cognition, attitudes towards biology as a discipline, and attitudes towards the biodiversity lab).

METHODS

The research was conducted at the University of Colorado at Boulder in 2011 during introductory general biology lab. The lab class ran concurrent with a lecture covering similar content, but was a stand-alone class and approximately 75% of the students in lab took the concurrent lecture. Most of the 850 students enrolled in the class were traditional students with freshman and sophomore class standings. Students were grouped into lab sections of 18 each and were instructed by 24 different graduate-student teaching-assistants (GTAs).

The lab curriculum was comprised of inquiry-based experimental labs intermixed with several non-experimental hands-on biodiversity labs. We focused this study on the newly redesigned plant biodiversity lab that began with a 3-week pre-lab (30 min per week) followed by a focal lab (3 hours). During the engaging, hands-on, pre-lab students observed with a microscope the stages in the life cycle of the C-Fern (*Ceratopteris richardii*). They pipetted spores on a growth medium and directly observed germinating spores, gametophytes, swimming sperm and live fertilization. In the focal lab students documented the life cycles of mosses, conifers and flowering plants through observations of living specimens, preserved specimens and microscope slides. Over the following week, each student incorporated his/her documented observations into a lab report that used evidence from the lab to address the two following overarching ideas. 1) Life originated in aquatic environments and then radiated to terrestrial habitats, and 2) Evolution through natural selection with adaptive radiation is an overarching theoretical framework that explains the current diversity of living organisms.

Classes were divided into two treatments, digital imaging (I) or hand drawing (D). Students in both treatments worked in groups of two. Twelve GTAs were randomly assigned to each treatment.

On the first day of class students chose whether or not to participate and only materials from participating students were coded and statistically evaluated. On week 2 students began a plant biodiversity pre-lab. On week 5 students worked on a 2-hour and 50 minute hands-on plant-biodiversity lab. On week 6 students took a practical assessment at the beginning of lab. On week 11 students took a multiple-choice assessment in exam for the associated lecture. On week 15 students completed attitude surveys in lab.

Imaging Equipment

Students were divided into groups of two. Each group in both treatments had one internally illuminated compound microscope with 3.6X, 10X, 40X and 100X objectives and 10X eyepieces, and one internally illuminated stereomicroscope with magnification from 0.7 to 4.5X and 10X eyepieces. For imaging, the stereomicroscopes were Meiji EMZ-8TR with a photo port separate from the stereo image. Each group of students had a Canon EOS TLi Digital Camera with a T2-9 Canon T Mount for EOS, MA 150/50 camera attachment for the Meiji EMZ-TR, and the CAEDRT1IK Canon EOS Rebel T1i digital SLR camera kit. The digital cameras were easily transferred from the compound microscope to the stereomicroscope with live imaging and capture through the computer. Once an image was captured, students retained the image on the classroom computer in their own folder and sent a copy via e-mail.

Assessment

A. Lab Report: APM assessed lab reports using a comprehensive rubric/checklist designed to compare results across all treatments. Rubric scores indicated the amount and type of evidence that was included in the lab reports and was divided into "knowledge and comprehension" (LO) and "analysis and synthesis" (HO; Crowe et al. 2008). Content in the rubric was divided into categories, a point was assigned for each correctly used content category and points were summed to produce a separate LO and HO score. In a second analysis lab reports were similarly scored based only on the content that related directly to the quiz. Grading reliability was checked periodically by randomly selected re-grades, and as a result, at one point in the coding process the first 150 lab reports were re-graded.

B. Practical Quiz: The practical quiz had five stations with three stations categorized as LO and two stations as HO according to the Blooming Biology Tool (Crowe et al., 2008). LO stations had two parts: 1) visual identification (generation style, knowledge), and 2) relating the visual identification to a representative aspect of plant life cycles (short-answer style, comprehension). Visual identification had two possible formats: 1) a microscope with adjacent slides so students had to use the microscope, and 2) a microscope image displayed on a computer. The two HO questions were categorized as a synthesis and an analysis question. For the analysis question students were provided data, were asked whether the data were consistent with evolution through natural selection and were asked to explain their answer. For the synthesis question students were provided specimens from one of the four plant divisions examined. Students were asked in a multiple-choice question which of four animal phyla was the equivalent in terms of adaptations to terrestrial life and to explain their answer. Importantly, all students had access to an on-line study guide with digital images from the lab.

Two versions of the quiz were used, both with the same analysis question and each of the remaining questions was paired between versions. One matched LO question (computer image) was excluded from the analysis because student performance varied between quiz versions. The remaining four questions -- two LO and two HO -- matched up well across quiz versions.

John M. Basey (JMB) and Anastasia P. Maines (APM) independently coded the same 30 quizzes using a common rubric. Codes were compared on each question with a *t*-test and no significant differences in grading were present (all $P > 0.05$). The remaining quizzes were coded separately.

To determine transfer of learning from lab report to quiz, components of lab reports that directly related to quiz questions were assessed for percent completeness. Transfer from lab report to quiz was quantified by subtracting the adjusted lab report score from the % score on the quiz. The adjusted lab report score was only those items from the rubric that directly related to quiz content. (Note: lab report questions were different than quiz questions, so a relative comparison at best can only be made.)

C. Multiple-Choice Exam: Ten multiple-choice exam questions related to plant biodiversity were written at the knowledge, comprehension and analysis levels of Bloom's taxonomy according to Crowe et al. (2008). The lecture professor (who did not have knowledge of the specific lab treatments) chose several exam questions from each level of learning to include on the lecture exam (5 knowledge, 5 comprehension and 5 analysis). In addition, all multiple-choice exam questions written by the lecture professor that pertained to lab learning goals were also included. At the end the assessment was comprised of 10 knowledge, 6 comprehension and 5 analysis questions.

D. Validation of Bloom's Categorizations: Two outside experienced reviewers independently classified multiple choice exam questions into Bloom's levels. Following classification a quadratic

Table 1. Model-averaged coefficient estimates for all variables present in models with strong support ($\Delta AIC_c < 2$) related to lower and higher-order learning for the lab report, quiz and exam relative to type of visualization (drawing or imaging). SE = standard error, CI = confidence interval (95%), and Relative Import = relative importance of the model. A negative effect size indicates a negative effect. Imaging is relative to drawing.

Explanatory Variable	Effect Size	SE	Lower CI	Upper CI	Relative Import	*Z* value	*P* value
Does lab visualization influence the lab reports produced by students?							
Lab Report Lower Order							
Imaging	-0.046	0.019	-0.083	-0.009	1.00	2.455	0.014
Lab Report Higher Order							
Imaging	-0.017	0.009	-0.035	0.001	0.64	1.802	0.072
Is the transfer/retention of information from lab report to quiz for LO and HO different for the different types of visualization?							
Lower Order Difference							
Imaging	2.637	2.172	-1.619	6.893	0.42	1.214	0.225
Higher Order Difference							
Imaging	-2.082	1.474	-4.972	0.807	0.49	1.413	0.158
Does type of visualization influence LO and HO scores on quiz and exam?							
Quiz Lower Order							
Imaging	-0.052	0.028	-0.107	0.002	0.66	1.889	0.059
Quiz Higher Order							
Imaging	-0.044	0.023	-0.090	0.002	0.65	1.882	0.060
Exam Lower Order							
Imaging	-0.011	0.019	-0.048	0.027	0.30	0.573	0.567
Exam Higher Order							
Imaging	-0.037	0.032	-0.025	0.010	0.42	1.172	0.241

Effect sizes have been standardized on two SD following Gelman (2008). Bold denotes parameters with strong effects because the 95% CI does not overlap zero.

Table 2. Model-averaged coefficient estimates for all variables present in models with strong support ($\Delta AIC_c < 2$) related to students perceptions of lab parameters relative to type of visualization (drawing or imaging). SE = standard error, CI = confidence interval (95%), and Rel Import = relative importance of the model. A negative effect size indicates a negative effect. Imaging is relative to drawing.

Explanatory Variable	Effect Size	SE	Lower CI	Upper CI	Relative Import.	*Z* value	*P* value
Overall Lab Rating							
Imaging	-0.608	0.219	-1.037	-0.178	1.00	2.774	0.006
Excitement							
Imaging	-0.562	0.213	-0.980	0.145	1.00	2.638	0.008
Time Efficiency							
Imaging	-0.696	0.227	-1.142	-0.250	1.00	3.061	0.002
Ease of Lab							
Imaging	-0.379	0.215	-0.802	0.043	0.30	1.760	0.078
Lecture Help							
Imaging	-0.296	0.242	-0.770	0.179	0.43	1.220	0.222

Effect sizes have been standardized on two SD following Gelman (2008). Bold denotes parameters with strong effects because the 95% CI does not overlap zero.

weighted kappa (Cohen 1968) was estimated for each reviewer relative to the independent classification by JMB that was used in this study. Each independent reviewer rated questions as knowledge, conceptualization, application, or analysis ($N = 42$).

E. The Colorado Learning Attitudes about Science Survey (CLASS): The pre/post formatted CLASS has been well validated and widely used (Barbera et al., 2008). The CLASS surveys students' beliefs about a science discipline such as biology and how those beliefs are influenced by classroom instruction. The CLASS is founded on the idea that attitudes and beliefs of novices are different than those of experts and instruction that fosters expert-like beliefs are wanted.

F. Survey of Attitudes Towards Specific Labs: This survey evaluated students' opinions specifically about digital imaging vs. hand drawing in the plant biodiversity labs as well as their opinions about two control labs that did not vary for all students. Reliability and validity of the survey has been established (Basey et al. 2008, Basey & Francis 2011). The survey simply prompted students to rate the plant biodiversity lab on a scale of 1–10 for the following categories: overall lab rating, how easy they thought the lab was to master (ease of lab), level of excitement, time efficiency and how much the lab helped with lecture.

Analyses

We used linear mixed-effect models to determine the effect of documentation style on CLASS scores, as well as LO and HO for the lab reports, the quiz and the lecture exam. Documentation style was treated as a fixed effect and TA as a random effect. We used linear regression for student-attitude assessments. Where appropriate, response variable scores were arcsine square root transformed prior to analysis. When continuous variables were included in models with binary variables, parameters were standardized by centralizing predictor variables to a mean of zero and a standard deviation of 0.5. All analyses were performed using the lme4 package in program R (R Development Core Team, 2012).

We evaluated support for competing candidate models with an information-theoretic approach (Burnham & Anderson, 2002) using Akaike's Information Criterion corrected for small sample sizes (AIC_c). Models were ranked by ΔAIC_c scores. Results of the full model selection are available in the online supplement. For all candidate models with $\Delta AIC_c < 2.00$ from the best model, Akaike weights (w_i) were used to calculate model-averaged coefficient estimates, unconditional standard errors (SE), 95% confidence intervals (CIs), and to weight the evidence of importance for each variable.

RESULTS

Classification of assessment questions into Bloom's levels was valid. The quadratic weighted kappa for each reviewer relative to classification used in this study was high (reviewer 1: $K_{qw} = 0.863$, se = .035; reviewer 2: $K_{qw} = 0.870$, se = .006).

Student lab reports were influenced by documentation style. Specifically, imaging relative to drawing had a small significant negative effect on the amount of LO students included in their lab reports, but did not significantly influence the amount of HO (Table 1). In addition, the transfer of LO and HO from the lab report to the quiz was not significantly influenced by documentation style (Table 1).

The combination of classroom activities and the lab report did not significantly influence learning by students in the different imaging treatments as assessed by the quiz and exam. However, it is noteworthy that imaging relative to drawing had a marginally significant ($0.05 < P < 0.10$) negative influence on quiz LO and HO scores (Table 1).

Imaging relative to drawing had a negative impact on how students rated the lab overall, time efficiency and perceived excitement; yet was not

Table 3. Model-averaged coefficient estimates for all variables present in models with strong support ($\Delta AIC_c < 2$) related to results of the CLASS. SE = standard error, CI = confidence interval (95%), and Rel Import = relative importance of the model. A negative effect size indicates a negative effect. Imaging is relative to drawing. Unfavorable is a shift away from the expert view and favorable is a shift towards the expert view.

Explanatory Variable	Effect Size	SE	Lower CI	Upper CI	Relative Import.	*Z* value	*P* value
Unfavorable							
Imaging	-0.489	1.318	-3.065	2.086	0.28	0.372	0.710
Favorable							
Imaging	-1.926	1.781	-5.417	1.565	0.39	1.081	0.280

Effect sizes have been standardized on two SD following Gelman (2008). Bold denotes parameters with strong effects because the 95% CI does not overlap zero.

perceived as significantly more or less difficult nor did it significantly help with lecture (Table 2).

Results of the CLASS indicated that there was no support for an influence of either documentation style on attitude shifts in either the favorable (more like experts) or unfavorable (less like experts) direction (i.e., null models had ΔAIC_c scores < 2.00 and no significant differences were present, Table 3).

DISCUSSION

The potential for digital imaging to enhance learning and attitudes of students in survey-style biodiversity labs is quite apparent and to our knowledge has not previously been quantitatively evaluated. This study used a quasi-experimental design because students were assigned into treatments alphabetically, but GTAs were randomly assigned to each treatment. Treatments were run concurrently, GTAs taught in both treatment styles, we factored out the GTA effect in the statistical analysis, and we had a large enough sample size for reliable results. Since we could not find a verified plant biodiversity practical assessment associated with our desired learning goals, we developed the two cognitive assessments for this study and used a post assessment design. The attitude assessments were previously verified and well supported.

The results did not support the contention that digital imaging would improve introductory college biodiversity labs. First, students who used hand drawing had a tendency to be more thorough when producing lab reports with respect to LO material than students using digital imaging. Why would this occur? Observations indicated that in the digital-imaging treatment, considerable lab time was occupied with technological issues that were not a part of the drawing treatments. Examples of issues were time spent learning the digital software, errors using the cameras (e.g. accidentally using the incorrect camera setting or not connecting the computer interface), problems using the computer to save images and problems e-mailing. In addition, students had a difficult time getting a quality image due to poor microscope skills. In order to get a good image students in the imaging treatment relative to the drawing treatment had to be more proficient in microscope usage (i.e. light adjustment to maximize resolution, focus, centering the object in question, not looking at their neighbor's drawing, etc.), and thus likely took up more time getting a good image than making a drawing. As a very rough estimate, one group per every other class would not complete their desired photographs because they could not get a good image. In such cases, however, we allowed the students to simply find an image from another student that was saved on the computer and use that image. In support of this contention, students thought that the digital imaging treatments were less time efficient than the drawing treatments. Thus, the lack of LO information in the lab reports of students may have been due to less overall time invested in writing the lab report because time was lost while imaging or working with images, or that the students simply did not have adequate images and did not include additional associated text to make up for the absence of an image. We did not assess students' comfort and familiarity with the imaging technology. Prior to the biodiversity lab, students had only one opportunity to become familiar with the imaging technology. However, they used the imaging technology in each of the three weeks during the pre-lab leading up to the focal lab.

Although observations support the contention that digital imaging improves microscope skills, results of the quiz do not support this. One LO quiz question required students to use the microscope to analyze a slide to answer one question. No differences were present for LO questions on the quiz between treatments.

Evidence from this study indicates that the primary drawback with digital imaging is in relation to students' attitudes. Students preferred the drawing treatment to the digital imaging treatment as reflected by the overall rating. Of the four explanatory variables associated with overall rating, students thought that the digital imaging treatment was less exciting and not as time efficient, but it did not influence their lecture learning experience and it was not perceived as any easier or harder. Of the variables explaining students' attitudes towards specific labs, excitement has had the greatest influence (Basey et al. 2008, Basey & Francis 2011). Observations indicated that certain students in the imaging treatments relative to the drawing were more excited during specific hands-on experiences. For instance when students examined the swimming sperm and took videos in the pre-lab, they appeared to be much more excited than the students in the drawing labs viewing the same thing (both groups were very excited at times though). Also, students seemed to get very excited when they were successful at getting a high-quality image on the large computer screen that was representative of the learning goal. Some students commented that they really liked the digital photography aspect of the lab. Several students wanted to use their images for their start up image on the screen of their computer. Contrary to these observations and similar contentions in the literature, the attitude survey indicated that students in general thought the digital imaging relative to drawing was less exciting.

Educational Implications

Whether or not to replace drawing in favor of digital imaging in hands-on biodiversity labs, emphasizing observations as evidence for higher-order integrated reasoning most likely depends on desired learning goals of the teacher. Results of this study fail to show that differences were present between treatments for cognitive learning of LO foundational information or HO integrated reasoning, as well as moving students to think more like experts in biology. However results of this study indicated that students overall were more excited about drawing, thought that drawing was more time efficient, and overall they rated drawing in lab as better than digital imaging. On the other hand, observations indicated that individual student variation is a potential factor to consider and allowing students the freedom to choose their preferred documentation style may be the optimal design.

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