Course-based undergraduate research experiences (CUREs) have been identified as a promising vehicle to broaden novices' participation in authentic scientific opportunities. While recent studies in the bioeducation literature have focused on the influence of CUREs on cognitive and non-cognitive student outcomes (e.g., attitudes and motivation, science process skills development), few investigations have examined the extent to which the contextual features inherent in such experiences affect students' academic and professional growth. Central among these factors is that of ethics and the responsible conduct of research (RCR)—essential cornerstones of the scientific enterprise. In this article, we examine the intersectionality of ethics/RCR instruction within CURE contexts through a critical review of existing literature that details mechanisms for the integration of ethics/RCR education into undergraduate laboratory experiences in the science domains. Building upon this foundation, we propose a novel, evidence-based framework that seeks to illustrate posited interactions between core ethics/RCR principles and unique dimensions of CUREs. It is our intent that this framework will inform and encourage open dialogue around an often-overlooked aspect of CURE instruction—how to best prepare ethically responsible scholars for entrance into the global scientific workforce.
students is clear from a professional standpoint (17, 18), to the best of our knowledge, few studies have examined the translation and integration of ethics/RCR education into CURE contexts. Here, we seek to address this concern and initiate exploration of the intersectionality between ethics/RCR and CURE instruction through: a) a review of current ethics/RCR education approaches used within course- or workshop-based laboratory environments; and b) the generation of a framework for how one might integrate ethics/RCR principles within the context of CUREs.

CURRENT STATE OF ETHICS EDUCATION IN UNDERGRADUATE LABORATORY INSTRUCTION

Efforts to survey current practices on ethics/RCR education within course- or workshop-based laboratory contexts yielded a variety of instructional approaches adopting diverse pedagogical strategies and content foci, including curricula with differential levels of reported effectiveness (see Table 1 for a non-exhaustive description of several such instructional techniques). Closer evaluation of these approaches indicated that the majority appear to adopt a standalone lecture- or seminar-based format in which ethics/RCR instruction is incorporated in tandem with individual, pre-existing laboratory courses. Conversely, and despite continued recommendations within the literature (22, 23, 30, 31), infusion of ethics/RCR education within laboratory environments was observed notably less often (see Appendix 3 for an example of such integration). Research indicates that this phenomenon may be attributable to a lack of requirements for ethics training within select STEM degree programs, as well as low faculty support, among other factors (31–33). Nevertheless, current methods for ethics/RCR instruction, including those referenced in Table 1, often combine both didactic (e.g., lecture) and constructivist (e.g., role-playing, case studies, debates) techniques. Given the extensive benefits associated with the use of active learning-based strategies within STEM contexts (34), it is perhaps unsurprising that those methods adopting a constructivist lens are documented as being more effective at promoting students’ awareness of the role of ethics/RCR within the scientific research arena than lecture- or seminar-based approaches (35–38).

With specific regard to the present discussion, literature searches within Google Scholar using the Boolean terms “ethics” [or “responsible conduct of research”] and “course-based undergraduate research experience” returned only two relevant hits that described a potential approach for integration of ethics/RCR education into both lower- and upper-division CUREs in the fields of chemistry and biology (20, 28) (described in Table 1). The relative absence of integrative RCR training within the context of CUREs is worrisome, as it has the potential to foster student perceptions that issues pertaining to ethics/RCR are unrelated to the actual research experience(s) in which they are engaged. Indeed, existing literature indicates that, even in instances where ethics/RCR training occurs in parallel with the authentic research experience (e.g., summer research-intensive programs), students self-report this factor as being one of the least informative and enjoyable elements of their program (39).

While this is the case, recent efforts to increase undergraduate exposure to and understanding of ethics in the context of their own independent research provides a potential avenue for examining the intersectionality of ethics/RCR in CUREs more acutely. In their analysis of outcomes associated with undergraduate enrollment in a Communities of Practice in Biochemistry and Molecular Biology (COP) course, Keiler et al. (24) noted, for instance, that students who completed the curriculum (see Table 1 for a brief description of the course) self-reported greater gains in scientific process and ethical decision-making skills than a comparison group who had not taken the class. Although the focus of Keiler and colleagues’ efforts pertained to undergraduates engaged in faculty-mentored research experiences, an adapted version of the COP structure that focused on the integration of ethics/RCR as it relates both to the content of student-driven investigation in CURE contexts and the process of engagement in scientific inquiry in situ could serve as a viable means to promote students’ development of ethical decision-making skills throughout course-based research experiences at all levels.

Regardless, as the prevalence of CUREs continues to increase, and as these experiences often serve as the first exposure undergraduate students will have to research (18), we contend that the integration of formal ethics/RCR education within such learning opportunities is necessary in order to achieve full immersion of students in authentic scientific practice. Furthermore, alignment of ethics/RCR principles with structural dimensions unique to CUREs is posited to provide an unparalleled opportunity for students to truly understand the implications of ethics/RCR in the scientific enterprise. One such mechanism for accomplishing this goal is proposed below.

ALIGNING ETHICS/RCR CORE PRINCIPLES WITH DIMENSIONS OF COURSE-BASED RESEARCH

In concert with Jagger and Furlong (30), we contend that the establishment of ethics/RCR education within CUREs should occur at both the course and programmatic levels. Given the varying structure and level of implementation of CUREs found within the literature (e.g., 6, 11), it is important to note that such approaches might not be feasible in their entirety. Instead, we strongly recommend, as have others (22, 30, 31), that the relationship between ethics and scientific praxis be emphasized in an iterative, meaningful manner within CUREs rather than presented in a decontextualized, standalone format (33, 40–44).

Yet, this viewpoint is antithetical to many of the curricular mechanisms employed to address the role of ethics/RCR in the science classroom (see Table 1). When juxtaposed
TABLE I.
Methods of RCR/ethics instruction in undergraduate research experiences.

| Reference          | Level | Mechanism of Implementation                                                                 | Summary of Outcomes Related to Ethics/RCR                                                                 |
|--------------------|-------|---------------------------------------------------------------------------------------------|---------------------------------------------------------------------------------------------------------|
| Balster et al. (19)| I     | A single one-hour session on research ethics integrated into a CURE co-requisite course      | Students self-reported that the ethics component of the co-requisite course increased their competency in RCR topics and attitudes toward ethics |
| Danowitz et al. (20)| UD    | One-session, case-based approach focused on research misconduct, laboratory safety, and authorship in a chemistry CURE | No specific outcomes are reported                                                                           |
| Frantz et al. (21) | I     | Four-hour professional development workshop on science ethics (methods not specified)      | No specific outcomes are reported                                                                           |
| Gasparich and Wimmers (22) | NR  | Case study, lecture, and discussion-style seminars in conjunction with a summer research program | Students perceived value in the course content                                                               |
| Hendrickson (23)   | NS    | Integrated, stage-appropriate introduction within a research-intensive laboratory course | No specific outcomes are reported                                                                           |
| Keiler et al. (24) | NS    | Discussion of case studies as part of a community of practice (COP) course for students conducting faculty-mentored research; undergraduates could complete the COP course multiple times throughout their research career | COP students self-reported greater gains in “learning ethical conduct in your field” on the Research Integrated Science Curriculum (RISC) survey relative to a non-COP comparison group |
| Mabrouk (13)       | NS    | One, 90-minute workshop on various ethics components presented in the first or second week of a summer research experience; small- and large-group discussion of case studies served as the primary mode of instruction | Increased content knowledge pertaining to ethics terminology; lack of ability to apply ethics concepts to their [students’] own research projects |
| Senchina (25)      | NR    | Video vignettes designed to introduce students to fundamental concepts in conducting human subjects research prior to student engagement in traditional laboratories; worksheets and group discussion accompanied the vignettes | Students self-reported greater understanding of ethics as it related to experimenter-subject interactions and indicated that they would use this knowledge when conducting their own experiments |
| Shachter (26)      | NS    | Standalone summer research program adopting case studies and decision tree approaches to teach ethics/RCR concepts | Increased student awareness, sensitivity, and judgment                                                      |
| Smith et al. (27)  | UD    | Videos, case studies, and discussions in an “ethics lab”                                   | Student enjoyment of the approach; no further assessment                                                   |
| Swanson et al. (28) | I     | One-hour discussion on laboratory safety and ethics as part of a single three-hour CURE session | No specific outcomes reported                                                                               |
| Wahila et al. (29) | I     | Lecture (time not specified) on ethics as part of a Freshman Research Immersion (FRI) sequence | No specific outcomes reported                                                                               |

RCR = responsible conduct of research; CURE = course-based undergraduate research experience; I = introductory; UD = upper-division; NR = not restricted (both lower- and upper-classmen could enroll in the course); NS = not specified.

alongside traditional, “cookbook” laboratories (2), research demonstrates that students perceive ethics to be of little value because “[cookbook laboratories] are just exercises after all” (13). While the non-authentic scientific nature of such experiences has been criticized within the literature for several decades (11, 45), Mabrouk and others contend, as do we, that ethics/RCR instruction needs to be an essential component of all laboratory instruction. However, and central to our focus, it is striking to note that this same perception is likewise apparent among students who participate in research experiences for undergraduates (REUs). In her analysis of students’ RCR knowledge following integration of an ethics training workshop into six REUs, Mabrouk (13) discovered, for instance, that participants showed marginal improvement in their understanding of ethics concepts and virtually no improvement in their attitudes toward and
Numerous prior studies and professional reports detail guidelines and/or recommendations for inculcating students with a sense of ethics and knowledge of responsible conduct of research in laboratory environments (e.g., 49, 50). Collectively, these frameworks reflect the importance of data acquisition and management, general research (mis)conduct in inquiry-based contexts, and the collaborative nature of scientific endeavors. In an effort to accomplish our specified objectives, we used the work of DuBois et al. (49) as a conceptual framework to facilitate ongoing discussion and refinement. This framework was selected intentionally due to its broad application across scientific domains (rather than identification of ethics/RCR components unique to an individual context or STEM discipline), as well as its focus on components of ethics/RCR that, via consensus, were posited to be of practical value from a pedagogical standpoint. The nine ethics/RCR categories that were identified within the Delphi panel report and that we appropriated for our own analytical purposes are outlined in Table 2. Adopting a similar approach, we first determined the extent to which each criterion and its associated sub-criteria were applicable within a CURE (either not at all, relevant for some CURES, or relevant for all CURES) based on evaluation of CURE learning objectives outlined in the published literature within the field, including those described for both lower- and upper-division coursework (1, 2, 5, 6, 8, 11, 51–54, as examples) (Appendix 1). This process involved iterative discussion between the authors and a panel consisting of student researchers and experts in the biological sciences until agreement was achieved (see Appendix 2 for a detailed description of this process).

To establish greater confluence between these principles and their potential role in CURE contexts, we subsequently sought to align each major criterion to one or more dimensions identified as unique hallmarks of a CURE (Fig. 1). These dimensions are described in Table 3 below and are adapted from Auchincloss et al.’s (55) definitional framework pertaining to components of course-based undergraduate research experiences in the biological sciences. This referent was selected purposefully due to its explicit focus on CUREs vs. alternate authentic research experiences (e.g., summer internships) as well as its accessibility to multiple constituents (e.g., instructors, education researchers, institutional stakeholders). While outside of the scope of the present article, we believe that this latter component, in particular, possesses significant longitudinal value as the lens shifts from identification of ethics/RCR factors relevant to CURE contexts toward development and evaluation of instructional approaches that reflect meaningful integration of ethics/RCR and CURE educational paradigms. As was the case previously, this alignment process entailed iterative discussion between the authors and the focus panel until full consensus was achieved.

We acknowledge that the overlay depicted in Figure 1 is a “first step” in identifying intersections in ethics/RCR and CURE instruction. Furthermore, as Auchincloss and colleagues (55) note, variation in the frequency and intensity of how each CURE dimension (and its ethics/RCR counterparts) is enacted within the classroom environment will undoubtedly exist. As such, the framework here is not a finite representation of the role of ethics/RCR education within CURES, but rather a vehicle to initiate conversation around a central but often implicitly overlooked element of preparing professionals for entrance into a globally-competitive STEM workforce.

CONCLUSION: A CALL TO ACTION

CUREs offer a pragmatic, broad-scale mechanism to engage emergent scholars in authentic research opportunities within the STEM domains (1, 55, 56). Current empirical evidence, within the bioeducation literature specifically, indicates that participation in such experiences has the potential to positively impact a diverse array of cognitive and non-cognitive student outcomes, including students’ conceptual understanding, attitudes, motivation, and science identity development in the discipline (see, as examples, 2, 7, 11). Despite these affordances, limited research has been conducted that explores the influence of contextual factors and elements of professional practice on the aforementioned constructs. In this article, we advocate for deeper examination of the intersectionality of ethics/RCR education and CURE instruction, particularly given the inherent objective of CURES to promote authentic research practices. We have offered a possible framework that represents this interrelatedness but acknowledge that substantial refinement and future research in this area are not only warranted, they are a necessity. For instance, how is ethics discussed in the CURE classroom, if at all? What types of ethical considerations need to be accounted for in developing, implementing, and assessing a CURE? Who is accountable for ensuring that responsible conduct of research is maintained in CURE environments? When coupled with existing, discipline-based education studies in CURE contexts, the answer to these and other questions will yield fruitful insights into how to best prepare the next generation of scientists to make innovative and well-reasoned contributions to the STEM arena.

SUPPLEMENTAL MATERIALS

Appendix 1: Expanded categories of RCR/ethics topics applicable to CURE contexts
Appendix 2: Structured outline of panel discussions and strategic outcomes
Appendix 3: Example of infusion of RCR/ethics into CURE contexts
TABLE 2.
Description of ethics/RCR core components.

| Component                                      | Description                                                                                                                                 |
|------------------------------------------------|-------------------------------------------------------------------------------------------------------------------------------------------|
| Data Acquisition, Management, Sharing, and Ownership | Acquisition, storage, and sharing of scientific data should comply with the highest ethical standards of trustworthiness, honesty, and transparency while maintaining appropriate confidentiality, respect of data ownership, and adherence to appropriate regulations when working with human or animal subjects. |
| Mentor/Trainee Responsibilities                 | Developing a fruitful mentor-mentee relationship requires professionalism, effective communication, and establishing clear expectations. Mentor responsibilities include modeling high standards of conduct, as well as fostering development of trainees’ professional skills and career advancement. Mentee responsibilities include working with integrity and advancing the research group’s goals. |
| Publication Practices and Responsible Authorship | Scientific publication standards include transparency, appropriate authorship, proper reference of relevant literature, and inclusion of negative or contradictory findings. |
| Peer Review                                     | The success of peer review relies on fairness, objectivity, timeliness, professionalism, and respect of confidentiality and intellectual property. |
| Collaborative Science                           | Successful collaborations can increase productivity. Collaborations require clarification of expectations and responsibilities, integrity, effective communication, and transparent decision-making. |
| Research Misconduct                             | Researchers must be aware of misconduct, including plagiarism, falsification, fabrication, and sabotage. Researchers must understand the institutional policies and consequences of misconduct and report any observed misconduct. |
| Conflicts of Interest and Commitment            | Conflicts of interest or time commitment can affect the quality or objectivity of the research. Researchers must avoid or manage conflicts of interest/commitment according to the appropriate institution/agency regulations. |
| Social Responsibilities of Researchers          | Researchers must actively consider the relationship between their research and the common good. This includes defining research priorities that contribute to the common good, using public funds in a responsible manner, contributing to society through service and public education, and considering potential negative consequences of their research (e.g., environmental impact, dangerous applications). |
| Current Issues in RCR                           | As research evolves rapidly, training for the responsible conduct of research must evolve accordingly to address the most current research trends. Examples of current issues that should be included in RCR training in the biological sciences: human genetic modification, research with publicly available large scale datasets, research with patient genomic, transcriptomics, or proteomics datasets, research with embryos and human organoids, behavioral/health research using social media or smart-phone collected data. |

*Ethics/RCR core components and descriptions are adapted from DuBois et al. (49).
RCR = responsible conduct of research.

FIGURE 1. Alignment of core ethics/RCR components and CURE dimensions. RCR = responsible conduct of research; CURE = course-based undergraduate research experience.
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TABLE 3.
Description of CURE dimensions.

| Dimension  | Description |
|------------|-------------|
| Broader Relevance | The notion that the research students perform as part of a CURE, and the products that emerge, are of practical importance outside of the classroom. |
| Scientific Practices | Actions pertinent to the inquiry process, including: question/hypothesis development, selection of appropriate research methods, acquisition and analysis of data, and communication of outcomes. Scientific practices are employed with the goal of generating new knowledge and understanding in the field. |
| Collaboration | Scientific research is inherently collaborative, resulting in teams of scientists who contribute their knowledge and expertise to address large-scale questions in the field. With respect to CUREs, students working in collaborative spaces are provided with the opportunity to enhance their leadership and communication skills, network with individuals inside and outside of their discipline, and learn to value the diverse contributions and critical feedback provided by their peers. |
| Iteration | The accumulation of new knowledge via the process of outlining, performing, analyzing, revising/reflecting, and repeating an investigation. Within CUREs, opportunities for iteration might emerge when students are “troubleshooting” failures or verifying results. |
| Discovery | Within the context of CUREs, discovery implies that students are testing novel hypotheses, the outcomes of which are unknown to both the students and the instructor. The discovery process necessitates expanding upon existing evidence in one’s area of research to, ultimately, generate new insights into the phenomenon being studied. |

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