

Why Do I Need a Lab Notebook? Teaching Responsible Conduct of Research with CURE Lab Notebooks

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Abstract

There are few instructional tools about data acquisition and management available for undergraduate students. I created this lesson as a Fellow of the Ethics Network for Course-Based Opportunities in Undergraduate Research (ENCOUR) to fill this gap by providing a lesson that introduces lab notebooks and builds connections to responsible and ethical conduct of research (RECR). While originally developed for a course-based undergraduate research experience (CURE) in microbiology, there are few disciplinary or course specific details included, making this resource easy to adapt to a variety of contexts. The lesson begins with a pre-class assignment which introduces students to the basics of keeping a lab notebook. The in-class instruction provides opportunities for student reflection, short lecture segments, and group work to identify and discuss the connections between data collection practices and RECR. Students who completed the lesson displayed a broader and more complete conception of the connections to RECR topics as well as the utility of the lab notebook.

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Learning Goals

Students will:

1. understand appropriate practices of data acquisition and management as related to lab notebooks in a course-based undergraduate research experience (CURE) course.
2. set up and maintain a lab notebook that supports responsible and ethical conduct of research.

Learning Objectives

Students will be able to:

- ◇ 1.1. identify and describe opportunities and threats for appropriate data acquisition and management in the context of a CURE (undergraduate laboratory course).
- ◇ 1.2. distinguish and differentiate opportunities and threats for appropriate data acquisition and management in the context of a CURE (undergraduate laboratory course).
- ◇ 2.1. implement appropriate data acquisition and management practices in the context of a CURE (undergraduate laboratory course).

INTRODUCTION

There has been increased attention to providing authentic research experiences within undergraduate curriculum (1). As these research experiences have increased, questions have emerged about responsible and ethical conduct of research (RECR) training within these contexts. Recommendations about the integration of this training within life science education have been provided (2). Student learning outcomes also have been proposed which include “Students will be able to define research misconduct, questionable research practices, proper data acquisition and management, collaboration, and authorship in the context of a CURE” (2).

Most research-intensive universities provide RECR resources and training on their websites, but these are usually written with principal investigators and post-graduate scientists as the intended audience. This is often in response to the RECR

training requirements of the major funding agencies (3, 4). However fewer resources are written with the undergraduate STEM student in mind. Additional resources exist in the form of case studies or validated instruments to assess knowledge of RECR topic (5).

Course-based undergraduate research experiences (CUREs) are a common format to incorporate training about RECR within the curriculum. These experiences may be connected to grant-funding and result in publishable findings. Therefore, it is important that students are educated about RECR topics as they undertake their work in courses with a CURE component.

[CUREnet](#) provides a compilation of CUREs for instructor use. Some of these options integrate RECR training, but there are few stand-alone undergraduate teaching resources that focus on the RECR topic of data acquisition and management. This lesson seeks to fill that gap by providing a lesson which provides basic

training about the principles of maintaining a lab notebook in a course-based undergraduate research experience while connecting this practice to one's RECR.

Intended Audience

This lesson is not specific to the course content of the original audience and can be easily adapted to other disciplines or majors. However, this lesson was initially taught to an undergraduate introductory microbiology course implementing the *The Art of Microbiology: An Agar Art Microbiology Lab CURE* (6). The original audience consisted of biology, exercise science, and pre-medical majors in their sophomore year and above. For most of these students, this was their first authentic research experience in the curriculum.

Required Learning Time

The lesson includes one 60-minute class or laboratory period with a required pre-class homework assignment. Additional bi-weekly meetings may be held with research teams, but these are an optional component of the lesson.

Prerequisite Student Knowledge

This lesson was written as an introduction to the RECR topics of research misconduct and appropriate data acquisition and management for undergraduate students, both science and non-science majors. The prerequisite skills needed to successfully complete the work are an ability to navigate the internet to links and a high school-level reading ability. Open-source website links with interactive text are included in the Supporting Files.

Prerequisite Teacher Knowledge

Instructors planning to use this lesson should have a basic understanding of the areas of responsible and ethical conduct of research, including the principles of data acquisition and management. For instructors desiring additional resources or training in this area, there are many open access resources on the internet. The Department of Health and Human Services provides an extensive library of videos, guidance documents, and more on [their website](#) for instructors who would like additional training. If more specific information about the recommendations for RECR training within the context of a CURE is desired, see the recommendations provided by Diaz-Martinez and colleagues (2) as well as viewing the resources available on the [Ethics Network for Course-based Opportunities in Undergraduate Research \(ENCOUR\) website](#).

SCIENTIFIC TEACHING THEMES

Active Learning

This lesson was designed with specific attention to the recommendations of Lang (7). Therefore, I include varied tasks which have active individual and group learning components, which were thoughtfully selected to maintain the focus and attention of the students. The pre-class assignment engages students in individual reading followed by a formative assessment. The in-class portion begins with reflection which provides an opportunity for students to connect the topic of the lesson with their pre-class reading. There are short lecture-style presentations of information interspersed with small group activities and whole class discussion.

Assessment

Assessment of student learning includes formative assessment during the lesson, ongoing formative assessment during regular meetings with the instructor and an end of class assessment consisting of 5 questions (see Supporting File S4).

Inclusive Teaching

This lesson seeks to engage students in multiple activities during the lesson to increase their engagement during the lesson (7). I fostered an inclusive teaching environment to address the needs and preferences of students with diverse learning preferences and backgrounds (8). The principles of Universal Design for Learning were also considered by applying the principles of several of the "checkpoints" outlined in the UDL Guidelines (9). For example, students were introduced to topics through reading which were available on an accessible website (Checkpoints 1.1, 5.1). Increased cognitive engagement was sought through individual reflection, small group work, and whole class discussion. This allowed students to demonstrate their knowledge using multiple means of engagement (Checkpoints 2.5, 5). Small group work and whole class discussion provided an opportunity to foster collaboration among class participants (Checkpoint 8.3). In addition, I used an anonymous response system (Pear Deck) to minimize negative feelings and conformity affect (10).

LESSON PLAN

This lesson begins with a preparatory homework assignment (reading and quiz) and then uses one class or laboratory period to discuss how maintaining a lab notebook supports responsible and ethical practices in data acquisition and management. The lesson is not designed to provide specific lab notebook formatting or directions. Therefore, if you have such requirements, this lesson could still be adopted with few modifications. A detailed description of pre-class preparations and a lesson plan are provided on Table 1.

Materials Required

Instructors should make physical copies of Supporting File S2 so each course participant will have a copy.

Instructor Preparation

To begin, create a homework assignment in your learning management system (LMS) that includes readings from the [Website Guide to Research for Undergraduates \(WebGURU\) website](#) about Lab Notebooks. WebGURU provides a host of information geared toward undergraduate researchers. Text for the homework page with appropriate links is available in Supporting File S1. In addition, create a quiz to assess learning from the homework assignment. The questions used in my course are provided in Supporting File S1. I used the Quiz tool in my LMS to create a self-grading quiz worth only 6 points, but this could also be completed on paper and turned in at the beginning of class. Instructors should also review and revise, as indicated in the Notes section of each slide, Supporting File S3 prior to the class meeting. It is ideal to include interactive question slides, as indicated in the presenter notes. I used Pear Deck for this purpose, but many options exist.

Instructor Instructions

Direct the students to the homework assignment where they will read information in WebGURU. The activity is expected to take no more than 30 minutes, but I recommend making this announcement at the previous class meeting and including it in any weekly updates or communications. Students then complete a quiz in the LMS platform with a due date immediately preceding the beginning of class (see Supporting File S1).

The Presentation Slides (found in Supporting File S3) provide structure for a 60-minute class period. After introducing the lesson with the provided lesson objectives (slide 2), class begins with 5 minutes of silent journaling where students reflect on their homework assignment and begin to think about the connections between that information and the class topic of data acquisition and management related to RECR (slide 3). After the reflection time, lead a short time of discussion to summarize student thoughts about the question. Then present a short lecture about research misconduct to include the definition and prevalence of research misconduct, as well as a short case study about Cyril Burt (slides 4–11).

Make sure students are seated with their lab teams for the remaining work in the lesson. For classes that don't use lab teams, divide the students into groups of 3 to 5 students for the class discussion. My students are separated into permanent lab teams prior to this lesson and are created to distribute valuable student resources across the teams based on the recommendations of Michaelsen and Sweet (11). Student teams are asked to access the [Retraction Watch website](#) and the associated database to complete two different tasks (slides 12–13). First, ask the students to spend about 10 minutes exploring the database site to create a list of "reasons for retraction" that relate to data acquisition and management. Follow this activity with a whole class discussion generating a list of reasons that are located. Write this list on the board or type it into a shared document which is projected for the class to view. Then ask teams to locate and share with the class a single paper whose retraction could have been avoided if appropriate lab notebook practices had been followed. I recommend that instructors familiarize themselves with this website along with the operation and information included within the database prior to the class. Additional details and recommended resources are mentioned in the Instructor Preparation section above. The recommended class time for this work accounts for the time needed for students to acclimate to the website and be able to locate appropriate information. However, your students may need a different amount of time to become familiar with the site and to locate the requested information.

Supporting File S2 is then distributed to each individual, but encourage students to work in their teams or pairs to annotate this example entry with an emphasis on why each component is included (slide 14). Follow this activity with another time of class discussion. If time is not available to complete this discussion, the annotated worksheets could be collected and reviewed by the instructor for feedback to individuals via written feedback or the whole class during the next class period.

The lesson concludes by providing guiding questions for lab teams to discuss how they will keep and maintain their own lab notebook over the course of the semester (slide 15). A short time may be available during this class period, but this component may also need to be assigned for outside-of-class work. This lesson does not attempt to cover specific requirements on formatting of a lab notebook. In my course, lab teams are required to meet regularly with me throughout the semester and data acquisition and management is one topic to which we return. Discussing the team's answers to the provided questions gives a good starting point for these discussions and also is helpful as the semester progresses and teams work to continue responsible and ethical practice.

Student Instructions

Specific student instructions are provided for LMS pages and during the in-class work in the Supporting Files described above.

Student Assessment

Assessment of student attainment of the stated learning objectives occurred throughout the semester. I held bi-weekly meetings with each student team to answer questions and gauge their progress on the CURE project. We also reviewed and discussed their processes of data collection and management during this time. This allowed for formative assessment with immediate feedback and additional instruction. An end of semester assessment was also collected. These questions are available in Supporting File S4.

TEACHING DISCUSSION

This lesson supported the attainment of the stated learning goals. Students were introduced to the basics of keeping a lab notebook throughout their work in a CURE course and were provided an integrated training about the RECR topic of data acquisition and management. Course participants were observed to set up and maintain their lab notebook over the duration of the class. One important assessment involved bi-weekly meetings with each lab team. Through this method and in reviewing other work submitted in the course, I found that teams were recording their data appropriately. Specifically, they were recording all details of measurements and observations with appropriate dates/ times and providing minutes of research team meetings and relevant conclusions. I was also able to provide oral feedback on ways to improve or simplify their work in this area. There were continued conversations about various weaknesses of the teams' data collection methods. In another example, some teams with digital notebooks struggled to provide access to all members due to the different devices in use. This involved some team members using an iPad and Apple pencil to take digital, hand-written notes on a program that was not accessible on all Windows based computers. Instructors should consider institutional resources that are available to facilitate accessibility of the lab notebook to all students. In some situations, the course may have a dedicated space where physical lab notebook can be stored and accessed by all team members. Other instructors may have access to digital tools through their institution that can alleviate this issue.

I also collected data prior to the beginning of laboratory work and at the conclusion of the class using the questions provided in the Supporting File S4. The pre-assessment was collected from students at multiple institutions, and included the students who completed this lesson. However, only participants enrolled in the course where the lesson was taught completed the post-assessment. This work was approved by the Southern Wesleyan University Research Compliance Committee (IRB approval #20-21.10). All students enrolled in the class ($n = 21$; 14 female, 7 male) completed four open-ended questions prior to this lesson and again at the end of the course. Students in the course represented sophomore ($n = 6$), juniors ($n = 7$) and seniors ($n = 8$) but no other demographic data about the students was collected. I analyzed the qualitative data for one question from the survey: *Describe how the process of keeping a lab notebook is related to one's responsible conduct of research.* This thematic analysis used the definitions and codes from DuBois and Dueker (12) and Mabrouk (13), but was open to new ideas that were present in the student responses. Code definitions and participant examples are presented in Table 2. A total of 8 themes emerged from the data and responses from the subset of students who completed this lesson are shared graphically in Figure 1. These themes included research misconduct (preventing falsification or fabrication), a connection to other RECR topics (authorship, research continuation), logistical needs for data collection (maintaining standards, organization), and no connection to RECR (vague connection to literature, "task" related to busywork).

When comparing the themes identified prior to instruction and at the conclusion of the course, there were some differences. Preventing fabrication or falsification was the most commonly identified theme. However, students demonstrated a greater awareness of the overall importance and utility of the lab notebook at the conclusion of the course, as evidenced by the increased frequency of themes present in the post-lesson assessment (see Figure 1). Additionally, the themes with no connection between use of a lab notebook and RECR topics were no longer present (vague connection to literature, "task" related to busywork). These findings provide evidence that this lesson helped students meet the learning goal of understanding the connection of their CURE lab notebooks to the RECR standards of data acquisition and management.

One surprising area of student difficulty was found in the use of the Retraction Watch website and database. Students did not intuitively understand how to search on this site to locate the needed information during the lesson period. I needed to move about the room to view student screens and provide specific guidance for each team on completing the requested task. Some student groups couldn't locate the link to enter the database. Others did not understand how to open the drop-down menus, as requested by certain tasks. While I've noted how instructors should familiarize themselves with this site prior to the class and also adjusted the time needed for this task within the lesson plan, I think it's important for instructors to be prepared for these questions. While our students are largely "digital natives" (14), they may still struggle with some computer applications or tools. An additional step to address this potential issue could be to assign the Retraction Watch User Guide as a reading prior to the class session.

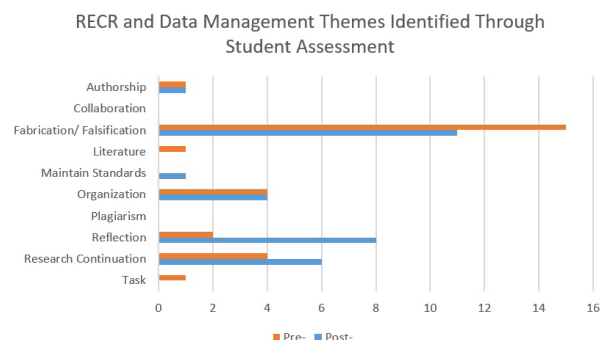


Figure 1. Students demonstrated a broader and more complete conception of the importance of lab notebooks to proper data acquisition and management following this lesson. The graph displays the number of students who mentioned RECR or data management themes in their pre- and post-assessment responses.

SUPPORTING MATERIALS

- S1. CURE Lab Notebooks – Homework Assignment. Instructions for setting up all homework components. Text to use when setting up the homework prior to the lesson with the instructor's LMS and questions for the pre-lesson homework quiz.
- S2. CURE Lab Notebooks – Lab Notebook Worksheet. File that is used for both the Homework Quiz and during the in-class activity.
- S3. CURE Lab Notebooks – Presentation Slides. PowerPoint slides that can be used in during the teaching session with this lesson.
- S4. CURE Lab Notebooks – Pre-Post Assessment. Pre-and/or Post-instruction assessment which can be used to understand the effectiveness of the lesson.
- S5. CURE Lab Notebooks – References and Resources. A listing compiled of resources that are helpful in preparing for and teaching this lesson.

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Table 1. Teaching timeline table.

Activity	Description	Estimated Time	Notes
Preparation for Class			
Create Pre-Class Assessment	Create an assignment in your LMS using questions provided in Supporting File S4.	15 minutes	This step is optional but was completed when the lesson was designed. Choose specific questions to capture the data important to you.
Create Lab Notebook Homework Assignment	Create an LMS page with instructions and links to appropriate pages. Also create a quiz in your LMS.	20 minutes	Text for the LMS creation of this homework assignment and questions for the homework quiz are provided in Supporting File S1. WebGURU links are provided here. The sample Lab Notebook can be Supporting File S2.
Review/ Edit Presentation Slides	Review the provided slides, make edits to personalize them to your class.	10 minutes	Check the Presenter Notes area for each slide for specific updates that are needed in Supporting File S3.
Make Copies of Worksheet	Make copies of Supporting File S2.	5 minutes	See Supporting File S2.
Class Session			
Lesson Objectives	Describe and highlight the objectives for this lesson and ongoing course are provided (slide 2).	3 minutes	Lecture slides with notes are in Supporting File S3.
Silent Journaling	Provide an opportunity for students to reflect on what they learned from the homework and start making connections to the topic of responsible and ethical conduct of research (slide 3).	5 minutes	Prompt is provided in slide 3. I used the Pear Deck platform for silent journaling followed by whole class discussion.
Mini-Lecture	Introduce students to “research misconduct” and examples (slides 4–11).	10 minutes	Review background knowledge and instructor notes. Also make noted changes to individual slides.
Team Research and Report	Teams view and report about real examples of research misconduct (slides 12–13).	20 minutes	This includes 2 different activities which view reasons for retraction related to improper data acquisition and management and then sharing examples.
Lab Notebook Worksheet	Students annotate example lab notebook pages with a focus on the reason each component is needed (slide 14).	10 minutes	Use Supporting File S2. The discussion following this assignment may be adapted to happen outside of class or at the start of the next class period.
Team Discussion	Lab teams discuss the mechanics of how they will keep and maintain their own lab notebook, focusing on possible challenges and discussing plans on how to overcome those challenges (slide 15).	Remainder of class/ Outside of class	It is important to make sure students troubleshoot their lab notebook method and to discuss ways they will address these issues. If you have a specific or required format for lab notebooks, you should modify this slide and the related discussion to be consistent with your expectations.
Post-Class Assessments			
Team Meetings with Instructor	Hold regular meetings with each lab team to discuss their research project and data collection and acquisition issues.	Variable	I require meetings every 2 weeks, and these have ranged in length between 5 minutes and 15 minutes.
Post-Class/ End of Semester Question	Create an assignment in your LMS using questions provided in Supporting File S4.	15 minutes	Choose specific questions to capture the data important to you.

Table 2. Code definitions and excerpts from participant responses.

Code Name	Definition	Sample Excerpt
Authorship	Excerpts reference researcher credibility or the idea of proving one did the work that is reported.	"It is proof that you did what you did."
Collaboration	Excerpts explicitly describe or reference the purpose of sharing and collaborating in the research process.	"This makes it possible for meaningful research findings to be shared with other researchers without confusion."
Fabrication and Falsification	Excerpts describe recording of data to allow for accurate analysis and/or accountability. This may include raw data, observations, or a log trail of thoughts.	"Maintaining a thorough lab notebook that includes all relevant portions of one's experiment ensures honesty and integrity in experimentation, a key factor of research. Keeping a notebook also promotes accountability and comprehensiveness in experimentation if one knows what steps must be taken to perform strong research."
Literature	Excerpts talk about connection to literature and have little to no information about one's actual research process or reporting.	"The practice of keeping a lab notebook is related to the research one might do, in that, we ourselves will be gaining better knowledge on why things are worded and formatted the way they are in scientific papers. This in turn will help us when conducting our own research allowing us to have a better understanding of what we are reading."
Maintains Standards	Excerpts describe the need to follow "standards" or remain "on track" but give no other specifics or details about the source of the standard/ track.	"When we're doing research, there's a certain set of standards (ethical and professional) that must be followed. By accurately keeping track of our procedures and having a firm grasp on every step taken in our experiments, we can be sure that we're staying in line with the rules of conduct required of us as scientists."
Organization	Excerpts explicitly state an outcome of "organized" data, but there is no connection to any other reason for organization.	"The practice of keeping a lab notebook is important to one's research because it helps keep data organized."
Plagiarism	Excerpts reference not using the work of others.	"This is related to one's responsible conduct of research because you must make sure you don't copy someone else's work."
Reflection	Excerpts describe the collection of data that can be returned to for additional thought or reflection during the research process.	"You can see other trends that you did not think of by having a notebook and writing down what you are finding."
Research Continuation	Excerpts describe the audience of the notebook as future research or reference a connection to future work.	"You need to make sure that everything is written down in case anyone wants to go back and repeat your steps or the experiment as a whole."
Task	Excerpts state no reason for keeping the lab notebook except that it must be done or it is expected.	"Keeping a lab notebook relates to responsibility because of the time and quality effort that needs to be dedicated."

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