CHAPTER

2

Unveiling the hidden curriculum: Developing rigor and reproducibility values through teaching and mentorship

Marina E. Tourlakis
Biology Department, University of the Fraser Valley, Abbotsford, BC, Canada

Introduction

Dr. John Ioannides' 2005 article arguing that much of the published science record was fit for the trash heap [1] set off a major cascade of introspection, finger pointing, counter arguments, and calls for reform [2] (see also Chapter 1). The question of how to maintain the integrity of the scientific enterprise is not a new one [3], nor have we lacked guidelines on how to conduct ourselves as scientists [4–6]. Nevertheless, Ioannides' study and several that followed (in addition to a variety of other alarm bells rung in academia [2,7–11]) demonstrate that revisiting how we train scientists is warranted.

Many institutions include graduate courses and seminars on academic integrity and the responsible conduct of research (RCR) in line with regulations from government and funding bodies [6,12–14]. However, programs are inconsistent and (ironically) lack rigor in their structure, communication, and application [13], and there is little evidence of their efficacy [12,15]. They typically consist of singular offerings despite calls to integrate RCR training across the curriculum [5,16]. Standalone offerings do not support long-term learning gains and can signal low importance [17,18]. Most importantly, this training is typically aimed at postgraduates, despite the increasing involvement of undergraduates in research [17]. RCR training should feature early and regularly in a scientists' training.

It is possible that training scientists to be rigorous and responsible practitioners is taken for granted, part of the "hidden curriculum"—if you made it to the PI position, you must be doing it right. However, the reproducibility crisis tells us otherwise. To address concerns regarding a lack of rigor in how research in genetics and genomics is conducted and communicated, we must make visible the "hidden curriculum" by providing overt and explicit training in RCR [19] in the classroom and the research lab. We are all responsible for supporting this culture change [13,20] (Fig. 2.1).

This chapter builds upon the problems and potential solutions discussed in Chapter 1, focusing primarily on the responsibilities of supervisors and trainees in genetics and genomics classrooms and research labs. These venues are where socialization of trainees into the scientific enterprise occurs. Expectations are set, behaviors developed, and reward (and punishment) systems established. Topics, activities, and strategies are presented for cultivating a culture of rigor. The perspective presented in this chapter is informed by a review of the literature from the past 20 years, focusing primarily on the last decade, on the

Rigor and Reproducibility in Genetics and Genomics. https://doi.org/10.1016/B978-0-12-817218-6.00015-2

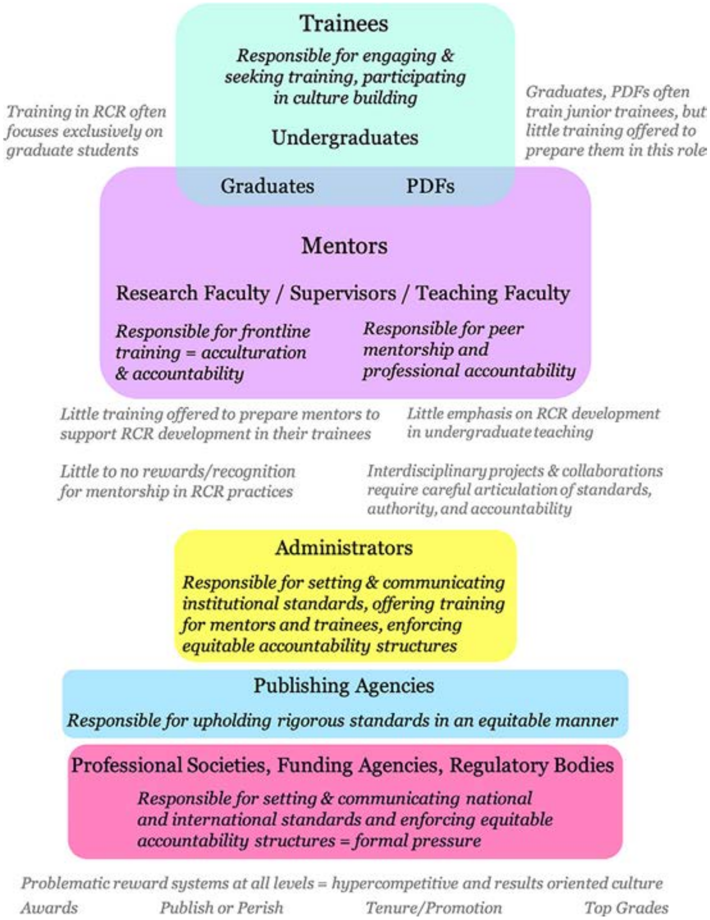

FIG. 2.1

Responsibility for RCR culture. All members of the academic and research community are responsible for supporting RCR training through appropriate engagement and upholding accountability. *PDFs*, post-doctoral fellows.

subjects of mentoring undergraduates and postgraduates (multiple disciplines), undergraduate teaching, learning and research experiences (primarily in bio/med disciplines), and responsible research practices in the sciences, as well as the author's own experiences as a trainee, educator, and mentor.

In the classroom

Science education has been subjected to considerable scrutiny in the past three decades. Prominent scientific societies have advocated for the relevance of science education for every member of society and called for a radical rethink of how we teach sciences [21–23]. Biology, and, by extension, genetics education has enjoyed a virtual explosion of research in teaching and learning in recent years [23] (Box 2.1).

Box 2.1 Professional development resources for teaching and learning biology

Teacher Training

- HHMI Summer Institutes on Scientific Teaching
- IRACDA (Institutional Research and Academic Career Development Awards program)
- CIRTL (Center for the Integration of Research, Teaching and Learning)
- MERIT (McMaster Education Research, Innovation and Theory program)
- PALM (promoting active learning and mentoring)

Communities of practice:

Communities of practice or faculty learning communities are an established mechanism for communal professional development [24]. Create a community of practice at your home institution or in your region to discuss, collaborate, and commiserate on your efforts to develop rigor and reproducibility values and competencies in the classroom.

For evaluating your teaching practice:

- The Classroom Observation Protocol for Undergraduate STEM
- Generalized Observation and Reflection Platform

Online teaching resources:

- Learn.Genetics and Teach.Genetics
- CourseSource.org
- Cell Collective
- HHMI Biointeractive
- Genomics Education Partnership
- Science Education
- National Center for Case Study Teaching in Science
- AAAS Vision & Change in Undergraduate Biology Education

Academic integrity focused organizations:

- Quality Assurance Agency (for Higher Education) Academic Integrity Advisory Group (UK)
- International Center for Academic Integrity

Examples of biology (or science) education journals: *CBE-Life Sciences Education*, *Frontiers in Education*, *Journal of Microbiology and Biology Education*, *American Biology Teacher*, *Science Education*, *Advances in Physiology Education*, *Cell Biology Education*, *International Journal of STEM Education*

Specific articles on teaching genetics:

- Redfield, "Why do we have to learn this stuff?" – A new genetics for 21st century students. Teach the Genetics of Our Time. *Plos Biology* 2012
- Radick, Teach students the biology of their time. *Nature News* 2016
- Plunkett-Rondeau et al., Training future physicians in the era of genomic medicine: trends in undergraduate medical genetics education. *Genetics in Medicine* 2015
- Series of Q&As with genetics educators in Volume 34 (Issues 1–5) of *Trends in Genetics* 2018
- Todd and Romine, The Learning Loss Effect in Genetics: What Ideas Do Students Retain or Lose after Instruction? *CBE-Life Sciences Education* 2018
- Hales, Signaling Inclusivity in Undergraduate Biology Courses through Deliberate Framing of Genetics Topics Relevant to Gender Identity, Disability and Race. *CBE-Life Sciences Education* 2020

Biology education societies and conferences: Society for the Advancement of Biology Education Research, The Western Conference on Science Education, Royal Canadian Institute for Science

Despite calls for change, undergraduate biology classrooms in many institutions persist in following the traditional structure of lecture and cookbook labs (students reproduce classic experiments with known outcomes). This focus on content mastery and memorization does not paint an accurate picture of science [25] nor adequately prepare learners for the rigors of research. By focusing on facts, we overlook (and even discourage) developing the rigorous thinking habits we expect from scientists: how did we arrive at this fact? how was confidence in this fact established? what did we think before this, and are there other theories? and why do we even care to know this? This training in scientific thinking continues to primarily occur at the postgraduate level.

In particular, biology education research supports the implementation of scientific teaching pedagogies [23,26] and authentic research experiences (AREs) at the undergraduate level [27–29]. Scientific teaching asks the educator to iteratively evaluate and revise lessons toward establishing an evidence-based teaching practice [23,26]. It takes a bottom-up approach that considers students' prior knowledge and tailors the approach to support students' progress toward achieving learning outcomes [28,30] (Fig. 2.2).

If we imbue our genetics and genomics undergraduate classrooms with scientific thinking and offer students opportunities to engage in research, we develop the habits of mind and professionalism that we expect from trainees and future scientists [23,28,31,32]. Integrating activities throughout the curriculum with explicit framing as "research integrity" or "professional conduct in science" can foster a community of learning that better reflects the scientific enterprise earlier in the training process. Moreover, providing a curricular framework can allow us to codify, regulate, and evaluate instruction in RCR (Fig. 2.2). Meanwhile, the collaborative learning environments, clear communication of expectations, and overt instruction on scholarly norms that student-centered teaching practices afford dovetail

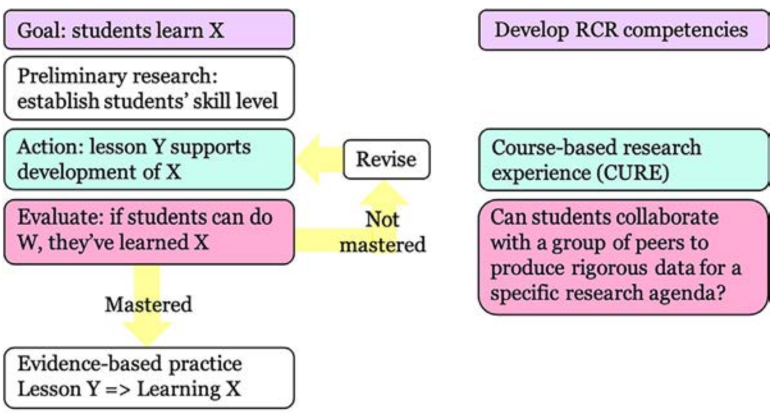

FIG. 2.2

Evidence-based pedagogies to support RCR training. Scientific teaching works toward establishing an evidence-based practice, in other words, a rigorous and reproducible practice. Similarly, authentic research experiences, particularly CUREs provide students with opportunities to wrestle with the realities of open-ended inquiry in collaboration with peers in a relatively low-stakes context. CUREs thus provide experiential learning opportunities not only to develop RCR competencies, but they contextualize these skill sets rather than making them a tired list of rules one is meant to know and follow. Besides being effective in terms of learning gains, these evidence-based pedagogical approaches allow instructors to model in their teaching practice the rigor they expect of their trainees.

with recommendations from research on academic dishonesty and contract cheating [13,19,33] as well as research on improving recruitment and retention of diverse learners to our field [34–36].

In practice

How then, does one apply best practices to integrate RCR instruction in genetics and genomics teaching contexts?

No single course can develop the complete set of skills and knowledge base required to cultivate a value for rigor and RCR competencies. Instead, all courses should include explicit RCR learning outcomes (Box 2.2).

Box 2.2 Applying a scientific teaching approach to your course (re)design

If we wish to apply the scientific teaching approach of backwards design to our curriculum (re)design, we need to contemplate a series of questions (adapted from [22,26]):

1. What are the learning goals of the lesson/course/curriculum?
2. What knowledge and skills are relevant to the subject area?
3. What should students know and be able to do at the end of the unit/course?

For example, we want to develop trainees who:

- *understand the importance of careful and honest data collection and reporting*
- *can explain sources of false positives and false negatives in an RNA-seq experiment*
- *can explain the concept of falsifiability and apply it to a specific experiment,* etc.

1. What evidence would suffice to indicate learning, i.e., what are the learning outcomes of the lesson/course/curriculum? (should be discrete, concrete, and measurable)
2. What do proficiency and mastery in the subject area at this level (intro course vs senior seminar) in the curriculum look like?
3. What evidence would I accept that a student has achieved proficiency or mastery across the relevant content and skills identified in (1)?
4. What evidence would convince my colleagues?

For example, at the end of this course, students will be able to:

- Introductory level:
- *Explain and provide examples of the scientific method*
- *Draft basic scientific reports that pass a replicability rubric: provide a thorough accounting of their research methods* (e.g., *what search terms and filters were used with what databases to conduct literature review) and their experimental methods (if applicable) and what papers and data were included and which were not.*
- *Distinguish between error and misconduct in research and provide specific examples to support their argument.*
- *Define and distinguish between conflicts of interest, commitment and trust using specific examples to support their argument.*
- *Define responsible research practices and explain their importance to the scientific literature.*
- Advanced level:
- *Critique published literature using a replicability and reproducibility rubric: how did the authors address bias, did the authors consider power and effect size, did the authors provide a thorough accounting of their methods to facilitate replicability, do the authors discuss what data was included and what was not, does the study include any enhanced research standards,* e.g. *was it pre-registered, do the authors provide open access to their data collections?*

Continued

Box 2.2 Applying a scientific teaching approach to your course (re)design—cont'd

- *Discuss epistemologies in science including the use of proof, the use of statistics, and the scientific method using historical and contemporary contexts.*
- *Design experiments and defend their design using a rigor framework: demonstrate how they are addressing bias, how they've considered power and effect size, how they are ensuring consistency in technique, how they will report their findings.*

1. What learning activities will support students to meet goals?
2. What experiential learning supports developing understanding and competency in content and skills identified in (1)?
3. What topics should be covered to support knowledge and skill development?
4. What skills should be overtly taught and/or scaffolded?
5. What types of disciplinary practice should be overtly taught and/or scaffolded?
6. What feedback will support progress toward learning goals and when should it be given?

For example, students will engage in an inquiry based research project to measure allele frequency for a heritable and easily scorable trait in Drosophila *over multiple generations.*

For an excellent example of designing RCR learning goals, outcomes, activities and assessments, see Diaz-Martinez et al. [17].

For specific recommendations on how to implement an RCR conceptual framework to your course design, see Clements et al. [12].

1. Make explicit the expectations of your classroom, the expectations scientists have of scientists, society has of scientists, and why this is so.
2. Support students with frequent feedback and mentorship to meet goals you set for them.
3. Evaluate whether your teaching activities are having the desired outcome.

The stakes: Responsible research practices, ethics, and societal context

The first generation learner in their first science classroom may be hearing the words "rigor" and "reproducibility" for the first time. Explicit discussion of the stakes contributes to students' abilities to understand the societal context of the scientific enterprise [22] (Box 2.3).

To introduce RCR in the classroom, you can include papers in your reading list that specifically address RCR [1,5,37,38]. Structure a discussion on why reproducibility can be challenging. Make clear that researchers need to work hard to be rigorous; a well-intentioned researcher can still produce sloppy science if they lack technical knowledge, do not thoroughly consider sources of bias, lack strong communication skills or a strong knowledge of statistics. Note how culture contributes, and how we learn from mistakes made.

Box 2.3 Specific Lesson Idea: Incidental findings and the duty to report

Learn Goals: *illustrate a relatable example of how excellent record keeping impacts real people.*
Student Learning Outcomes: *students will be able to* (1) *explain why risk assessment of variants changes over time using specific examples,* (2) *defend a position on long-term data storage policy in context of reporting incidental findings.*
Suggested plan: *assign policy statements on incidental findings and use case studies to illustrate considerations and challenges associated with reporting incidental findings over short and long-time frames.*

The stakes can be articulated at 3 levels:

1. **Personal** sloppy work will not serve the individual scientist well in the long run and models bad behaviors to the next generation of scientists.
2. **Local** science is a cumulative endeavor; it is critical that the foundation on which others build their work is sound.
3. **Societal** society depends on sound science: it provides evidence for decision making at the individual to government levels and fosters wonder in the world around us; trust in the scientific enterprise is needed to support these roles (from *On Being a Scientist*, pp. 2–3 [5]).

Importantly, make explicit the alignment of these stakes with behaviors and skills you value in your course assessments including good citation practices, academic integrity, strong communications skills, ethics, etc.

The nature of science

Many undergraduate students view science as an enterprise based on absolute answers, conducted by objective scientists. When we teach science as a series of memorizable facts and following protocols toward known outcomes (i.e., cookbook labs) we feed into this falsehood. Instead, show students that revision and correction are the norm and that resiliency in the face of repeated failure are fundamental traits of the successful scientist [31,39].

In the genetics classroom, provide a more accurate representation of science by featuring dogmatic revolutions (retroviruses, internal ribosome entry sites, etc.), calling attention to how theories evolved based on new evidence, rigorous testing, and skepticism. In the teaching lab, opt for open-ended, inquiry-based lab activities (see *Experiential Learning and CUREs* below).

Teaching the true nature of science will better prepare students for the rigors of research and foster responsible consumption of scientific information in the media [40,41] (Box 2.4).

Science communication, publishing and peer review

Developing a value for RCR practices is incomplete without a thorough examination of communication practices in science. Explicit instruction in best practices for sharing scientific findings and how sharing of scientific findings is the primary mechanism for correction, progress, and reward in science [2,43] are necessary components of a genetics curriculum.

POP OUT (Quote): "Instances in which scientists detect and address flaws in work constitute evidence of success, not failure, because they demonstrate the underlying protective mechanisms of science at work." Alberts et al. [43].

Box 2.4 Specific Lesson Idea: Multiple hypotheses

Learning goals: *introduce science philosophy and develop a value for rigorous hypothesis testing.*
Student learning outcome: *students will be able to connect evidence with claims in context of hypothesis testing.*
Suggested plan: *assign Platt's Strong Inference essay [42] as a first day reading for a lab course. Assign questions in prelabs referring to this text and prompting students to generate multiple hypotheses and what evidence they'd accept as refuting each.*

Providing explicit instruction in how to engage with scientific literature is a must in any introductory science course. Foster critical reading skills by devoting lecture time to a tour of a scientific paper, explaining the author list (and decision-making thereof), the different components of the paper and their ordering, citation of figures and tables in the text, the acknowledgement and disclosure statements, and the reference list. We do a disservice to trainees if we assume they enter the postsecondary classroom with this knowledge.

Similarly, provide multiple opportunities for students to develop and practice science communication (written, visual, quantitative, oral). Explain to students that producing coherent data presentations and drafting thorough methods sections in their lab reports develop skills scientists need to support their claims. Provide students with a target audience and specific genre-exemplars (research article, perspective, review) to guide their rhetoric [44]. And use draft revision cycles to emulate peer review and foster a value for iterative improvement post feedback (Box 2.5).

Peer review also opens the door to learning about the sociocultural contexts of errors in the literature and academic misconduct. Engage students with case studies [45] that discuss famous errors or retractions, or have students research the history, motivation, and effectiveness of preprint servers [43] (Box 2.6).

A note on narrative: motivated by the rise of anti-science rhetoric (e.g., climate-change denial, anti-vaxxers), and an impression that scientists are poor communicators, many scientists are encouraged to employ narrative tools to communicate their work to the broader public. This could form the basis of a vigorous discussion with students: debating the merit of using narrative as a science communication tool. Possible sources to inform such an activity:

- Dahlstrom and Scheufele's (Escaping) the paradox of scientific storytelling [46]
- Dahlstrom's Using narratives and storytelling to communicate science with non-expert audiences [47]
- NPR Scicommers
- ASAP Science
- Science Sam

Box 2.5 Specific Lesson Idea: Critical reading of literature

Learning goals: *orient students in the reading and critique of literature in molecular genetics AND practice writing in this genre.*
Student learning outcome: *students will be able to name the purpose of the structural components of a research article in the discipline of molecular genetics, and emulate this in their own writing.*
Scaffolded activities:
(1) *students work in small groups to interrogate the rhetorical structure of a research article and articulate the purpose of each section*
(2) *students emulate the style in their own writing of a scientific report based on a provided context and data set,*
(3) *students engage in a focused peer review and reflect on how their writing style was impacted by their rhetorical analysis and peer review feedback.*
(4) *instructor-facilitated debrief with the class to highlight key takeaways regarding the genre's rhetorical structure, the utility of that structure for a) communicating rigorously and b) facilitating replication, and any process takeaways for students (this activity helped me recognize, challenged me to, introduced me to, etc.).*

Box 2.6 Preprint servers as educational tools

The topic of peer review can be used in the classroom to develop an understanding of the process of science while critically engaging with literature. In preparation for a class on peer review, scientific method or other aspects of the process of science, set students a homework task to visit the website of a preprint server (e.g., bioRxiv, medRxiv, arXiv) and their corresponding Wikipedia pages. Ask them to prepare brief answers to the questions,

- What problem(s) do pre-print servers aim to address and how?
- Based on your preliminary investigations, is there evidence that they are achieving their aim(s)?

Have students bring their answers to class to contribute to small group discussions. For a larger class, have students submit one question the activity raised on the subject of rigor in science to a question bank prior to class which you can then draw from to inform your large group discussion. To follow the class discussion, have students submit a brief reflection answering the prompt: Reflecting on your ideas of how science proceeds, did pre-print servers confirm or challenge your prior notions?

For a more advanced course, consider the following essay prompt: The essay On Being a Scientist [5] *discusses the importance of not releasing results prior to them being peer-reviewed. The recent surge of pre-print servers appears to subvert this cultural expectation. Further, during the COVID-19 pandemic, it became commonplace to read the phrase "These findings have not been peer-reviewed" in media reporting science for public and expert audiences. How do traditional and contemporary peer review structures support or hinder the progress of science during an urgent public health crisis?*

Quantitative reasoning and analysis

Quantitative reasoning (QR) is a foundational skill for success in genetics and genomics [22]. Increasingly, there are calls to integrate QR and mathematics into the biology classroom rather than relying on prerequisites [22].

As genetics and genomics instructors, focus on the most common types of quantitative analyses in our field (e.g., William Noble provides a great primer on multiple-test correction) and how these connect with your course's goals. Should students memorize an equation? Should students be able to explain in words (an important component of QR) what a test compares and what information it yields about the data, or the claims the data is being used to test? Perhaps, they should be able to select an appropriate statistical test and explain their reasoning.

Connect lessons to RCR by using real data examples to show how confidence is built and how it might be abused (see here for a great reading). Helping students understand the meaning behind equations and statistics can help build a healthy skepticism of data and data presentations, which is key to understanding issues of reproducibility.

It is crucial to establish the prior knowledge and capabilities of your students and, where possible, tailor your lessons or tutorial support to meet them appropriately. Provide many opportunities for practice and multiple examples. To help make expectations clear, use a QR Rubric (see here for an example).

Beyond teaching quantitative analysis, strive to engage students in QR in every class: ask them to explain a graph to the student sitting next to them, or what an odds ratio means, or *what exactly a frequency of 0.27 means* (Box 2.7).

Sloppy science and academic misconduct

Consistent with the call to be overt and explicit in RCR training, we must engage with missteps in the scientific record. Several examples of published and retracted papers in the literature afford the

Box 2.7 Specific Lesson Idea: Why do GWAS studies require a replication study?

Learning goal: *illustrate the problem of false associations in genome-wide research and introduce methods for multiple test correction.*
Student learning outcome: *students will be able to explain the quantitative reasoning for replication populations in GWAS studies using probability and false discovery concepts.*
Suggested plan: *assign a GWAS study and work with students to answer the following: what is the purpose of a replication population? what, if any, criteria differ between the original and replication population, and why? what is false discovery and why does it happen in GWAS studies? What are the stakes? How is an FDR established and what are permissible levels and why?*

instructor contexts for teaching biological concepts while also making explicit **expectations for RCR**, **mechanisms for correction**, and **consequences for academic misconduct**.

Specific cases can be used to illustrate lapses in rigor and to discuss peer review processes, mentorship, retraction procedures, and the impact of academic misconduct on trainees (refer to [43,48,49] (Table 2.1; Box 2.8).

Experiential learning and CUREs

Experiential learning (EL) is a crucial component of RCR training. Virtually, all undergraduate biology courses include some EL component, most typically in a laboratory setting. Labs offer an invaluable mechanism for demonstrating the fallibility of experimental sciences, the importance of reference measures, consistent technique, variables, sources of error, the concept of falsifiability, and multiple hypotheses, and the importance of rigorous reporting (Box 2.9).

As noted earlier, cookbook labs continue to feature prominently in biology courses [27,34]. Cookbook labs have been derided for their rigid structure and confirmatory approaches which contribute to a notion that science is about collecting evidence to fit your hypothesis [21,22]. This mainstay of the science curriculum can instill in students a sense of failure when the evidence they collect does not line up with what the lab manual tells them [26]. What is more, it does not afford opportunities to foster creativity and flexibility, necessary attributes of scientists [30]. Therefore, biology educators are mobilizing to increase the prevalence of inquiry-based labs in biology curricula [27] (Box 2.10).

CUREs are rich with RCR training opportunities [52–54]:

- Students struggle productively and receive an authentic experience of how science progresses through discovery, iteration, collaboration [31,32,55]

Table 2.1 Student accessible readings on reproducibility.

D. Butler, Biomedical researchers lax in checking for imposter cell lines. *Nature News* 12 October 2015
Journals unite for reproducibility. *Nature Editorial* 5 November 2014
L.P. Freedman, et al. Reproducibility: changing the policies and culture of cell line authentication. *Nature Methods* 12(6) June 2015 493–497
Challenges in irreproducible research *Nature Special* collection of commentary and articles
D.B. Allison et al., Reproducibility: A tragedy of errors. *Nature Comment*. 3 February 2016
Kimmelman et al., Distinguishing between Exploratory and Confirmatory Preclinical Research Will Improve Translation. *PLOS Biology Perspective* 20 May 2014

Box 2.8 Case-based learning

Case studies are a powerful tool in education as they situate abstract concepts in specific contexts through storytelling, discussion, and role play. Case studies can be used to make RCR issues come alive for trainees. They can be as simple as reviewing a specific study in one lecture period with guided questions to foster concept mastery and discussion, or, they can be multi-day forays into an issue. Generally, they work best if tackled within small groups. The National Centre for Case Study Teaching in Science is an excellent resource for a variety of cases, many of which can be pitched to different levels and adapted to one or multiple lecture periods. NB: to maximize relatability, make sure to include diverse identities in the Case Study.

Examples of famous retractions that can be investigated in a case study format:
1998: Wakefield and a link between MMR and autism.
2010: The #arseniclife affair (see ref. [45] for a case study on this topic).
2014: Obakata stem cell scandal and tragedy.
2020: AlShebli et al., mentoring study.

- Students wrestle with reproducibility by embedding iteration in their design [56]
- Students develop a sense of ownership and identity as a scientist due to a perception of contributing to bonafide research projects [56]
- Students develop an appreciation for collaboration due to the multi-site aspect of many CUREs [27]
- Students develop RCR practices due to the skills required for collaboration, e.g., careful and detailed record keeping, frequent discussion of process and progress, and peer review

Box 2.9 Cultivating a culture of rigor in the teaching lab

- Promote patience and attention to detail as key qualities of the scientist: tell students that science requires a cool head. If they find themselves too excited in an inspired or anxious way, they should take a 5-min break to cool down.
- Cultivate strong observational skills: train students to use their eyes, ears, touch and nose (not taste!), and not just rely on measurements.

Case in point: students in an introductory biology courses were exposing beet root samples to various solvents to investigate the chemical makeup of membranes. They measured betacyanin leakage into the solvent as a proxy for membrane integrity using a spectrophotometer. A group of students had the misfortune of using a faulty instrument. In their report, the group noted their measurements did not make sense and they pronounced the experiment a failure. However, photographs they had taken during the exercise revealed betacyanin leakage did indeed correlate with solvent concentration. This prompted me to make explicit to students that they reconcile their qualitative and quantitative observations in their reports. One of the many times I have realized that what might seem obvious to me is not necessarily so to the novice scientist.

- Prioritize rigorous practices in your assessments: **drop the long form lab report** and have students utilize evidence-based writing-to-learn practices to develop understanding and scientific writing skills [44]. For example, have students focus solely on drafting data presentations, using genre exemplars from the literature, iterative attempts, and feedback, to master data analysis and data presentations. See this book's DataVerse for a sample short form lab report (https://dataverse.scholarsportal.info/dataverse/RandRinGenomics)
- Provide overt and explicit instruction on record keeping (i.e., lab notebooks), including formative and summative assessment thereof.

Importantly, we need to recognize that the bulk of teaching in the undergraduate lab is conducted by trainees (i.e., teaching assistants). Teaching faculty must commit to training TAs on how to support RCR practices [50,51].

Box 2.10 A quick guide to converting a cookbook lab into a basic inquiry-based lab

1. Review your established protocol and determine which components are flexible (and safe) for students to modify
2. Articulate a specific learning outcome for the lab and a specific objective “In this lab, we will investigate how X impacts Y”
3. Make a list of available reagents and instruments, including safety precautions and constraints (e.g., give students a range of substrate amount to use in a reaction, or a range of time to expose samples to a stimulus).
4. Task students (in small groups) to complete a prelab that they will discuss with their TA/instructor prior to commencing their work. This discussion is a key step to correct for concept errors while engaging students on the subject of experimental design, e.g., no, you cannot reasonably achieve this during our lab period, or yes, that could be a source of false positives. Prelab questions:
5. What is your research question and hypothesis, including rationale thereof?
6. What is your strategy for collecting sufficient data to build confidence in your result?
7. What controls will you include in your experiment? What could give you a false positive or false negative?
8. What is your proposed protocol? Specify reagent amounts and incubation times, as well as how many biological replicates and technical replicates you’ll employ.

This strategy works best if you have static groups and 3 or more labs of increasing complexity for students to practice designing experiments and iteratively improve.

Example: convert a PCR-based lab by allowing students to determine primer, template and Mg2+ amounts and/or template sources. Importantly, can included design aspects in the prelab that you then keep firm in the actual lab (e.g., *annealing and extension time could be part of the design but for logistical reasons be constrained to one protocol during the lab)*

Further, evidence is building that CUREs play an important role in recruitment and retention of diverse learners to STEM fields [54] and provide a more equitable structure for developing tacit knowledge in how to do research [27,29], particularly as students from historically underrepresented groups are less likely to land a position in a research lab, or even seek one [27,28,35]. CUREs offer an economical avenue to provide virtually all undergraduate students with an opportunity to develop research acumen [31]. For more on the benefits of CUREs and how they can support genetics and genomics teaching, see Chapter 7.

It is important to note that labs and CUREs typically operate as group projects. Group work is an important venue for developing RCR behaviors. The skills developed during group work can be leveraged during future difficult conversations with lab members or supervisors. For excellent resources on navigating group work dynamics, see here.

In advising

Undervalued or at best newly valued, academic advising is an increasingly prominent aspect of the undergraduate experience [57], especially in honors programs [58]. Teaching faculty engage in some form of advising during office hours, informally after class, and sometimes by e-mail. Many programs assign all undergrads to a faculty advisor, but advising remains a component of the faculty members portfolio that has little structure, training, oversight or recognition, despite being increasingly associated with student success [57]. These often close relationships with faculty members provide a venue where soft skill development, culture, values, and habits of mind are formed [57]. Setting goals, reflecting on if/how those goals were met, and ultimately connecting evidence (study habits, performance) with outcomes, we develop habits in learners that bear fruit in the classroom, lab, and beyond. By making the implicit explicit in discussing our own training and work experience, we establish values and expectations early. Further, these interactions help trainees develop interpersonal skills with faculty that will prepare them for positive and negative interactions in their later training and careers. In essence, advising is a form of mentoring and should be approached with an intention to foster specific outcomes, in our case, a value for rigor (Fig. 2.3).

In the research lab

The research lab and its immediate environment (department, university, research institute) is where the stated causes of the reproducibility crisis manifest: poor experimental design [1], communication breakdown [59,60], problematic reward systems [61,62], dismal career prospects, and academic misconduct [13]. Moreover, these causes often converge on issues of mentorship; mentoring networks

Set structured expectations

Advisors are expected to:
- Establish benchmarks for goal meeting,
- Socialize advisees by talking about their career trajectory and/or daily activities,
- Help advisee make meaning of their grades and academic performance, encouraging strong but sustainable study habits,
- Assess goal progress regularly and encourage revision as needed, and reflection on why things went well, or why they didn't
- Model honest, collaborative and respectful dialogue

Advisees are expected to:
- Set an agenda for all meetings,
- Establish professional goals
  short term small goals, e.g., term paper
  medium term larger goals, e.g. graduating
  long term large goals, e.g. career
- Reflect on courses, internships, etc. with regular frequency to identify strengths, growth areas and connect to goals.

Start an advising record

✓ Draft a two-column table:
column A = *mentoring activity*
column B = *mentoring goal*
✓ Populate each column with a list of activities and goals (include realized and aspirational items)
✓ Make connections between activities and goals (use a different colour to draw connecting lines)
✓ Keep the table handy and revisit it daily, weekly or monthly for a set period

FIG. 2.3

Simple activities to cultivate habits of mind consistent with rigorous practice in the advising relationship. Interested in improving or professionalizing advising at your institution? A longstanding undervaluing of advising and mentorship might be attributed to the difficulty in "measuring" the work and the impact of the work. Creating structures and accountability can formalize the work and make it measurable. This exercise has the added bonus of providing participants with material to include in their next grant, promotion documents, or job application. This exercise can also be adapted to use with trainees, either asking them to reflect on mentorship they provide to junior members or asking them to reflect on what support they expect and need from their advisor/mentor and what activities they notice.

play a major role in socializing the next generation of scientists [20]. As such, mentoring features prominently in recommendations for improving the quality of research [63] and has become a major focus of higher education literature and university administrations.

Who is a mentor? Mentors are typically more senior to their mentee and serve as a source of knowledge, inspiration, emotional support, and networking. Mentorship goes beyond co-authorship or collaboration or who happens to be your assigned supervisor. A mentor is someone who has tacit knowledge of a system and *uses this knowledge to help a novice navigate that system*. In academia, many individuals serve as mentors and individuals at all levels of career should seek multiple mentors to support different components of their professional identity (Box 2.11).

In addition to mentorship from senior staff/supervisors, peer mentoring plays a critical role [7,65], particularly in retention of persons from historically underrepresented groups who are less likely to have a supervisor in tune with their needs [64]. In the trainee context, mentorship of junior trainees (undergrads) often falls to senior *trainees* (postgrads) [66]. Interestingly, the triad structure of faculty-postgrad-undergrad, provided there is direct and frequent interaction between faculty and undergrad, outperforms the dyad structure of faculty-undergrad when reporting gains in scientific thinking [7]. The same study suggested undergrads mentored solely by postgrads may develop technical skills but not enjoy the same exposure to the broader context of research and lifestyle of a scientist and thus not relate or be exposed to the realities of a career in science [7]. On the other hand, if trained exclusively be a faculty mentor, undergrads may ask fewer questions and generally be more cautious in their interactions, less willing to demonstrate vulnerability or ignorance for fear of jeopardizing their standing with their supervisor [7].

It follows that we need to support faculty supervisors to be the mentors they want to be, and part of this equation is for faculty to foster peer mentoring networks in a manner that includes their oversight and direct involvement [65]. In short, training the mentors, be they faculty, senior staff, or senior trainees, is important [64].

Box 2.11 Developing a mentorship network

Social networks increase the resources available to individuals which in turn help them gain institutional knowledge and confidence in navigating new cultures [64]. For example, a trainee may form a mentoring relationship with their supervisor to support their professional identity as a scientific researcher, but seek out a different mentor to aid them in navigating academia as a Person of Color. Trainees and junior faculty should seek out a network of mentors to support the different facets of their professional identity.

For trainees and junior faculty: seek out mentors who embody your values and inspire you. Remember your official supervisor should not be the only person you seek mentorship from - you can and *should* seek mentorship from individuals at varying levels of seniority, positions, and locales.

It is important to have at least one mentor who you see yourself in. Think about what your professional goals are and seek a mentor who mirrors them back and has ostensibly had a similar personal journey getting there [20].

The journals *Nature* and *Science* have mentoring resources on their career pages that can help you identify the type of mentoring you require and how to get it, including advice on how to man.

For mentors: seek to support your mentees according to your position and lived experience. Be honest about where and how you can help. Set clear boundaries so that mentees have reasonable expectations for the type of support they will receive, and can decide accordingly how to expand their mentorship network.

In practice

Keeping things simple, one can focus on two approaches for mentoring RCR practices:

Habits of mind

The responsible researcher reflects on and interrogates data, but also their own actions and motives. Cultivate a reflective research practice: by continuously asking questions about your groups' process, reviewing the reproducibility literature with your research group, and participating in quality assurance programs, you will be forced to reflect on your own policies and procedures and as a result, perhaps identify spotty practices or weak areas that might leave you vulnerable to an integrity breach [67].

Protocols

Foster rigorous organizational practices. The responsible researcher develops practices to make their research easily replicable. Easy is important here: the more one separates their findings and communication thereof from the process, the more difficult it will be for an independent researcher to replicate and build upon the work and hence establish the reproducibility of the key claims [68].

As in the classroom, take a scientific approach to your mentoring:

1. determine goals,
2. determine what evidence will suffice to demonstrate goals are met,
3. provide training that will support development,
4. assess through observation and feedback from your team and colleagues, and
5. revise as needed.

Importantly, do not let the tenor of RCR training be punitive or judgmental, cultivating a culture of rigor benefits everyone—the habits of mind and protocols will likely result in more efficient work, more rigorous work, and more efficient communication with your team members and collaborators [67,68]. Remember to be explicit, foster honesty, provide training/support, and be kind [69]. The remainder of this section outlines key components of a successful ongoing mentoring program.

Communication of expectations

It is the responsibility of all members of a research group to build a culture of rigor. However, given their authority and power, mentors set the tone and provide leadership, training opportunities, and clear communication of expectations for RCR practices.

A new junior member of a lab is tasked with a lot of 'meaning making'. They need to assimilate information about the specifics of the biology, the technicalities of experiments, the context of their project goals, and how that all fits within the team, the field, and the cultural norms of the team [69]. Mentors can guide meaning making through their actions and words. As a mentor, be sure to include explicit instruction on the expectations of team members and lab standards (Box 2.12).

Be a predictable mentor. Make expectations clear early on [69] (Box 2.13).

Lab meetings and journal clubs

Do not rely on the trainee to ask all the right questions, or for you to have remembered to cover everything in an initial training session. This is particularly relevant for trainees with prior research experience or with interdisciplinary projects where the specific expertise may lie outside the immediate

Box 2.12 Training to emphasize RCR

Explicit training on how to collect data, make measurements, record your procedures and report your data is critical. Take the time to enumerate and communicate to new members of the lab (regardless of their training level) the practices that you do not even think about, having committed to muscle-memory many years ago, and conduct regular peer-peer (or senior peer/mentor-peer) audits of lab notebooks [67].

An excellent way to train that provides the learner with hands-on training in techniques *and* first-hand experience with replication is to task trainees with replicating a key result published by your group [69].

Ground rules:

- safety: workplace hazards, including harassment
- ethics: conflict of interest, commitment or trust, scientists' responsibility to society, human and animal research ethics
- maintaining equipment in good working order

Data collection:

- how *and when* are lab notes recorded? (offering a template or exemplar is important, see here for an excellent resource on lab notebook practices)
- how many technical and biological replicates are needed to build confidence in a result?
- how are new reagents such as antibodies tested for quality assurance?
- how are biological samples such as RNA tested for quality assurance?
- what statistical tests are typical and what error rates/confidence scores acceptable?
- what imaging software do you use?
- what settings (if any) are permissible to manipulate (and to what degree) when acquiring images, and how is this recorded and reported?
- how are mistakes/contaminated reagents/etc. reported?

Data communication:

Engage in ongoing discussions about science communication practices. Take time to highlight rhetoric used in presentations during lab meeting and papers during journal clubs. Debate concerns about "clean stories" in publishing eroding the accuracy of the record [63]. When it comes time to draft a manuscript with a trainee, discuss your process, ask them about their comfort level with writing and data presentation drafting to identify what they will need from you in terms of additional communications training support. Make clear your expectations for writing and timelines, and how you will approach revision cycles.

Collaborations:

Take care to share your data collection and communication standards at the outset of collaborations in a meeting with collaborators, ideally with trainees from all groups in attendance, and follow up in writing. Mentor your trainees in respectful dialogue to navigate disagreements and empower them to speak with you if they have concerns by creating spaces for one-on-one discussions and signaling your confidence in their judgment through actions and words.

Box 2.13 Incorporating RCR into the interview process

Potential supervisor:

- Outline training that new members of the research group should complete prior to engaging fully in lab activities
- Share a "Welcome letter" with all new lab members (regardless of level or position) that outlines expectations, responsibilities of all members of the lab, including the faculty member [70]

Aspiring trainee:

- Ask what type of training will occur (if this is not offered)
- Ask questions about rigor, accountability, and integrity, e.g., at what stage in the research does the supervisor typically seeks to publish a study, how authorship is determined, and who is involved in writing manuscripts.

research group. Lab meetings and journal clubs are great mechanisms for identifying and correcting problematic behaviors.

Lab meetings Here is where team members demonstrate their rigor in record keeping, analysis, communication, and respectful dialogue. It is recommended that lab meetings include presentations that provide the full context (what, why, how) for the data being shared. This serves to develop presentation skills of trainees while also prompting team members (including the supervisor) to recall the key questions and hypotheses at play. Taking it one step further, make it a habit to ask at these meetings "what else might explain what you saw?" to force everyone to always consider other explanations, including but also beyond human or instrument error.

Journal clubs Here is where team members demonstrate their critical thinking and communication skills. Beyond critiquing the rigor and replicability of featured publications keep an eye out for publications on reproducibility or other aspects of research integrity to include featured articles. It is important to not hide these issues away, and instead to discuss them openly, so trainees see your values and your expectations, and have an opportunity to ask questions in a safe space.

Trainee engagement

Trainees in turn must engage meaningfully with training, including asking questions, providing feedback, and likewise modeling appropriate behaviors for junior members (see also [69]) (Box 2.14).

Accountability structures

Surveys of trainees have demonstrated dissatisfaction with current RCR programs in terms of training along with perceptions of inconsistent consequences based on position [71]. To address this within the research space, supervisors can provide documentation in the form of contracts that specify roles and responsibilities of lab members (including those in leadership), non-negotiable practices, resources for support, and consequences for misconduct. Many institutions have such contracts as part of their graduate programs; however, generating a personalized contract that is unique to your circumstances helps communicate your specific values and expectations as the team leader and can include all members of the lab, not just graduate students.

Include in your document portfolio **accepted workflows for research design, file management, data sharing, protocol documentation, reagent and biologicals storage**, etc. Importantly, **set revision dates to ensure that documentation reflects feedback from members** and stays current with

Box 2.14 What can trainees do to contribute to RCR practices?

- Review the literature on philosophy of science to refamiliarize oneself with the foundational tenets of science.
- Make time for developing RCR skills (e.g., attend workshops on data management, data presentation, scientific integrity, reproducibility, etc.) and employ tools that can assess methods and reporting quality (e.g., SciScore).
- Model rigorous behaviors: practice excellent record keeping, be a meeting wizard, conduct data analyses promptly, consult with experts (your supervisor, collaborators, statisticians), consider multiple hypotheses, be a critic of your own work and that of your team… but a constructive critic that attacks data and ideas, not people.
- If your institute or department does not offer workshops on RCR practices, ask for them or design one yourself (in consultation with experts)—looks good on your CV too!
- Seek out opportunities to assess rigor (e.g., engage meaningfully in lab meetings, journal clubs)

best practices. Similarly, ensure team members have access to and are aware of your institution's research integrity policy and relevant regulatory bodies in your region.

Finally, create accountability by developing goals *in consultation* with your trainees. Commit to a mutually agreed upon framework and timeline for evaluating benchmarks, including mechanisms for review and revision.

Go further

- *Post a signed contract that stipulates your rights and responsibilities as the team leader in a prominently visible spot in the lab space to demonstrate that cultivating a rigorous research and learning space requires everyone, including the "boss", act with integrity.*
- *Some institutes include a graduate student oath and ceremony that pledges integrity.*
- *Does your institution have a whistleblower policy that applies to research integrity breaches? If not, advocate for one* [16,48].

Administrators, including **deans and department or program chairs**, have an important role to play in supporting RCR by creating institutional structures to foster dialogue and accountability (see Ref [13] for core elements of effective integrity policies). Administrators should delineate when and how formalized discussion of RCR should occur in training. This should include language about RCR in syllabi for any courses or programs that involve research (e.g., honors thesis programs) and directions to faculty on RCR components that must be included at formal checkpoints in the training process. Structures might include (adapted from X):

regular informal drop-in hours for trainees to discuss RCR issues with a program administrator

- a checklist (technical and biological replicates, controls, sample size, etc.) for reporting on RCR practices at each committee meeting
- a diverse group of faculty and/or senior trainees with specific training on conflict management and RCR practices who serve as advisors to trainees
- structured time in each committee meeting for the committee, *sans* supervisor, to have a frank discussion with the trainee

Conflicts of interest or commitment

Create a space that welcomes difficult conversations about conflicts of interest and commitment. We must also consider implicit and explicit biases reflective of individuals' lived experiences that play out in the collection, interpretation and reporting of data, and actively work to recognize, correct, and whenever possible, mitigate the impact of such biases on our work. Make a habit of acknowledging biases you may have to ensure these do not creep off your radar, and to encourage self-checking in your team. And ensure team members have access to and understand your institution's COI policy.

Feedback and reflection

Foster an open and honest conversation through feedback and reflection on your team's research practices. For example, provide specific and targeted feedback to trainees on their progress toward benchmarks and schedule monthly blue-sky lab meetings to discuss research directions. Use the latter as a means to revisit landmark research papers in your field, in reproducibility, or philosophy of science, encouraging everyone to engage in vigorous critique of the scientific process, including your own. Demonstrate your commitment to evidence-based mentoring practices and your openness to correction by incorporating feedback from these sessions into your practice.

What to do if you are worried about integrity in your lab

If you are worried about integrity practices in your lab or research unit, your first move should be to find and review the institutional research integrity policy and identify the appropriate reporting structure. You should also start a written record of dated observations and collect any correspondence relevant to the concern. Human resources departments and ombuds offices can share resources for having difficult conversations. If you are the supervisor, it is likely that you should first discuss the matter with your trainee or staff member. If you are a trainee, it is likely that you will need to identify a trusted mentor to assist you in moving forward. Start familiarizing yourself with policy at your institution and in your region/country [48].

Mentoring for equity, diversity and inclusion (EDI)

It is worth noting the argument that increased regulation and oversight to support RCR can be make-work and inhibit progress and academic freedom [6]. But a lack of policy tends to favor individuals in privileged circumstances and disadvantage those in vulnerable positions. A particular area that needs attention and research is to determine how to support RCR competencies in diverse learners through mentorship. For example, there are unique considerations for supporting international English as a second language (EAL) trainees who tend to be underserved by current support systems for RCR training [71]. Further, there is a growing body of literature focused on how mentoring practices impact retention of diverse individuals to STEM fields [20,28,35]. It is the responsibility of the mentor to engage with the literature on the experiences of historically underrepresented groups in STEM fields [20,35]. Moreover, it is imperative that institutions and their leadership incorporate best practices into their policy frameworks for mentorship and integrity training along with affording professional development opportunities for their research faculty to enact these changes. Part of modeling RCR behaviors includes educating oneself on EDI issues that might impact your mentoring and the research outcomes of your trainees so you can offer appropriately tailored support.

Support for mentorship in RCR practices

Several resources are available, aimed at various levels of engagement, to improve mentoring relationships, and develop RCR practices (see Box 2.15).

A key challenge is that the realities of the contemporary scientific enterprise may preclude the (otherwise) simplest intervention to improve rigor and reproducibility in research: slow down [2,72]. Fast science and pushes from government, funding agencies, and institution executives to grow the graduate student population strain effective mentoring. Effective mentorship requires meaningful interactions between trainees and faculty [65]. Unfortunately, the reality is that supervisors have myriad obligations that can sideline mentoring of junior members. It is the responsibility of the faculty member to recognize when they cannot fulfill this obligation [6] and the responsibility of government, funding agencies, and institutions to support responsible mentorship practices.

Box 2.15 Mentoring resources for mentors and mentees

- The "Welcome letter"
- Dr. Tracey Bretag: internationally recognized expert on evidence-based academic and research integrity programming. University of South Australia Business School, Adelaide, Australia
- National Research Mentoring Network
- STEMM mentoring
- UCSF Office of Career and Professional Development
- Science Careers
  - The Individual Development Plan platform is an important tool for all postgraduates. Mentors can also use as a framework to support RCR. Trainees can use this as a conversation starter about the mentoring they need, or to broach difficult conversations on RCR.
  - Articles provide advice for scientists at many stages of career and de-stigmatize difficult topics, e.g., Navigating conflict with your supervisor (2020)
- Nature's Mentoring Collection
  - Notable posts include "Why you need an agenda for meetings with your principal investigator" (2018) and "Great mentoring is key for the next generation of scientists" (2019)
- Gandrud, C. Reproducible Research with R and RStudio (2020)
  - a handbook for establishing R and RStudio workflows
- Responsible Science: Ensuring the Integrity of the Research Process Volume I NSF 1992 (especially Chapters 2, 6, and 7)
  - Includes definitions, historical context, and recommendations for teaching, mentoring, institutional policies to cultivate rigorous research practices and advocates for a national (US) body responsible for fostering, monitoring and assessing research integrity.
- NAS, On Being a Scientist: A Guide to Responsible Conduct in Research: Third Edition
  - Can serve as a primer for new lab members. Includes case studies that can serve as topics in journal clubs, lab meetings, workshops. Or, simply post to the cork board in the lunchroom to spark some introspection or discussion across research groups!
- Committee on Science, Engineering, and Public Policy, Philip A. Griffiths, Chair, *Adviser, Teacher, Role Model, Friend: On Being a Mentor to Students in Science and Engineering*, National Academy Press, 1997
  - A companion piece to On Being a Scientist, this collection outlines responsibilities and recommendations for mentors.
- M. Baker How quality control could save your science. *Nature News Feature* 27 January 2016

Conclusion and future work

It is an exciting time to be a biology educator, especially in the fields of genetics and genomics. There are an unprecedented number of resources and mentoring networks to support rigorous teaching practices, and no shortage of inspiring research stories to contextualize the knowledge foundations of our field. It is perhaps an overwhelming time as well, as precarious labor conditions and increased scrutiny raise the standards of the profession.

Similarly, today's research faculty are overwhelmed with a number of obligations besides their commitment to research. Research faculty are teachers, mentors, business and people managers, and get little to no training in any of these responsibilities [20]. The robust literature advocating for reforms to how we teach and how we mentor is daunting when squared with these additional responsibilities.

However, there are incremental changes one can make, and evidence-based practices (learning communities) that can assist in implementing changes to teaching and mentoring practices.

The iterative improvement and building of ideas that we take for granted as foundational to scientific inquiry should likewise be reflected in how we train. Conditions change: what was once status quo may no longer be appropriate, for any number of reasons. Do not simply use your training experience as the benchmark, reflect on your experience as a trainee, as a mentor, and improve upon it. Better yet, consult the literature and get involved. The education research community has yet to systematically tackle issues of RCR training and no doubt could benefit from the participation of researchers at multiple institutes. Work needs to be done to establish whether or not the approaches reviewed here and elsewhere yield desired outcomes [20].

A vital component of the equation is that the considerable work to build and maintain evidence-based practices in teaching, learning, and mentoring is valued through recognition and compensation. Despite a growing body of literature supporting the importance of undergraduate research experiences and the importance of direct interactions between faculty and undergraduates, this mentoring work continues to go unrewarded and unrecognized in many institutions [66]. Similarly, despite wide acknowledgement that science's myopic view of rewarding research output in the form of publications [2,16,72], change is slow. If we are serious about maintaining the integrity of our research enterprises, we need seismic shifts in policy to value the work needed to revitalize research culture. People in positions of power (administration, professional societies, and funding agencies, Fig. 2.1) need to put words into action and actively promote and value (with promotions and remuneration) the considerable work being done to prepare the next generation of scientists that does not directly contribute to publication record.

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