

Measuring and Advancing Experimental Design Ability in an Introductory Course without Altering Existing Lab Curriculum †

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Introductory biology courses provide an important opportunity to prepare students for future courses, yet existing cookbook labs, although important in their own way, fail to provide many of the advantages of semester-long research experiences. Engaging, authentic research experiences aid biology students in meeting many learning goals. Therefore, overlaying a research experience onto the existing lab structure allows faculty to overcome barriers involving curricular change. Here we propose a working model for this overlay design in an introductory biology course and detail a means to conduct this lab with minimal increases in student and faculty workloads. Furthermore, we conducted exploratory factor analysis of the Experimental Design Ability Test (EDAT) and uncovered two latent factors which provide valid means to assess this overlay model's ability to increase advanced experimental design abilities. In a pre-test/post-test design, we demonstrate significant increases in both basic and advanced experimental design abilities in an experimental and comparison group. We measured significantly higher gains in advanced experimental design understanding in students in the experimental group. We believe this overlay model and EDAT factor analysis contribute a novel means to conduct and assess the effectiveness of authentic research experiences in an introductory course without major changes to the course curriculum and with minimal increases in faculty and student workloads.

INTRODUCTION

The incorporation of inquiry-based research in the form of authentic research experiences in the classroom has expanded, responding to a critical need, especially considering the known advantages of the apprenticeship model of undergraduate research (1, 2). Moving beyond the classical model of undergraduates following a recipe to gain anticipated results is thought to increase engagement and ownership in the educational experience (2–4). The use of semester-long inquiry-based experiences and their many benefits is well supported in the literature; such experiences allow students the time to synthesize and place into context a unique research question to achieve higher-order learning (1, 2). Unfortunately, incorporating inquiry-based undergraduate

research in lower-division courses presents unique challenges due to time, space, and financial limitations. There are also practical implications in terms of restructuring subsequent upper-division courses because lab content and the proper use of equipment may be required in advanced courses and fit into a hierarchical structure of student learning. This may dissuade faculty from instituting semester-long experiences, who may instead choose shorter projects or none at all. Although short lab experiences of one to three lab periods are valid in their own right, with supporting data of their effectiveness, they offer much less time for student creativity and synthesis (higher-order thinking) (1, 2, 5–7). A combinational approach to conducting semester-long research experiences without losing crucial skills and content in an existing curriculum would require an overlay of the two. Despite these barriers, it is important to engage biology students early in their academic careers; to expose them to how science really works; and to build excitement for future learning opportunities in this STEM discipline. It is also important to develop empirically validated educational tools toward achieving this goal (8).

Previously, we used a self-reported assessment, Student Assessment of their Learning Gains (SALG), to demonstrate higher-order learning after students completed a semester-long research experience in an introductory biology course

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for majors (9) and in an upper division neuroscience course (10). However, the subjective nature of this evaluation led us to find a more objective assessment technique. Furthermore, there is a need for larger sample sizes, comparison groups, pre-test/post-test designs, and construct validity in the measurement of novel research-based curricula (8). The Experimental Design Ability Test (EDAT) provides an objective, validated, and well-documented means to measure these gains in introductory courses (11–15). To this end, we designed a semester-long research experience for students, with the following goals: 1) provide a model for a research experience integrated into existing classical cookbook lab sequences (8) as an overlay; 2) provide psychometric analysis of the EDAT assessment to delineate factors that may prove to be more useful for the analysis of this assessment tool; and 3) provide assessment of this overlay research experience and objectively identify learning gains in the areas of advanced experimental design against comparison groups over multiple semesters and years using the EDAT. The overlay model we identify here integrates a semester-long research experience into an existing lab curriculum. The emphasis of this overlay model is teaching experimental design skills; however, in order to make this a viable option for both faculty and students, with minimal workload increases, we have identified specific means to provide the time through scheduling and lab content delivery. Therefore, we provide a model of conducting research experiences with students that is both adaptable to specific institutions and effective as measured through the EDAT.

METHODS

Participants

Students in the experimental ($n = 267$) and comparison ($n = 337$) courses were enrolled in an introductory biology course with a thematically linked lab component designed for biology majors (BIOL1107K), which includes both lab and lecture. There were no differences in the lecture content between experimental and comparison groups. To avoid volunteer bias, students were not informed of, or recruited to enroll in, the course using the overlay research experience described here (8). To increase generalizability, assessment of the overlay design with the EDAT, pre-test ($n = 604$) and post-test ($n = 560$), took place in multiple BIOL1107K courses in multiple semesters from 2011 to 2014 with concurrent experimental and comparison groups (8). Demonstrating external validity, no differences in academic ability (GPA: $t(367) = 0.776$, $p = 0.438$; Freshman Index: $t(262) = 0.722$, $p = 0.471$) or STEM major affiliation (STEM vs. non-STEM: $\chi^2(1) = 0.061$, $p = 0.805$) were noted between the comparison and experimental groups (Table 1). Course attrition in the experimental (9.5%) and comparison groups (9.1%) was similar and accounts for the decreased post-test data. All procedures were performed in accordance with and approved by the University's Institutional Review Board (IRB).

TABLE 1.
Analysis of participants in the comparison
and experimental groups.

Measure	Comparison	Experimental
GPA	3.03 (0.04)	2.98 (0.06)
FI	2,780.43 (18.28)	2,759.85 (21.28)
STEM	75% (25%)	74% (26%)

GPA = grade point average; FI = freshman index; STEM = science, technology, engineering, and mathematics.

GPA and FI (= (high school GPA \times 500) + SAT) data are reported as mean (standard error). STEM data are reported as percent STEM majors (non-STEM majors).

Experimental design ability test

The EDAT was administered in a pre-test/post-test experimental design to both experimental and comparison course sections as previously described (14, 15). The pre-test and post-test EDAT were administered during the first and last lab meeting of each course, respectively (Fig. 1). Participation of students enrolled in the experimental and comparison courses was anonymous, voluntary, and any answer to the EDAT prompt was incentivized with a small bonus credit representing 0.75% of the total course grade. EDAT coding was conducted as previously published (15). EDAT coding was performed by multiple researchers who were blinded to the experimental condition. Researchers awarded a single point for each EDAT concept that was included in the student response (15). To establish interrater reliability, each researcher independently coded the same 90 randomly chosen student responses. Intraclass correlation coefficient (ICC) was used to assess interrater reliability of EDAT scorers (17). The average ICC measure was 0.866, $F(90,90) = 7.478$, $p < 0.001$, which demonstrates a very high degree of reliability among all raters.

Comparison group lab design

Comparison groups conducted 10 cookbook labs (8) that were thematically linked to the lecture content over the 15-week semester (Fig. 1, Appendix 1). Two additional weeks were used for comprehensive lab exams, which comprehensively covered five labs. Each of these labs emphasizes course content, with the additional exposure to basic lab equipment and techniques. Due to the large number of 1107K sections, weeks interrupted with a holiday were not utilized to keep all sections on the same schedule. Additionally, the first and last weeks of the semester were not used due to the drop/add period or unforeseen weather cancellations, respectively.

Experimental group lab design

Experimental groups completed eight of the ten cookbook labs; two of the labs not completed in the experimental

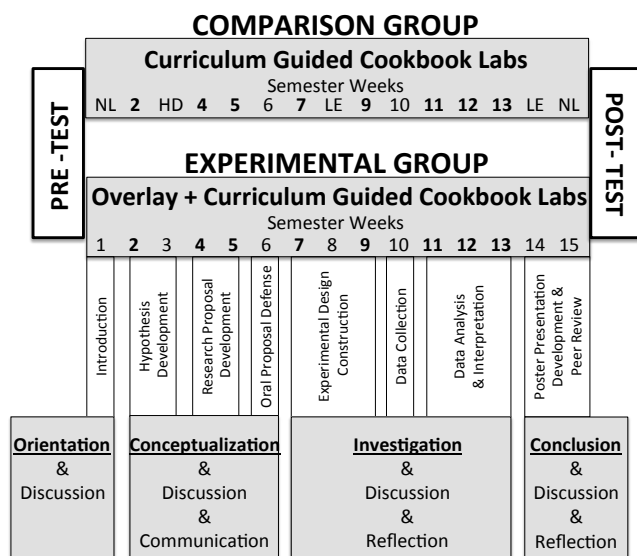


FIGURE 1. Timeline of the comparison group and experimental group with identified key components of inquiry-based learning. Both comparison and experimental groups completed a 15-week semester lab in an introductory biology course with pre-test and post-test EDAT evaluations. Labs that remained the same between the comparison and experimental groups are bolded. The comparison group did not hold lab (NL) on the first and last week and also one holiday-interrupted week (HD). The experimental group did not take comprehensive lab exams (LE). The experimental group conducted an overlaid experiment of their own design during the semester that maps onto the key features of inquiry-based learning (key features adapted from Pedaste et al. 2015) (16).

group covered content that was highlighted in the lecture (Fig. 1, Appendix I). Additional lab weeks were gained by including a lab during the first and last weeks, with no lab setup, and scheduling all lab meetings to avoid school holidays. Additionally, frequent, short assessments replaced the comprehensive lab exams to gain two additional lab meetings. In total, students in the experimental group met fifteen times, completing eight of the ten cookbook labs while having seven meetings to work on the semester-long research project. Graded portions of the overlay lab (hypothesis, oral presentations, and poster) along with the cookbook lab assessments (quizzes) represented the same portion of the total BIOL1107K grade in both the experimental and comparison groups. Quizzes given to the experimental group did not include content from the research experience.

Overlay lab procedure

Students in the experimental group (and not the comparison group) designed and conducted an overlaid experiment throughout the semester (Fig. 1, Appendix I). They were introduced to the basic concepts of behavioral testing and coding in a murine model. All procedures were conducted according to the *Guide for the Care and Use of*

Laboratory Animals (18). Emphasis was placed on constructs that are easy to operationalize in a simple two-group design with the manipulation of a variable such as olfactory, auditory, and visual cues. The students were challenged to develop their own questions regarding how one of these variables may alter a measurable behavior. Student groups developed and submitted a unique hypothesis and then developed a proposal to test their hypothesis. Feedback on the group's idea was provided after the submission of an outline of their experimental design. Short oral presentations were given with the intent of "selling" the group's idea. A class vote identified one hypothesis that would be tested for that course section. Students provided feedback to refine the experimental design and built behavioral testing chambers. After each group collected their data, students analyzed the pooled class data. Each group independently developed a scientific poster to display the overall project. In the final week, posters went through a peer review process.

Statistical analysis

All analyses were performed using SPSS IBM Statistics (v23.0, Somers, NY).

RESULTS

EDAT exploratory factor analysis

To determine whether the assessment instrument contained latent variables, an exploratory factor analysis with promax rotation was performed on the 10 items from the EDAT (14, 15). The Kaiser-Meyer-Olkin (KMO) measure was used to verify sampling adequacy for the analysis, KMO = 0.732, and Bartlett's test of sphericity indicated that correlations between items were sufficiently large, $\chi^2(45) = 1,434.513$, $p < 0.001$. The following criteria were used to retain factors: 1) factors with eigenvalues > 1.0 ; 2) an examination of the scree plot; 3) factors containing at least three items; 4) factors with high coefficients on one factor; and 5) factors with high communalities (19, 20). Using these criteria, two factors with good reliabilities were extracted that combined to explain 39.53% of the variance (Table 2). A goodness-of-fit test confirmed this model, $\chi^2(26) = 63.140$, $p < 0.001$. Table 2 shows the factor loadings after rotation and suggests that Factor 1 represents a basic understanding of the experimental design, while Factor 2 represents an advanced understanding based on the hierarchal progression of coding questions with increasing difficulty the EDAT was originally designed to contain (15). Factor 1 represents EDAT coding questions 1 to 4 in the EDAT coding rubric (Table 2). Factor 2 represents EDAT coding questions 5, 7, and 10 (Table 2).

EDAT analysis

Composite EDAT scores were analyzed in a 2 (group: comparison/experimental) \times 2 (test: pre-test/post-test)

TABLE 2.
Factor loadings for exploratory factor analysis with Promax rotation of the EDAT ($N = 1,164$).

EDAT Assessment Questions (numbering from original coding instrument)	Factor	
	1	2
Recognition that an experiment can be done to test the claim (1)	0.455	-0.013
Identification of what variable is manipulated (2)	0.803	-0.066
Identification of what variable is measured (3)	0.686	-0.007
Description of how the dependent variable is measured (4)	0.409	0.152
Realization that there is one other variable that must be held constant (5)	0.074	0.635
Understanding that the larger the sample size, the better the data (8)	-0.030	0.696
Awareness that one can never prove a hypothesis, that there are possible sources of error, that there are limits to generalizing the conclusions (credit for any of these) (10)	-0.011	0.313
Understanding of the placebo effect (6)	0.194	0.030
Realization that there are many variables that must be held constant (7)	0.016	0.279
Understanding that the experiment needs to be repeated (9)	-0.008	0.256
Eigenvalues	2.549	1.404
% of variance	25.495	14.038
α	0.644	0.541

Factor 1 = basic understanding of experimental design; Factor 2 = advanced understanding of experimental design. Items clustering on each factor appear in bold. Numbers in parentheses represent numerical order of questions from the EDAT scoring rubric.

ANOVA to assess the effect of the novel research overlay on experimental design understanding. There was a significant interaction between group and test, $F(1, 1164) = 17.369$, $p = 0.013$ (Fig. 2A). Students in the experimental group demonstrated greater improvement on the composite EDAT from pre-test (mean (M) = 3.760, standard error (SE) = 0.102) to post-test (M = 5.429, SE = 0.105) than those in the comparison group (pre-test: M = 3.588, SE = 0.091; post-test: M = 4.765, SE = 0.095).

Factor loadings were used as dependent variables in 2 (group: comparison/experimental) \times 2 (test: pre-test/post-test) ANOVAs to assess the effect of the novel research overlays on experimental design understanding according to each factor. While students improved on their basic understanding of experimental design (Factor 1) from pre-test to post-test, $F(1, 1164) = 111.257$, $p < 0.001$, there were no differences in these gains between students in the experimental and comparison groups, $F(1, 1164) = 0.272$, $p = 0.602$ (Fig. 2B and 2C). However, students in the experimental group demonstrated higher gains in advanced understanding of experimental design (Factor 2) than did the comparison group, $F(1, 1164) = 9.630$, $p = 0.002$.

DISCUSSION

The goals of this research were to design and assess the effectiveness of teaching experimental design through an overlaid authentic research experience in a lab for introductory biology majors. In acknowledgement of the

resistance to change and the necessary alterations to a biology curriculum, this research identified the effectiveness of a research experience overlaying existing labs without disrupting the standard lab curriculum. In the present study, we implemented a research experience as an overlay to the classical cookbook lab experience and provided psychometric analysis of the EDAT and identified learning gains in advanced experimental design.

Goal 1: Implementation of the overlay model

The classic model for a biology lab is a sequential yet independent set of cookbook labs for the students to conduct, usually in small groups. This type of experiential learning provides many advantages, including facilitating collaboration and the reemphasis of lecture concepts and content with the additional benefit of data collection and subsequent statistical analysis. Students also learn to use and apply a variety of equipment and techniques expected for future biology courses and post-graduation careers. Given the large number of students, especially at the introductory level, who require these labs, faculty time, budgetary resources, curriculum, and course objectives dictate the content of the labs they conduct (1, 2, 6). Unfortunately, these restrictions can limit student achievement of advanced competencies (5).

While both cookbook and inquiry-based labs provide some level of authentic learning through active participation (21), labs that are designed around one topic, such as those in cookbook labs, remain singular in scope. This

singularity does not provide students the opportunity to integrate their own experiences and ideas into their experimentation, a process which is documented to increase critical thinking skills (22). Furthermore, these cookbook labs often require little intellectual input from the student regarding the experimental design or the process of science (1, 23). To incite ownership of their results and engagement in their learning experience in a way that mirrors that of independent research studies, students, especially those at the introductory level, should participate in an authentic research experience rather than simply following a recipe or list of instructions to arrive at a known conclusion (7, 24). Active exploration stimulates curiosity, creativity, and enthusiasm for science (25, 26).

Given the recognized benefits of active learning, embedded undergraduate research experiences in biology curricula are strongly encouraged (2). The overlay model described here structures a student-driven, authentic research experience into an existing introductory biology lab in which students complete standard labs necessary for our current biology curriculum (1). The overlay was carefully structured so as to minimally increase student workload, which could have impacted its external validity (8). Students in the experimental group did participate in three additional lab periods. However, these lab periods did not require additional study time, as they were largely skills-based labs. By combining labs to focus on techniques required of students in future courses and adjusting lectures out of lab to focus on specific content not covered in labs removed from the experimental group sequence (Weeks 6 and 10, Fig. 1), we ensured students were utilizing time in the lab normally dedicated for other content requirements for their oral presentations and data collection. Through lab scheduling to miss holiday break days (Week 3, Fig. 1), time was provided for students to work on creative ideas for their experiment without requiring them to participate in this idea construction for the entire lab period. Primarily, this time was dedicated to having faculty input to ensure that the experiment was both ethical and possible given the resources and limited time students had to conduct the actual data collection. Additionally, to provide time for an introduction and poster development and formatting, students met during the first and last weeks of the semester (Weeks 1 and 15, Fig. 1), yet both of these time periods required little preparation from the students out of lab, and the last week meeting was optional. By substituting comprehensive lab exams with shorter, more frequent assessments (Weeks 8 and 14, Fig. 1), students were provided time for building their behavioral devices and setting up the materials they needed to conduct the experimentation along with a lab period for poster development.

In combining the two formats, our goal for this overlay design was for students to be able to receive the advantages of curriculum-guided cookbook labs while still having the time to be creative and actively engaged in their own experimental design without the creation

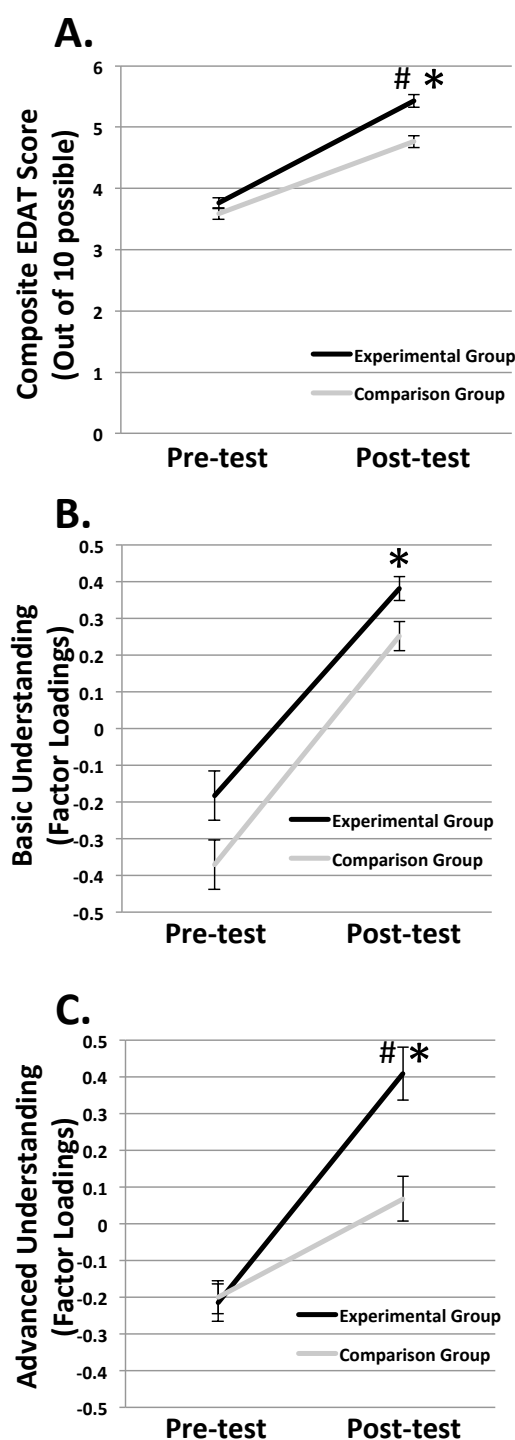


FIGURE 2. Analysis of pre-test and post-test EDAT evaluation in experimental (black) and comparison (grey) groups. Significant pre-test to post-test differences were observed in the composite EDAT scores (A), basic understanding factor loadings (B), and advanced understanding factor loadings (C) (* $p < 0.05$). Significant experimental to comparison group differences were observed in the composite EDAT scores (A) and advanced understanding factor loadings (C) (# $p < 0.05$), but not in the basic understanding factor loadings (B) ($p > 0.05$). Error bars represent standard error of the mean; EDAT = experimental design ability test.

of perceived additional work. The use of student groups in the framework of inquiry-based learning increases collaboration and remains consistent with the traditional format of cookbook labs in the rest of the semester (7). The design of this overlay maps well onto the inquiry-based learning framework (Fig. 1) and its key components (16). The open-ended nature of this research experience is what defines it as an authentic research experience (27). Instead of focusing on how the student's experiment related to the literature, the focus was placed on the use of creativity, manipulation of variables, inclusion of controls, and analysis. Additionally, students were required to thoughtfully consider future directions of their research with the intent of increasing experimental design abilities and the added benefit of increasing higher-order thinking skills gained in this practice (22).

If faculty are to implement this overlay model to teach experimental design skills to students, there must be a convincing argument made that 1) the model is effective (Fig. 2) and 2) the model will have minimal impacts on faculty workload, similar to the minimal impacts on student workloads. In the overlay example presented here, we provide a framework of coding murine behaviors; however, we believe that the overlay model can be adaptable to the institutional context and resources as well as faculty expertise as long as the overlay model and emphasis on student creativity is maintained. In this overlay model, faculty or teaching assistants are required to be present for three additional lab periods (Weeks 1, 3, and 15, Fig. 1). However, these lab periods require little additional preparation outside of the first lab (Week 1, Fig. 1), which is designed to introduce the basic ideas and concepts to the students so that they can begin their creative process of experimental design. Despite the additional lab component this overlay model requires, additional faculty workload is minimized by the selection of one experimental design chosen by the students after their oral presentations and by having the students be responsible for the construction of their behavioral apparatus. Investigations of behavior in species not under federal guidelines for care and use would make this model less time intensive if an institution does not have the space or resources to conduct murine experiments. Furthermore, online resources for other fields such as genetic studies make this overlay design a viable option for institutions with limited resources or large numbers of students. The documented effectiveness of using online resources for data collection does not preclude the creativity of student experimental design and has a significant effect on learning gains similar to live data collection (10). Our hope is that others will adopt this effective model for their specific setting to increase students' experimental design abilities.

Goal 2: Assessment of the EDAT

The EDAT assesses student gains in experimental design in an objective, open-ended response format (14, 15).

Several key components of the student's understanding of the experimental design process are assessed by the EDAT. The EDAT assessment follows a theoretical hierarchical progression to produce a cumulative measurement of experimental design abilities for each individual on a theoretical scale (15). Analysis of the EDAT has since taken on alternate forms with recognition of face validity and, therefore, potential construct validity of individual questions or groups of questions (14). In our own analysis, we observed trends in the pre-test and post-test student scores that indicated the possible presence of underlying factors. Exploratory factor analysis is a common tool used to determine the relationships between individual items in order to uncover latent factors contained within assessments (4). Our analysis revealed two factors we term "basic" (EDAT coding questions 1 to 4) and "advanced" (EDAT coding questions 5, 7, and 10) understanding of experimental design, which were named because of the hierarchical progression of EDAT coding questions representing increasing difficulty from question 1 to 10, as defined in the original EDAT description (Table 2) (15). Additional analyses based on factor loadings reveal a novel finding and support novel uses for the EDAT. We believe that in an introductory course, the original 10-point scale may contain the appropriate factors for analysis of experimental design gains (15). The exploratory factor analysis supports this conclusion and provides faculty additional tools to study gains in advanced experimental design without the confounding effects of the interrelated assessment of basic experimental design understanding.

The analysis of EDAT factors described here provides faculty with an easy-to-use and validated means to assess experimental design learning gains, yet it should be noted that there are other facets to experimental design not included in this assessment. The E-EDAT includes additional prompts and an expansion of the scoring rubric to provide more insight into specific items not covered in the original EDAT such as variability in populations and sample size (11). However, altering the rubric and prompts will require revalidation of the entire assessment tool (12), and the factors we describe here may provide distinguishable gains even in upper-division courses. The Critical Thinking Assessment Test (CAT) (5, 28) and Molecular Biology Data Analysis Test (MBDAT) (29) provide insight into experimental design as well as graphical and mathematical interpretations of data and their application to real world problems. These are fundamental to the interpretation of data conducted in the overlay project described here; however, our assessment intent was to focus holistically on the experimental design process rather than on quantitative skills. The Biological Experimental Design Concept Inventory (BEDCI) provides a means to specifically measure elements of experimental design understanding in a guided multiple-choice format, yet it fails to allow for the coding of creatively composed student answers (30). The Rubric for Experimental Design (RED) is a validated rubric developed from the combination of several surveys that reveals five areas of difficulty students have in

the area of experimental design (31). The use of the RED as a feedback mechanism for perfecting any inquiry-based overlay along with BEDCI, MBDAT, CAT, and the E-EDAT in future studies will allow for an ability to assess convergent and divergent validities as well as the unique benefits of each toward the assessment of learning gains.

Goal 3: Overlay lab increases gains in experimental design ability

We identified specific experimental design learning gains using the EDAT assessment instrument, and we used time-matched comparison groups to identify specifically how the overlay of a research experience would alter these gains (Fig. 2). We observed significant experimental design gains in the analysis of Factor 1 (basic understanding), Factor 2 (advanced understanding), and cumulative EDAT scores from pre-testing to post-testing in both the experimental and comparison groups. This was an anticipated result because both groups completed labs thematically linked to the lecture content, which require a basic understanding of the aspects of experimental design including hypothesis testing, identification of variables, and data collection. In fact, the overlay design did not change the post-test gains in Factor 1 (basic understanding) in relation to the comparison group. Interestingly, the experimental group exhibits significantly increased post-test gains in Factor 2 (advanced understanding) and in the cumulative EDAT score versus the comparison group. Experimental group increases in Factor 2 indicate that the overlay design provides increased gains in the advanced application of experimental design abilities. Additionally, cumulative score increases encompass several rubric items (EDAT scoring questions 6, 8, and 9) that did not fall under either identified factors, so these cumulative gains may not be limited to Factor 2 increases (Table 2). It should be noted that because of the hierarchical structure of the EDAT scoring rubric, these additional questions, although not identified as mapping onto the advanced understanding factor (Factor 2), do represent a more advanced understanding of experimental design and have face validity. Since the effects of additional lab periods were not isolated in this study, an argument could be made that the differences noted between comparison and experimental groups were due to students' additional time on task. The restructuring of lab exams only altered the assessment of labs shared by the comparison group. Several additional overlay components may explain increases in measured experimental design abilities including ownership in the students' projects, additional time for analysis of results, and reflection on how the experiment could be altered in the future. However, the model described here allows others to alter an existing lab structure, while maintaining institutional and departmental learning objectives, with minimal increases in student and faculty workloads. Furthermore, incorporation of research into the curriculum is documented to increase engagement, which itself is a documented means to increase

learning gains (24, 25). Specifically, the focus on an alternate hypothesis, future directions, and close examination of the experimental design were encouraged in the development of the poster presentation, and this is in direct opposition to the limited conclusions or future directions in cookbook labs observed by us and others (5). Encouraging students to consider refinements to their research promotes more creativity, thoughtfulness, and understanding of scientific practices, further extending the advanced understanding of experimental design.

CONCLUSION

Taken together, these data indicate that involving students in the process of science as an active and dynamic process (1) over the course of a semester increases advanced abilities in experimental design. These gains are more clearly illustrated with analysis of two factors isolated from the original EDAT scoring rubric. Analysis of these two factors indicates that classical cookbook labs do increase experimental design abilities but not to the extent of our overlay design, which promotes increases in both basic and advanced scientific learning gains. The overlay of a semester-long experience, therefore, provides a viable alternative to more drastic changes to existing lab curriculum. An alternative option to in-class activities is the use of online research resources, which require little to no in-lab preparation and still provide the inquiry-based research experience with assessed higher-order thinking increases (9, 10). Anecdotally, we observed that this overlay design provides learning opportunities for written and oral communication development and problem solving. Exploring the nature of the increased engagement we noted in our students would also delineate specific constructs associated with learning and motivation and give additional information to refine lab research experiences for targeted groups of students (25, 26). Additionally, the incorporation of primary literature into this overlay design could increase experimental design abilities and enhance scientific literacy of students even at the introductory course level (5, 13, 32). It is our hope that our novel analysis with the EDAT assessment and description of an overlay design will provide additional tools necessary to successfully assess and incorporate authentic research experiences in introductory biology courses.

SUPPLEMENTAL MATERIALS

Appendix I: Supplemental Figure 1

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