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What Knowledge of Responsible Conduct of Research Do Undergraduates Bring to Their Undergraduate Research Experiences?

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Supporting Information

ABSTRACT: Over a three-year period, chemistry and engineering students participating in six Research Experience for Undergraduates (REU) programs were surveyed before and after participating in a research ethics training workshop. The goal was to learn what undergraduate students already knew about key concepts in research ethics at the start of their research experience and to learn the impact of participation in the workshop on their knowledge and understanding of important research ethics concepts. At least two-thirds of the respondents could define fabrication of data, falsification of data, plagiarism, intellectual property, and confidentiality before participating in the training workshop. More than a third, however, could not define the terms personal misrepresentation, authorship, and conflict of interest. Though many students had factual knowledge of the key concepts at the outset, they were found to be unable to apply this knowledge to their summer research projects. Participation in the workshop was found to lead to improved comprehension of all the key science ethics terms selected for study in this project by all participants as reflected in the participants' ability to define the key concepts at the end of the workshop. Participation in the workshop, however, was not found to improve students' ability to apply their knowledge to their research projects. Student responses indicate that the students lacked critical local information on ethical standards needed for them to successfully apply their knowledge to their research projects. These findings together with those of our earlier work point to the importance of engaging individual faculty research mentors in their students' research ethics training.

KEYWORDS: *Chemical Education Research, First-Year Undergraduate/General, Second-Year Undergraduate, Upper-Division Undergraduate, Ethics, Undergraduate Research*

FEATURE: Chemical Education Research

INTRODUCTION

Research ethics is considered an essential component of research training for student scientists, and as such, training in the responsible conduct of research (RCR) is a requirement for all students, undergraduate and graduate, working on National Institutes of Health (NIH)[1] or National Science Foundation (NSF)-funded research programs.[2] NIH has published suggestions regarding the form and content that should be covered in RCR training, while the NSF has delegated its responsibility for these issues to the institutions requesting NSF financial support. Topics NIH has stated appear in most "acceptable" RCR training programs include human subjects, laboratory safety, conflict of interest, mentor/mentee responsibilities and relationships, collaborative research, peer review, data management, and authorship.[1a]

Given the requirement of research ethics training for federally funded research programs, it is surprising how little we know about the efficacy of research ethics training. What little we do know suggests there is room for improvement. Heitman et al.[3] surveyed new graduate students at several heath science universities prior to their participation in responsible conduct of research training concerning their knowledge and awareness of core RCR concepts and ethical standards and concluded that, while new [graduate] students' knowledge varies widely, very few enter with what most research mentors would consider an adequate knowledge of core concepts and standards.

The results of several studies suggest that ethics training may increase students' knowledge of research ethics concepts but not necessarily ethical decision-making or attitudes about RCR. In a study of self-reports of participants in research ethics courses, Plemmons, Brody, and Kalichman[4] found participants were more likely to report an increase in knowledge and to a lesser extent changes in skills and attitudes as the principal impact benefit of their research ethics instruction. Powell et al.[5] investigated the effectiveness of brief RCR training programs

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for short-term research programs and reported that the only statistically significant gain was for the participants' knowledge of RCR. No statistically significant gains were observed either in the students' ethical decision-making skills or their attitudes toward RCR training.

A quantitative meta-analysis of 20 empirical investigations of science ethics program evaluations concluded the overall effectiveness of ethics instruction is modest at best.[6] The authors of that study argued that instructional program factors were important factors contributing to training effectiveness. Antes et al. argued that efforts that were case-based rather than stand-alone, involved several sessions, and included practice activities appeared to show greater instructional effectiveness. Another contributing factor may be the goals of the individual instructors leading the ethics training. Plemmons and Kalichman[7] looked at the overall goals of 50 instructors from 37 institutions who teach RCR courses and discovered that instructors' goals and the instructors' perceived necessary skills varied widely from teaching ethical decision making to making students aware of policies and regulations.

LITERATURE REVIEW

So what do we know about undergraduates and research ethics? We know surprisingly little concerning students attitudes toward research ethics either in the classroom, the teaching laboratory or the research laboratory. In one study of natural science and engineering students,[8] over 40% of those surveyed admitted they had either falsified or fabricated laboratory data at least once in their laboratory courses. These students offered an array of rationalizations for their actions such as inadequate materials, facilities, assistance, and limited time. There is some evidence to suggest that student scientists view the classroom laboratory differently than they do the research laboratory. Sweeting,[9] reporting on her development of a course on professional ethics for undergraduates, stated that a number of her students felt cheating on laboratory experiments was not unethical "because they are just exercises after all." In a thoughtful study, Del Carlo and Bodner,[10] found that undergraduate chemistry majors' employ distinctly different standards for academic honesty in these environments. For example, student chemists working in the classroom environment considered copying from others dishonest but felt sharing data in this setting to be an acceptable practice. Mabrouk and Peters,[11] in a study of chemistry and biology undergraduate research students, reported that 8% of the student respondents experienced ethical dilemmas in the course of their undergraduate research experiences. The most frequently experienced ethical dilemmas involved issues of assignment of credit, confidentiality, plagiarism, and fabrication/falsification of laboratory data.

For the past several years, we have been studying undergraduate and high-school students' understanding of key research ethics concepts and their ability to apply this information to their research projects. In a recently published study, we[12] surveyed undergraduate researchers following their participation in a case-based research ethics training workshop at several times throughout their research programs. We found that student understanding of some key research ethics concepts such as plagiarism, fabrication and falsification of data, and confidentiality evolved over the course of their research experience, but that for a significant number of students, understanding of the concepts of intellectual property and authorship was never satisfactorily resolved.

Many science educators, including this author, approach their work within the conceptual framework known as constructivism.[13] In constructivism, learning is viewed as an active, mental process in which student learners construct knowledge based on their unique set of past experiences and understanding. In this model, for learning to be effective, it is important to know and utilize the knowledge, experience, and ideas the student learner brings to the table. Consequently, in the present study, we have taken a step backward in time to ask what knowledge of key RCR concepts undergraduates have at the start of their research programs and to determine whether their participation in a science ethics training workshop impacts their knowledge of these concepts and their ability to apply this information to their research projects.

RESEARCH METHODS

Over a three-year period, six undergraduate research programs—four of these programs were for engineering students, and two were for chemistry and biochemistry majors—participated in the study. All six programs took place on the same campus, that of a research university. Three were NSF-funded REU programs (two in chemistry and one in engineering), and three were privately funded programs. The number of participants in each program varied somewhat, from 9 to 16 participants. In each undergraduate research experience program, we were invited to present a workshop on research ethics at some point during the first 2 weeks of the research program.

A case-based approach to research ethics training described recently[12] was used in each workshop. The workshop was 90 min long. The research ethics workshop opens with the presentation and discussion of a relatively recent research ethics incident that has made headlines in the scientific and/or public press. In recent years, the cases of Michael LaCour,[14] Vipul Brighu,[15] and Marc Hauser[16] have been introduced. Discussion subsequently focuses on the research process and the fundamental dependence of the research process on research integrity throughout the research process. In the context of stepping through the research process, eight key ethical concepts are introduced and illustrated by targeted discussion of case studies in which allegations of poor record keeping, fabrication/falsification of data, plagiarism, conflict of interest, and personal misrepresentation were raised. Workshop participants are then divided into pairs or groups (depending on the number of workshop participants). As time permits, the pairs or groups read, discuss, and present to the group as a whole several open-ended case studies so that all of the participants have a chance to work through the process of ethical decision making for themselves. The cases that form the basis of these workshops are available to anyone on WebGURU, the Web-based Guide to Research for Undergraduates.[17] The same instructor led all six research ethics training workshops using the same set of training materials. Student satisfaction with the workshop, the facilitator, and handouts has always been strongly and consistently positive. (Interested readers are encouraged to examine Table 1 in ref 12.)

At the start of each workshop in this study, all workshop participants were asked to complete a pre-workshop survey. Immediately following each workshop, the survey instrument was readministered to all participants.

The survey instrument was a modified version of a survey instrument used in a recently published study of research

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Table 1. Formal Definitions of the Research Ethics Terms Evaluated in This Study

Research Ethics Concept	Definition
Personal Misrepresentation	a form of misconduct in which an individual provides a false or misleading oral or written declaration of their educational background, technical skills or expertise, or achievements
Falsification	the practice of omitting or altering research materials, equipment, data, or processes so that the results of the research are no longer accurately reflected in the research record
Fabrication	the practice of inventing data or results and recording and/or reporting them in the research record
Plagiarism	the practice of using another person's original ideas, processes, results, or words without giving appropriate credit to the other person
Intellectual Property	Nonobvious ideas, creative inventions, or processes such as trademarks, copyrightable works or patented inventions
Authorship	the practice of identifying those individuals responsible for the integrity and quality of ideas, experimental work, interpretation, and written expression of a significant work being published
Confidentiality	an agreement based on mutual trust that protects intellectual property and limits to whom and what information may be disclosed
Conflict of Interest	a situation in which an individual who is acting to represent the interests of another has personal, fiduciary, or professional interests that have the potential to impede their ability to act impartially on behalf of the other person

ethics.[12] The instrument was designed to test the students' knowledge of key research ethics concepts and to demonstrate their ability to apply their understanding of key research ethics concepts to the research project on which they were initiating work. Students' knowledge of key research ethics concepts was evaluated based on their ability to define the concepts in writing. The students' ability to apply their understanding of these concepts to their research project was gauged by their responses to a series of closed-form opinion statements evaluated using a 5-point Likert scale (vide infra).

The survey tool was designed to be completed in under 10 min. No personal or demographic information was solicited, so the survey was strictly anonymous. The survey tool (see Supporting Information) contained 19 questions and was divided into two main sections. The first section contained eight research ethics terms that the students were asked to define in the space provided. The eight research integrity terms participants were asked to define were the following: personal misrepresentation, falsification of data, fabrication of data, plagiarism, intellectual property, authorship, confidentiality, and conflict of interest. Participants were informed orally preceding the survey not to worry if they could not define one or more terms and that it was fine to leave the space blank if they were unfamiliar with a term. The second section consisted of 11 opinion statements designed to test the students' ability to apply their knowledge of several key research ethics concepts, specifically, intellectual property, confidentiality, authorship, and falsification/fabrication, to their research experience. A five-point Likert scale (strongly agree, agree, uncertain, disagree, strongly disagree) was used to assess the participants' relative agreement/disagreement with each opinion statement.

Participation in the pre-workshop and post-workshop survey studies was voluntary. The pre-workshop survey was administered at the start of the workshop by the workshop presenter, and the surveys collected before the start of the actual workshop. Students were not told that they would be asked to complete the same survey at the end of the workshop. The post-workshop survey was administered by a preselected undergraduate research program administrator at the end of each workshop once the workshop presenter had left the room. Completed post-workshop survey forms were collected by the administrator who then returned the surveys to the workshop leader. Unsigned consent was used which means the students receive a sheet requesting their participation in the study, outlining briefly the purpose of the study, that their participation is anonymous, and indicating that they can decide for themselves whether or not they wish to participate in the study. In two workshops, the pre- and post-workshop surveys were numbered so that paired pre- and post-participant responses could be evaluated. In all workshops, students who did not wish to participate in the pre- and/or post-workshop surveys simply did not have to hand in their surveys. No students in any of the workshops declined to submit completed pre- and/or post-workshop instruments. The study as outlined above was reviewed by the local IRB and approved. A total of 68 usable surveys were obtained from the pre-workshop survey, and a total of 66 usable surveys were obtained from the post-workshop survey. A total of four pre-surveys and five post-surveys were incomplete. The participants had completed less than half of the survey. So those surveys were not evaluated or included in our data analysis. The overall response rate was 94% for the pre-workshop survey and 92% for the post-workshop survey.

DATA ANALYSIS

Scaled survey data were analyzed using PASW Statistics v. 22 (SPSS, Inc.). Scaled survey data for each respondent cohort were compared. No statistically significant difference was observed between the student responses for the six cohorts, so the data were aggregated and then analyzed.

The definitions data were coded and analyzed as follows. All of the pre- and post-workshop research ethics workshop definition data were downloaded as an Excel spreadsheet from SPSS. The data in each column represented a different definition category, and each row represented a different student's definitions. The data were not marked pre- or post-workshop to avoid any coder bias. A written set of formal definitions for each research ethics term was created (see Table 1). A formal set of coding rules (see Table 2) was also created. Twenty sets of student responses corresponding to each student's pre- and post-workshop responses for each of the definitions were then coded by two coders. Both coders were chemistry faculty members who actively mentor and publish with undergraduates. The coders worked independently and used the same formal definitions and coding rules. Coders evaluated each definition as either correct or incorrect.

The primary coder reviewed the secondary coder's evaluations against their own. Reliability checks were performed for each definition. Checks varied between 100% (plagiarism) to 90% (personal misrepresentation, intellectual property, and conflict of interest). The coders then met, discussed, and resolved any differences in coding. On the basis of the discussion, the definitions (Table 1) and coding rules (Table 2) were revised. Both coders then proceeded to code the

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Table 2. Rules Used in Coding Participants' Research Ethics Concept Definitions

Rule Hierarchy	Coding Rule
1.	The definitions that respondents provided for each of the eight key research integrity terms should be coded as correct or incorrect.
2.	Whenever the workshop participant writes nothing, the definition is coded as incorrect.
3.	The length of a participant's definition should not bias the coder in evaluating its correctness as participants were directed to "do their best to define each in your own words in the space [small] provided."
4.	Whenever the workshop participant writes anything in the definition that is incorrect, then the definition is incorrect.
5.	Whenever the definition is so vague that it could serve as the definition for another research ethics concept, the definition is incorrect.
6.	Whenever the definition is simply a restatement of the words used in the term being defined then the definition is incorrect.

remaining participant pre- and post-responses. Reliability checks for each definition varied between 100% (plagiarism and confidentiality) to 90% (conflict of interest). Differences in coding were again identified and adjudicated. The second time around, it was determined that no changes needed to be made to either the definitions or the rules. Differences in coding most frequently occurred when the student definitions were vaguely or unclearly worded.

Examples of student definitions that were considered to be correct are shown in Table 3. Examples of student definitions that were considered incorrect are provided in Table 4.

RESULTS

Definitions of Research Ethics Terms

Data from two of the workshops, representing a total of 18 participants, were collected in a manner that allowed for a paired analysis of the pre- and post-workshop definitions. Placing equal value on each of the eight definitions, an average score was calculated pre- and post-workshop for each participant's definitions of the eight research ethics terms. The mean score for the affected students rose from 64% (SD = 16%) pre-workshop to an average score of 85% (SD = 11%) post-workshop. with the use of null hypothesis significance testing, the mean increase in student scores is statistically significant, $t(18) = 5.1$, $p < 0.001$. Another way to gauge the importance of a statistically significant result is to calculate a standardized effect size. With the use of the pre-test standard deviation as a conservative estimate of the population standard deviation and therefore a suitable unit of measure for effect size, the standardized effect size is 1.4, a relatively large value, essentially equivalent to 1.4 standard deviations. On the basis of these results, we conclude that participation in the research ethics workshop did lead to a significant improvement in student comprehension of the eight key research ethics terms.

Figure 1 presents a quantitative picture of the respondents' ability to define the eight key research integrity terms pre- and post-workshop across all six workshops surveyed. The majority of participants were able to define many of the key research ethics terms, specifically, fabrication of data, falsification of data, plagiarism, intellectual property, and confidentiality prior to participating in the research ethics workshop. Over one-third of the respondents was unable to define personal misrepresentation, authorship, and conflict of interest. After the workshop, most of the participants were able to define all the research ethics terms with the exception of personal misrepresentation and conflict of interest; more than one-third of the participants were still unable to define these terms or to be able to define the terms correctly.

As can be seen in Table 3, after the workshop, participants' definitions of the key research integrity concepts were more clearly expressed and more sharply defined. Students' definitions often included related research ethics concepts and terms. For example, in defining confidentiality, one student wrote: "lack of openness, not being able to share information." Another student, providing a definition of plagiarism wrote: "use of someone else's intellectual property without giving proper credit." This suggests that students were making important functional connections between the research integrity concepts (openness and confidentiality; intellectual property and plagiarism).

Some useful insights into students' prior knowledge of research ethics can be gained by examining the incorrect responses provided by the respondents before participating in the research ethics workshop. Most respondents were able to provide a definition of many of the eight research integrity terms pre-workshop with two exceptions. The three research ethics terms for which respondents were least likely to provide a definition were personal misrepresentation (31% provided no response and 31% provided incorrect responses), conflict of interest (21% provided no response and 63% provided incorrect responses), and authorship (16% provided no response, and 26% provided incorrect responses).

On the basis of the incorrect definitions (Table 4) provided, it appears that participants unfamiliar with the term "personal misrepresentation" attempted to deduce the meaning of the term "personal misrepresentation" based on what they thought the words "personal" and "misrepresentation" would mean when used together. Examples of definitions that the participants provided before participating in the workshop that support this interpretation include "not fully understanding what has been said and filling in wording yourself" and "your own misunderstanding of something which you then present incorrectly." It is interesting that undergraduates are not familiar with the term "personal misrepresentation." Certainly, there have been a number of relatively recent examples of prominent individuals in science who were accused of this form of misconduct.[14b,18] Thus, it should be easy to find real case studies with which to introduce and discuss this issue with undergraduates.

Undergraduate respondents also appeared to be unfamiliar with the concept of "conflict of interest" before participating in research ethics training. On the basis of the definitions the respondents provided, it appears that several attempted incorrectly to infer the meaning of this term, too. Examples of definitions consistent with this view that students provided pre-workshop include "differing ideas; usually between colleges" and "people may wish research others things and don't have time for others ideas/projects." The definitions offered suggest that some students may have heard about this form of misconduct previously but did not develop a meaningful understanding of the issues involved. Consequently, we suggest that faculty and workshop leaders make no assumptions that students come to their ethics training with any prior knowledge of this issue.

On the basis of the definitions the respondents provided before participating in the research ethics workshop, a significant number of students seemed to have an incomplete understanding of authorship. Authorship in some students' minds principally relates to the "ownership" of data. Authorship

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Table 3. Examples of Definitions Provided by Respondents Able To Define Key Research Integrity Terms Correctly before and after Participating in a Research Ethics Training Workshop

Research Ethics Concept	Pre-Workshop Responses	Post-Workshop Responses
Personal Misrepresentation	When a person claims to have more experience and knowledge than they do	Misrepresenting yourself and achievements
	Pretending to be someone you aren't	Falsely representing your credibility and/or education to boost others trust in you
	Stating you have credentials and expertise in a field you do not	Falsely representing yourself in order to receive some benefit, job, etc.
	Lie or mislead someone about your personal info/skill set	Pretending that you have accomplishments that you actually don't
Falsification of Data	Actively changing the data, even if it is false to make sure the outcome is "true"	Altering data
	Making data reflect the results you want changing the data	Modifying your data to support your hypothesis
	When an analysis is done but the data is changed to better fit the desired results	Changing data to fit your hypothesis Changing of data to fit a wanted result
	Skewing data toward more favorable results despite actual results	
Fabrication of Data	Data that was not obtained experimentally but claims to be so	Make up data for an experiment that was never conducted
	Make up results for something that never happened	Making up data where none existed
	Creating data or just making it up	Creating data that never happened
Plagiarism	Copying or using someone else's work without citing them	Copying other ideas without giving proper credit
	Copying someone else's work without giving proper credit	Copying someone elses[sp.] work without giving credit
	Using information as if it was yours without using reference	Use of someone else's intellectual property without giving proper credit
Intellectual Property	Ideas or concepts that could be assigned as property	An idea which one can put to use or someone else can, an idea can be patented
	The idea that ideas are "property" and that the person that comes up with the idea deserves recognition	Ideas that can be realized in the real world and typically protected by a patent
	Ideas that one can get patented	Something that can be thought of and reduced to practice
Authorship	Being credited for a research paper because of contributions to the research	Earned through contribution to a work through ideas, data collection, analysis, etc.
	The person who writes a paper and was integral to the research gets authorship	Name in a byline, receives credit, need to meet certain criteria to earn this
	Significant contribution to a project and its publication	Who is responsible or credited for the research project
Confidentiality	Agreement to limit the amount of info you tell others not involved	Agreement of what can be discussed and who it can be discussed with regarding projects
	The agreement of knowing what can and can not be discussed about certain areas of a project	Keeping work secret usually to protect intellectual property
	When something needs to be kept secret from others, and maybe made viewable only to specific people	Lack of openness, not being able to share information
Conflict of Interest	Personal interests affect objectives in a biased way	Having a relationship/ideas that can lead to bad judgement[sp.] in the workplace
	One has a personal stake in the outcome which may bias them	Having goals that conflict; a personal interest may inhibit the ability to be objective
	When a person has a pre-existing association with something that would compromise the integrity of their project	having goals that conflict; a personal interest may inhibit the ability to be objective

was also incorrectly viewed by some respondents both before and after ethics training as evidence of one's "ownership" of intellectual property. Recognizing that this is a common misconception, we recommend that faculty and workshop leaders involved in research ethics education consider discussing the relationship between intellectual property,[19] copyright,[20] patents,[21] and authorship[22] when discussing the RCR core areas of responsible publication practices and practicing collaborative science.

Over half of student respondents were able to define plagiarism, falsification of data, fabrication of data, confidentiality, and intellectual property before participating in research ethics training. Respondents who were unable to define fabrication of data and falsification of data pre-workshop frequently appeared to confuse the two terms (see Table 4). Those participants who provided incorrect definitions of intellectual property before participating in ethics training seemed to appreciate that the concept of intellectual property relates to one's creative ability. This group, though, did not appear to appreciate that these "thoughts" must result in a creative work or invention, i.e., they must take some tangible form. Examples of definitions provided by respondents that support this view include "one's own idea, you own it" and "the ideas, the thoughts that you came up with on your own and originally thought of by you." Consequently, we suggest that faculty and workshop instructors recognize that students may

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Table 4. Examples of Definitions Provided by Respondents Unable To Define Key Research Integrity Terms Correctly before and after Participating in a Research Ethics Training Workshop

Research Ethics Concept	Pre-Workshop Responses	Post-Workshop Responses
Personal Misrepresentation	Misinterpreting the data, prompts and/or any other relevant research component as conforming to the biases of personal opinion	Representing data in a misleading way
	Not fully understanding what has been said and filling in wording yourself	Not given full of proper instructions then filling in with your understanding
	Your own misunderstanding of something which you then present incorrectly	Not properly representing one's thoughts/experience
Falsification of Data	Adding, omitting data that did not happen	Making up data
	Data that was not obtained experimentally but claims to be so	Not using data correctly
	Not sure about the difference between these two (falsification and fabrication)	Utilizes prior data that have been published to your own work
Fabrication of Data	Changing the results of the data gotten from an experiment so that it fits what the expected results should be and claiming it is true	Changing data
	Changing your results to match a specific conclusion	Changing data results to fit expected outcome
	Knowledge conducting tests incorrectly to yield favorable data	Changing data to match a specific conclusion
Plagiarism	Failing to properly sort	In text: using two or more words in sequence without citation: using a patented idea without permission
	The use of two or more consecutive[sp.] words from another's work without citation	
Intellectual Property	Credit needs to be given to the one who did the study	Knowledge claimed by an entity Your thoughts
	Information or data you have collected that belongs to you	
	The reasoning behind the protection of your idea	
	Thoughts/ideas that are your own, you personally wrote yourself, lab notebooks/journal notebook, your understanding of information	
Authorship	Ownership of intellectual property	Claiming intellectual property
	The owner of certain data	You own it, wrote it
	Wrote a paper, didn't plagiarize	Owning something/being a part of owning something
Confidentiality	Right to privacy	Not stealing others' research when they trust you to review their paper
	Closed information	Keeping things quiet
	Keeping a secret	secrecy
Conflict of Interest	Differing ideas; usually between colleges	Disagreements with team members, labs, etc.
	When someone you know is involved in something bad	Multiple different interests for data
	When intentional doing poorly benefits you	Working in the same type of field as a competitor

have an incomplete understanding of intellectual property and that they consider developing or use exercises and examples in their discussion of intellectual property that help students make this important connection.

As shown in Figure 1, a significant reduction in the number of respondents unable to define or incorrectly defining the eight research integrity terms was observed after the students participated in the research ethics workshop. Following the workshop, some participants were still found to be unable to define satisfactorily two concepts, specifically, personal misrepresentation and conflict of interest. In the workshop, we use a complex case study that involves several other research ethics concepts including intellectual property, confidentiality, and plagiarism. Those students who were unable to define the term conflict of interest following participation in the workshop seemed to appreciate that the issue was linked to this case study but still did not fully appreciate the issues involved with this research integrity concern. Consequently, we plan to use a more straightforward case in the future that does not involve quite so many different ethical issues.

Application of Key Research Ethics Concepts to Research Projects

The workshop participants' ability to apply their understanding of five key research ethics concepts (intellectual property, confidentiality, authorship, and fabrication/falsification) to their research experiences was assessed based on their responses to a series of nine fixed response statements evaluated using a 5-point Likert scale (strongly agree, agree, uncertain, disagree, strongly disagree). As stated earlier, data from two of the workshops, representing a total of 18 participants, were collected in a manner that allowed for a paired analysis. Table 5 provides a snapshot changes in the paired scaled responses pre- and post-workshop.Table 6 shows the percentage of respondents from all six workshops who were uncertain concerning the issues of intellectual property, confidentiality, authorship, and fabrication or falsification of data as related to their research projects pre- and post-workshop. As the changes in Table 5 show, many students left the workshop with questions about intellectual property, confidentiality, and authorship as these issues related to their

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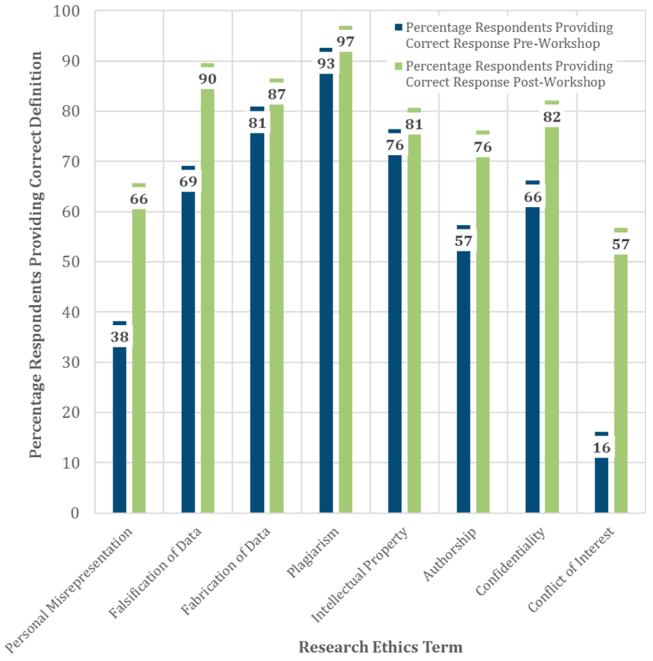

Figure 1. Graph showing the effect of workshop participation on students' ability to define eight key research ethics terms (N = 68 pre-workshop; N = 66 post-workshop).

research projects. For some students, participation in the workshop allowed them to resolve uncertainty they had before the workshop regarding ownership of the intellectual property relevant to their research project and the criteria for authorship in their research groups, while for other students, their participation in the workshop raised questions for them regarding these same issues.

The key finding is that no significant change was observed in the students' ability to apply their knowledge of key research integrity concepts to their research projects after participating in the research ethics workshop. More than half of the respondents indicated that they did not know the requirements for authorship in their research group nor whether their name would go on the byline of any presentations or publications resulting from their research. Nearly half of the respondents indicated that they did not know with whom they could discuss their research project. Over one-third of the respondents indicated that they did not know who owned the intellectual property relevant to the research project on which they were to work.

One explanation for the lack of improvement in the respondents' ability to apply their knowledge of research ethics to their research projects is that the students lacked critical information on research policies in their laboratories which is needed in order for the students to successfully apply their knowledge to their research projects. It is generally recognized that the criteria and standards for authorship vary widely among the STEM disciplines, technical journals, and in research laboratories even in the same STEM discipline.[22a] Individual lab principal investigators usually provide local leadership and guidance for their research teams or information on intellectual property, authorship, confidentiality, and other issues not discussed here including openness, laboratory safety, etc.

In our prior study,[12] we investigated the evolution of undergraduate students' ability to understand and apply their knowledge of research ethics over the course of their research

Table 5. Changes in Paired Undergraduate Students' Fixed Responses to Application Statements before and after Participating in a Research Ethics Training Workshop

Survey Statements for Response, by Topic	Undergraduate Students' Responses Relative to Ethics Workshop Participation, Percentage Respondents (N = 18)			
	Uncertain Immediately before	Remained Uncertain Immediately after	Uncertainty Resolved Immediately after[a]	Raised Uncertainty Immediately after[b]
Intellectual Property				
My research project involves intellectual property	22	17	6	0
I know who owns the intellectual property relevant to the research project on which I will work	50	33	17	11
Confidentiality				
I can discuss my research project openly with my family and friends	39	28	11	0
I know with whom I can discuss my research project	44	33	11	6
Authorship				
My name will go on the byline of any presentations and publications that result from my work this summer	50	44	6	6
I know what is required for authorship in my research group	72	39	22	22
Fabrication/Falsification				
It is "OK" to "modify" data, omit data, or make up research data that will appear in a published research article	6	0	6	0
It is "OK" to "modify" data, omit data, or make up research data for an undergraduate research project	6	0	6	0
It is "OK" to "modify" data, omit data, or make up data in an undergraduate laboratory experiment	6	0	6	0

[a]Participants indicated they were "Uncertain" before the workshop and changed their responses to either "strongly agree, agree, disagree, or strongly disagree" immediately after the workshop. [b]Participants indicated that they either "strongly agree, agree, disagree, or strongly disagree" with the statement before the workshop and changed their responses to "Uncertain" immediately after the workshop.

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Table 6. Percentage of Respondents Uncertain Concerning the Implications of Key Research Integrity Concepts in Their Undergraduate Research Projects before and after Participating in a Research Ethics Training Workshop

Survey Statements for Response, by Topic	Undergraduate Students' Responses Relative to Ethics Workshop Participation, Percentage Respondents		
	Immediately before (N = 68)	Immediately after (N = 66)	Immediately after, Literature Comparison[a]
Intellectual Property			
My research project involves intellectual property	25	20	24
I know who owns the intellectual property relevant to the research project on which I will work	37	39	21
Confidentiality			
I can discuss my research project openly with my family and friends	34	29	50
I know with whom I can discuss my research project	34	41	24
Authorship			
My name will go on the byline of any presentations and publications that result from my work this summer	57	59	44
I know what is required for authorship in my research group	59	56	49
Fabrication/Falsification			
It is "OK" to "modify" data, omit data, or make up research data that will appear in a published research article	4	0	0
It is "OK" to "modify" data, omit data, or make up research data for an undergraduate research project	4	0	0
It is "OK" to "modify" data, omit data, or make up data in an undergraduate laboratory experiment	4	0	0

[a]See ref 12.

programs. We found that, over time, undergraduate students' understanding of several issues improved. Within 2 weeks, nearly all the undergraduate students understood how confidentiality might impact their ability to discuss their work with others and knew with whom they could discuss their research projects. However, at this point many students were still ignorant regarding intellectual property and authorship. Over 20% did not know who owned any intellectual property related to their research projects, and more than half did not know the standards for authorship in their laboratories. At this point in time, 38% of the students stated that they had met with their faculty advisor or graduate student mentor in order to clarify their understanding of their research group's policies regarding the issues that had been discussed in the workshop such as intellectual property, authorship, confidentiality, etc. We also found that a significant number of students remained ignorant regarding intellectual property and authorship even at the end of the research programs at which point only slightly more than half (53%) of the undergraduates reported having consulted their research advisor or graduate student mentor for clarification regarding these issues.

It is worth mentioning here that the post-workshop data from the present study are in good general agreement with those from our earlier study.[12] Overall, more than half of the respondents expressed that they were uncertain concerning the requirements for authorship in their research groups and that they were uncertain as to whether their name would appear on any presentations and publications that result from their work. A smaller but still significant percentage of respondents indicated that they were uncertain about intellectual property and confidentiality as these issues relate to the students' research projects.

Some relative differences were observed in the responses of the participants immediately following the research ethics workshop in this study as compared to our earlier work.[12] In the present study, the percentage of respondents expressing uncertainty concerning confidentiality issues related to their research project was somewhat different than in our earlier work. In the present study, a lower percentage of respondents (29% vs 50%) expressed they were uncertain about the statement "I can discuss my research project openly with my family and friends", while a higher percentage of respondents in this study (41% vs 24%) stated they were uncertain that "I know with whom I can discuss my research project." We do not have any insight into a possible reason for these differences.

DISCUSSION

We believe that the observation that many undergraduates already know and believe they can apply their understanding of many of the core RCR concepts prior to participating in research ethics training is important information for faculty teaching undergraduate research ethics courses and workshops as it means that undergraduate students are bringing some prior knowledge of RCR subject matter to the table which should enable deeper conversations concerning these issues than perhaps many instructors are currently undertaking. We have also identified a number of misconceptions that students have concerning key research ethics concepts. We feel that this information could be used to better inform the content of the research training programs we provide for undergraduates and allow for more attention to be paid to discussing the key research ethics concepts that most students do not know.

In many articles we found describing research ethics training courses, colloquia, discussion boards, or workshops for undergraduates in chemistry, case studies and role-playing exercises frequently seem to focus on issues related to falsification, fabrication, and plagiarism.[9,23] Given our finding that most students have some familiarity with fabrication of data, falsification of data, and plagiarism but lack understanding of confidentiality, intellectual property, authorship, and conflict of interest, we would like to recommend that workshop and course developers consider devoting more of their often limited time and effort to teaching students about these concepts and helping their students to develop a solid understanding of the core RCR concepts. Second, given that we have shown that

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J. Chem. Educ. XXXX, XXX, XXX−XXX

students are not able to apply their understanding of these concepts locally to their research projects, we recommend that research ethics training programs actively engage students with their faculty research mentors so that students can learn how to apply their knowledge of openness, confidentiality, data management, authorship, and intellectual property to their research projects, to promote deeper understanding. One useful mechanism that could be used to facilitate student−faculty discussion is via a research learning contract[24] completed at the start of the student's research project.

In interpreting this work, it is important to recognize some of the limitations of the study. These include limited generalizability as the study involved a relatively small number of students all of whom were involved in an undergraduate research experience, all of the summer research programs took place on the campus of one graduate research university, and all of the research ethics workshops were led by the same person. Future studies might include the participation of students from other STEM majors, other types of academic institutions, and other training program formats including courses, short courses, etc.

CONCLUSIONS

In this study we have shown that participation in research ethics training workshops appears to be an effective mechanism for providing undergraduates with much-needed content knowledge concerning research ethics as evidenced by students' ability to define key research ethics terms. We have also found that many undergraduates come to their research programs with an understanding of falsification, fabrication, and plagiarism. Though most students are familiar with many of the research integrity concepts, many students are not familiar with personal misrepresentation, authorship, and conflict of interest. We have identified some common misconceptions that should be considered when developing and offering research ethics training to undergraduates.

We have also shown that many undergraduate students complete their research ethics training unable to apply their knowledge of research ethics to their undergraduate research projects. In our earlier work,[12] we showed that the necessary conversations with faculty research advisors do not appear to be occurring "organically" and that while many students appear to grow in their ability to apply their knowledge over the course of their research programs, many undergraduates appear to be uninformed regarding their laboratories' policies on intellectual property and authorship even at the end of their undergraduate research experience. Consequently, we are investigating mechanisms such as research learning contracts,[24] checklists,[25] and graduate student mentoring programs[26] to facilitate conversations regarding local policies for data management, openness and confidentiality, intellectual property and authorship so students can confidently apply their understanding of research ethics to their research projects.

ASSOCIATED CONTENT

Supporting Information

The Supporting Information is available on the ACS Publications website at DOI: 10.1021/acs.jchemed.5b00264.

Pre-and post-workshop survey instruments (PDF, DOCX)

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Notes

The authors declare no competing financial interest.

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