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Romi L. Burks and Matthew M. Chumchal (27 October 2009)
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EDUCATION

To Co-Author or Not to Co-Author: How to Write, Publish, and Negotiate Issues of Authorship with Undergraduate Research Students

Romi L. Burks[1]* and Matthew M. Chumchal[2]*

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This Teaching Resource emphasizes the value of publishing with undergraduates and may be particularly helpful to incoming faculty who are new to the process of working with students. Beyond simply extolling the virtues of undergraduate research, we examine how such deep learning experiences for students can translate into unique opportunities for the faculty to demonstrate devotion to both teaching and scholarship. Along with highlighting the reasons faculty should consider publishing with undergraduates, we identify the particular challenges that accompany this suggestion and discuss strategies for overcoming them. Our resource includes two decision trees for helping faculty determine whether publishing with undergraduates represents a reasonable and attainable goal and whether an undergraduate has earned authorship. Based on our experience at primarily undergraduate institutions, we provide a list of strategies that may facilitate writing with undergraduates and lead to certain milestones in the careers of both students and faculty.

Introduction

As we approach 2010, a clearly discernible buzz of excitement and trepidation hovers over national discussions of biology education (*1*). In 2003, BIO2010 (the National Research Council's treatise on biology education) set the stage for rethinking how biology educators might teach an increasingly content-rich field by putting a greater emphasis on scientific methodology and critical thinking (*2*). A growing movement to integrate the concept of science as a process into all biology curricula has emerged among educators teaching at community colleges, primarily undergraduate institutions (PUIs), and research-tiered universities. A parallel rise in peer-reviewed materials to facilitate this transformation has accompanied this movement (*3*). However, even before these recent calls sounded and before "how to" depositories of electronic resources appeared, faculty successfully engaged students by mentoring them in their own research.

[1]Associate Professor of Biology, Southwestern University, 1001 East University Avenue, Georgetown, TX 78626, USA. [2]Assistant Professor of Biology, Texas Christian University, 2800 South University Drive, Fort Worth, TX 76129, USA.

E-mail, burksr@southwestern.edu (R.L.B); m.m.chumchal@tcu.edu (M.M.C.)

Although the number of acronyms used to refer to undergraduate research experiences—undergraduate research (UR), undergraduate research experience (URE), undergraduate research opportunity (URO), or research experience for undergraduates (REU)—can generate some ambiguity, no confusion should exist regarding the clear, documented benefits that come from these experiences (*4*). Laundry lists of positive outcomes exist (*5*); however, many studies stress the personal and professional development of the student into a future scientist as a laudable outcome of UROs (*6*). Although these experiences expose students to elements of the scientific process from question development to presentation of results, UROs rarely include attention to the process of writing papers for publication (*7*). Writing to future young scientists, Nobel laureate Peter Dougherty declared that "unpublished science is unfinished science" (*8*). Therefore, in one sense, an URO that does not include exposure to scientific writing and peer review omits one of the most important parts of the scientific process (*5*, *7*). This may be the most important reason to publish with undergraduates (Table 1).

The rise of undergraduate-only journals may provide one avenue for students to publish their research (*9*). However, the utility of this format for both student and faculty (*10*) is the subject of considerable debate (*5*, *9*, *10*). For students with research deemed "publishable" by the faculty member, a traditional peer-reviewed regional or national publication will generally lead to a higher-quality publication that provides a contribution to the scientific community as a whole. Because guiding students through the process of publication is time intensive, faculty may not be able to commit to the process if the research will not be published in a format accessible and considered credible by the scientific community. For students simply seeking writing experience or whose results are not suitable for publication in a traditional journal, courses on scientific writing that incorporate peer review (*7*) and expose students to discipline-specific writing guides can help students get a sense of the process (*11*).

The logistics of conducting research with undergraduate students, let alone co-authoring papers with them, can appear daunting, and faculty incentives for doing so vary (*12*). However, we optimistically speculate that the rewards of teaching students to be contributing scientists may make a greater impact than the science itself (*1*–*4*). In addition to encouraging publications that include undergraduates, we hope to stimulate further thinking about the role that scientific writing plays in national discussions about transforming biology education.

Teaching and Scholarship: Balance, Blend, or Bipolar

We assert that the first step to achieving a stable and lasting balance (*12*) between researching with and teaching undergraduates simply involves not considering these areas as bipolar. Boyer's model of the Teacher-Scholar (*13*) identified distinct categories of scholarship, made explicit links between scholarship and teaching, and continues to play a prominent role in rethinking biology education at differently sized universities (*14*). The assumption that being a successful researcher makes one a better teacher may rest on the premise that the successful researcher stays abreast of his or her field. Subsequently, the teacher-scholar shares more current knowledge with classroom students. Yet, the rapid nature of change in current biological knowledge makes it challenging for anyone to stay on top of cutting-edge developments, even just in their own fields. Consequently, biology education has started to drift away from content-driven learning outcomes to process-driven objectives (*1*, *2*).

Table 1. Reasons to publish with undergraduates.

	Reasons you should publish with undergraduates	References for support
1	You likely got your career start by doing undergraduate research.	(*25*, *26*)
2	Publishing with undergraduates best represents excellence in teaching, because few things exist that are harder to teach than writing.	(*7*, *13*, *14*, *19*)
3	Authoring with undergraduates creates a multitude of opportunities for students to learn about and discuss ethics.	(*21–24*)
4	Students who publish as undergraduates tend to be more competitive for professional schools, and institutions often track or assess the number of graduates who go on for higher degrees.	(*4*, *6*, *25*)
5	Students able to participate in the writing process may serve as the best indicator of the deep learning experience.	(*1*, *2*, *15*, *17*)
6	Publications with students help recruit future students.	(*4*)
7	Publishing the paper completes the scientific method and illustrates the real world of a scientist to the student.	(*5*, *7*, *8*, *18*)
8	Publishing with undergraduates serves as clear evidence of broader impacts that funding agencies require.	
9	Publications with undergraduate authors that indicate a sustainable research program may be viewed as positive by tenure and promotion committees, especially at PUIs.	(*12*)
10	Mentoring undergraduates all the way through the publication process is a rewarding experience that allows you to give back to the scientific community in exchange for the training you received on the path to becoming a scientist.	

Additionally, successful researchers may make better teachers because they are more likely to apply the same critical, scientific approach they use in their research to evaluate their effectiveness in the classroom. Whatever the reason, the assertion that a direct positive link exists between good teaching and research productivity has recently been supported [(*15*), but see (*16*)]. The 2005–2006 FSSE and NSSE (Faculty and National Survey of Student Engagement, respectively) results found a significant positive effect of the time faculty spent on [their] research and scholarship on students' self-reported general education success (*15*). However, this result only occurred at institutions that emphasize "deep learning" (that is, a focus on both substance and the underlying meaning of information in contrast to "surface-level processing"). In contrast, at institutions where deep learning did not receive as much emphasis, the average amount of time faculty spend on research and scholarship produced small, but statistically significant, negative effects on students' self-reported general education and personal and social development outcomes (*15*).

Recognizing that the current trend in science education (*1*) points toward actively engaging students in the process of science (*17*) and that substantial teaching takes place outside the traditional classroom, probably no better way exists to teach students about research and the process of science than bringing them into a research lab (*6*). Although sometimes reserved for graduate students, this model of engagement can also be used to expose undergraduate students to the "real world" of science (*18*). Using one's own research to teach about all the steps—identify a question, explore the literature, develop methods, execute an experiment, analyze the results, synthesize the conclusions, and place the research in the larger context—required for a publication seems an effective way to teach students about science as a process.

Although we focus on faculty members, many graduate students and postdocs may find themselves mentoring undergraduates at larger institutions. Learning to consider undergraduates as contributors to the research process provides practical experience for academic researchers and may even add highly prized publications to curriculum vitae. Finally, publishing with undergraduates serves as clear evidence of "broader impacts" that funding agencies require.

To Publish or Not to Publish (with Undergraduates)

Time is the most limiting factor for research productivity and teaching effectiveness (*6*). Although we certainly want to accentuate the benefits of publishing with undergraduates, it would be foolish to suggest that a faculty member adopt such a plan to his or her own peril. Expectations regarding publications at many PUIs vary but rank markedly lower than at research institutions (*12*). At most PUIs, faculty members who do not perform well in the classroom cannot expect to remain employed, regardless of how excellent their record of publication. However, faculty at research universities, and some PUIs, experience tremendous pressure to produce a body of work suitable for publication in a peer-reviewed journal in a relatively short period of time. Important pre-tenure assessments or annual reviews typically cycle faster than the time it takes to mentor undergraduates through the scientific publication process.

Consequently, faculty members (particularly untenured ones) should consider a number of factors before deciding whether publishing with undergraduates represents the best career move (Fig. 1). Publishing papers with undergraduates takes more

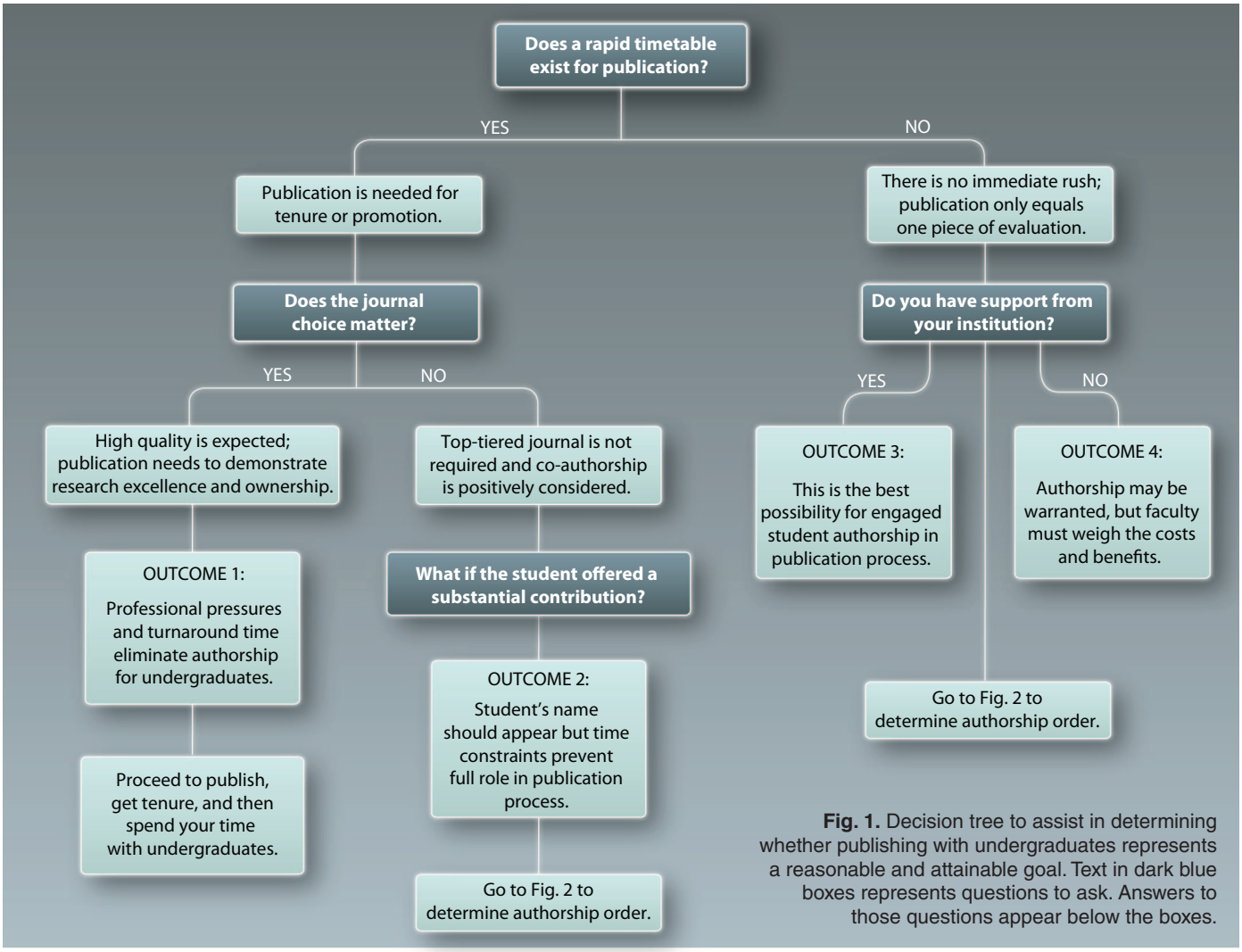

Fig. 1. Decision tree to assist in determining whether publishing with undergraduates represents a reasonable and attainable goal. Text in dark blue boxes represents questions to ask. Answers to those questions appear below the boxes.

time than if the faculty member wrote the paper alone (our conservative estimate would be 4 times as much time). Having undergraduates in one's lab (relative to no students) can enhance productivity when extra hands help. However, undergraduates typically require a lot more time and supervision than the average graduate student. Undergraduates generally do not inherently possess any less talent than the average graduate student, simply less experience. In addition, their schedules make it difficult to find sufficient blocks of time needed to focus on developing scientific writing skills (*19*) or make substantial research progress in a timely manner. Therefore, not unexpectedly, time to publication represents the first benchmark to consider when deciding whether or not to publish with undergraduates (Fig. 1).

In an ideal world, one's institution integrates this type of teaching and mentorship into the faculty teaching load. However, at some institutions, research with undergraduate students does not count as part of the teaching load and is only encouraged if it does not negatively impact productivity (that is, lots of undergraduates in the lab + publications = good; lots of undergraduates in the lab + no publications = bad). Consequently, publishing with a student may not earn the additional recognition we believe the achievement deserves (Fig. 1).

The spatial and temporal scales at which most UROs occur (for example, laboratory study versus field study, and research for one semester versus several years) may ultimately limit one's choice of journals or other outlets. To evaluate how publishing with undergraduates may directly influence performance evaluations, faculty need to determine how their institutions view authorship and the importance of journal quality and then make choices that enhance the likelihood of tenure and promotion (*12*). Publishing requires resources, not just in time but also financially. When publishing with undergraduates, in addition to the typical costs of laboratory resources and page charges, there may be costs related to travel to allow face-to-face writing time with the students after they graduate. Thus, it is essential that faculty have access to resources and support from their institutions to make publishing with undergraduates a viable option (Fig. 1).

Publishing with Undergrads

Once committing to mentoring a student through the publication process, where do you start? First, we wish to make a distinction between publishing with undergraduates versus employing an undergraduate to

work in the lab on menial, but important, tasks and then simply having his or her name listed among the authors without that undergraduate contributing intellectually to the scientific and writing processes. In the latter case, the undergraduate may have little or no involvement in writing the paper. In regard to student development, this scenario does not reach much further than the experience of working in a research lab (*6*).

We find that successfully mentoring a student through the publication process begins early—during the recruitment and project development phase—not as the project nears completion. When a student approaches us about doing research, we inform them that they will get out of the experience what they put into it. For some students, the experience ends up short-lived because research is not for everyone. Although we believe that undergraduate research can result in peer-reviewed publications, pushing students more interested in technician-level experience into independent projects with expectations that the work will be published will result in frustration for both the student and the faculty member. We encourage faculty to look for students who show potential to assume a greater role within the lab's research. Over time, these individuals should earn the option of developing their own projects within the faculty member's area of research.

Do not be afraid to mention the "best-case scenario" early in the recruitment phase: that, if appropriate, the results the student obtains could be used as the basis of a new manuscript or part of a developing publication. However, temper that best-case scenario with a clear dose of reality that not all research efforts yield such outcomes and that such decisions come later in the process. It is important to discuss issues about authorship and writing with undergraduates on Day 1, making sure it is clear to the student what it takes to accumulate enough data for publication and the level of commitment required to participate in a research project from the development to the publication phase (a process that often takes several years).

Most students do not come into the faculty research lab with set plans of their own. When planning research projects, faculty have been trained to think in terms of publication—asking questions that fill a gap in the literature, designing experiments that will withstand peer review, or tweaking a project to test a slightly different hypothesis. Although they may be research novices, undergraduates should also start their projects aware of the considerations that go into publishing. To encourage their engagement, we suggest offering subtopics or types of experiments from which the student can choose and later develop ownership. Students will rarely stick out the publication process with a project in which they do not hold a strong interest. We recommend working with the student in the early stages of the process to identify potential journals for publication. We ask students to peruse tables of contents, read the aims and scopes of journals, and investigate journal turnaround time. Such a practice helps students consider the larger context of their work, provides clear formatting instructions, and gives them a better perspective for the long-term nature of research.

Once the work is complete and you and your student are ready to write, you will once again find yourself challenged by issues of time. Good writing, especially science writing that engages the reader (*19*), takes time. When seeking advice about writing (*20*), two main messages consistently emerge: Write early and write often. We add one more message: Write something. For undergraduates, "something" can mean starting with a one-page outline or research sketch, then expanding to a short proposal, revising the proposal into a short synopsis of pilot experiments, and then transitioning that piece into the traditional format of a scientific paper as the research progresses. Poster and oral presentations given at scientific meetings also represent excellent starting points for a manuscript because these formats often serve as outlines for the full-length manuscript. Of course, getting started can constitute the most difficult part of the writing process, so we recommend taking time to get a student started and offer different strategies for writing with undergraduates (Table 2). After a student begins writing, we find it very important to emphasize stepping-stones in the writing process and also to celebrate progress, even in small increments. We also advise creating checklists that remind students of basic rules that promote clarity in writing (*20*).

Who's Still Interested?

The cycle of publication—from conception of idea to paper in hand—can unfortunately take longer than the average undergraduate tenure. As you get ready to write, it is important to tackle the issue of authorship. Adopting objective guidelines to determine who deserves authorship and the order of authorship (*21*) for a scientific paper may alleviate or even eliminate anxiety commonly associated with this process and thereby avoid unpleasant incidents of disagreement (*22*), hurt feelings, or negative effects on a student's professional development.

Despite some efforts to provide objective guidelines for assigning authorship, determining authorship remains fraught with ethical concerns (*23*), owing largely to a vague notion of what constitutes the minimum contribution to be included as an author. No clear guidelines or advice appears to exist for faculty members that conduct research primarily with undergraduates. Although similar scenarios can occur with graduate students and postdocs, issues of authorship may become even more problematic when they involve undergraduates because faculty may have a greater tendency not to fully acknowledge their contributions (*21*). Therefore, we strongly recommend that faculty working with undergraduates spend time reflecting on this issue.

Some journals publish a byline or contributor statement that credits each author with specific contributions, but this has yet to become the norm (*21*). Creating a byline for each potential author, regardless of journal requirements, could help faculty members assess the contributions of each collaborator and reach more objective authorship decisions. One approach proposed by researchers working in the field of psychology suggests explicit criteria for determining authorship and a point system to determine order of authorship (*24*). Although a point system provides a means of objectively determining authorship, it could be problematic when applied to undergraduates because their intellectual contributions will rarely match that of more experienced members of the lab (*21*). Consequently, faculty need a better system for determining authorship with undergraduates and particularly for deciding whether a student should or can function as first author.

We recommend posting decision trees (Figs. 1 and 2) so that students know authorship decisions are not arbitrary. With multiple semesters or summers, undergraduates may produce enough data to tell their own stories. We suggest that the transition point from story mimic to storyteller provides the best indication that a student may be a viable first author (Fig. 2). Alternatively, students may participate in a tag-team approach where they pick up where others left off. In this case, we suggest that

Table 2. Recommended strategies for writing and publishing with undergraduates.

Strategy	Implementation	Rationale
Write early and often.	Have students write research proposals that eventually end up as papers.	The scientific process begins with the literature and posing questions.
Save frequently.	Have students save each draft by date.	You may change your opinions of sections as the paper progresses.
Give students their own flash drives.	Require students to back up copies of their work weekly.	Flash drives are cheap. Lost efforts are priceless.
Designate times for writing.	Have students keep logs of their writing efforts.	Waiting for the "inspiration" to write results in very few words.
Designate set times for talking about the writing process.	Take 10 to 15 min to first discuss which parts went smoothly or proved difficult.	Students have different strengths and weaknesses. Upfront identification of these saves time.
Reinforce that "red marks" should not be taken personally.	Show students select drafts of papers from your own graduate adviser.	It is the peer-review process that upholds scientific integrity and quality.
Do not forget that you were once an undergraduate.	Keep a paper that you wrote as an undergraduate nearby. Read a paragraph before meeting with your student.	Students feel better about the process if they know that the faculty member went through similar growing pains.
Provide two grade assessments: effort and quality.	Use this to stress that effort can only take a student so far.	Constructive criticism, engagement in the literature, and careful responses to reviews improve quality.
Set and keep clear deadlines.	Treat independent research as a course with a syllabus and agenda. Failure to meet a deadline should affect the effort grade.	Work is more focused with a deadline. Faculty and students need to plan their work for research in the context of their other obligations.
Break writing down into small steps and celebrate progress.	Mention your student's efforts in front of one of your colleagues.	Positive reinforcement training can work wonders. Students also respond well to food rewards.
Do not accept careless writing.	Return paper to student if any page has more than four typos.	Students must proofread and not waste time better spent critiquing content than grammar.
Treat the student's paper as a submission to a journal.	When returning drafts, request that students respond to each comment as they would to an actual reviewer.	Introducing this aspect of the peer-review process early helps students respond better to journal reviewers.

often the student contributing the last piece makes the best choice for first author. He or she likely can coherently tell the entire story, because this student is in a position to see how all of the results came together. However, faculty should make sure that past students leave the lab with a clear understanding of how their contributions may be integrated into future publications and that future students might be in a position to be the first author. In general, faculty members should be careful not to make promises they cannot keep regarding authorship order.

In determining whether a student earns the right to first authorship (Fig. 2), faculty need to find out if the student wants the responsibilities that go along with that honor. At a minimum, this includes a long-term commitment to working on the publication even after they graduate, a professional and ethical responsibility to represent the lab well, a realization that publishing in a peer-reviewed journal requires more than just "A-level" work, an ability to follow directions (be it the journal's or the faculty's), and the skill to keep all authors updated in writing.

A continuum of increasing leadership and independence exists alongside the different configurations of undergraduate authorship (Fig. 2). A postgraduation "memorandum of understanding" is one mechanism to convey the responsibility of authorship and the consequence of failing to meet the expected obligations. Such a document is not legally binding but pro-

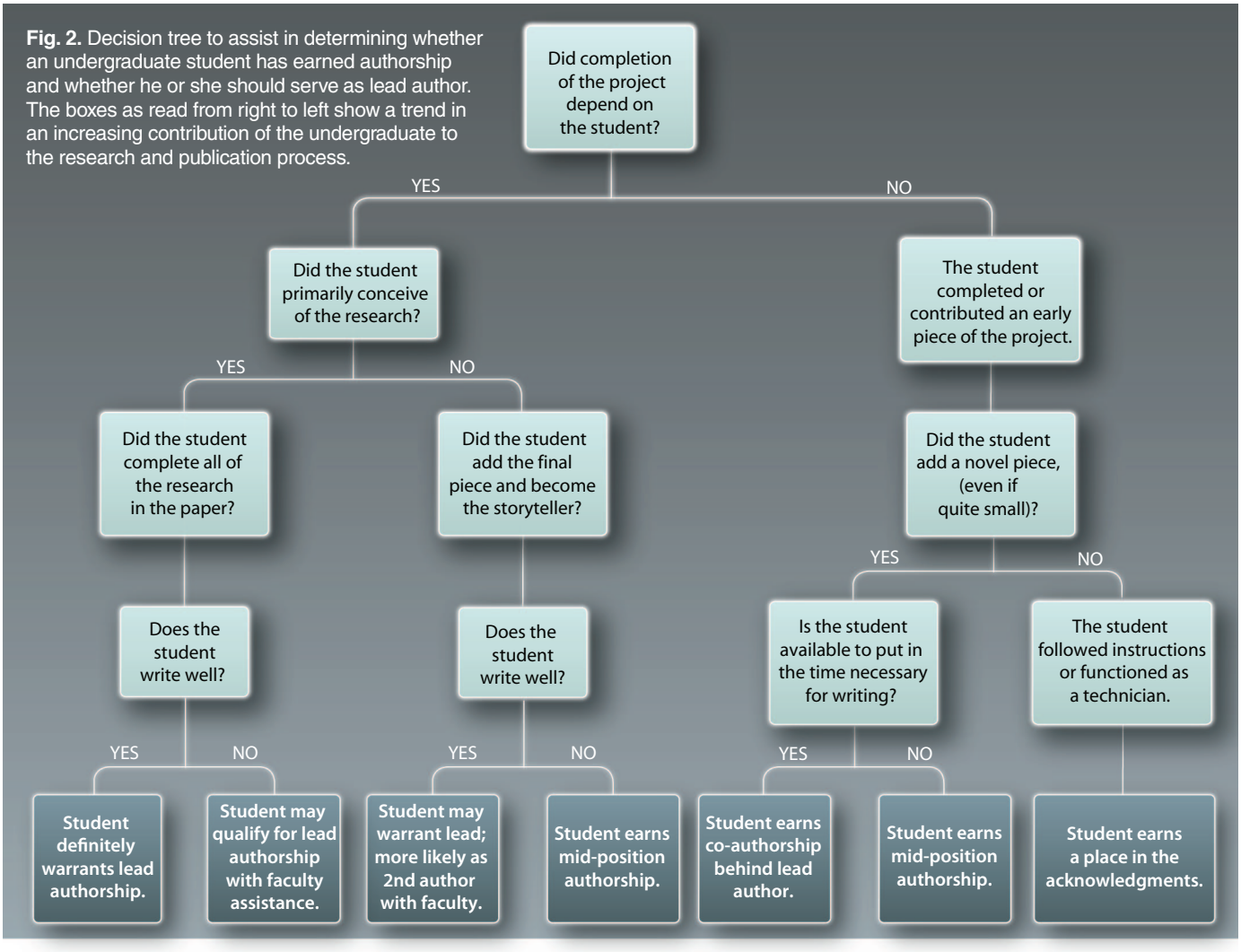

Fig. 2. Decision tree to assist in determining whether an undergraduate student has earned authorship and whether he or she should serve as lead author. The boxes as read from right to left show a trend in an increasing contribution of the undergraduate to the research and publication process.

vides a mechanism to delineate the responsibilities and establish working timelines and deadlines. In terms of enforcement, the decision for authorship ultimately rests with the faculty member, because undergraduate students generally do not submit papers on their own. The document allows the faculty member and student to agree to the terms of authorship.

Finally, when the time comes to write or respond to reviews, we find that a face-to-face writing retreat is helpful, although it may be necessary to obtain funding for this from the institution or include it in the publication costs in grants. Sometimes the alumni office may be willing to cosponsor the travel of a former student in exchange for an opportunity to highlight (for example, in an alumni Web page, blogs, or brochures) ongoing faculty-student interactions. Alternatively, a department may be willing to contribute funds for travel expenses if the alumnus agrees to meet with current research students. Although substantial progress can be made with word-processing tools that track changes in documents or through wikis, we feel that nothing can really substitute for a few hours of intensive work in person. As a last practical note, we suggest scheduling "writing workshops" with the co-authors and editing the manuscript as a group. For example, group editing can be done by projecting the manuscript onto a screen. Then, the authors can make changes based on collective input. If it is impossible to meet in person, then video chats on online meeting applications are another possibility.

Closing Thoughts

Undergraduate research increases scientific understanding, confidence in research skills, and interest in graduate school and future science, technology, engineering, and mathematics (STEM) careers (*25*). About one-third of both faculty and students surveyed (*6*) reported that students who took advantage of UROs had noticeable gains in their ability to present and defend an argument orally. Yet, substantially fewer respondents (8% faculty, 7% students) recognized parallel gains in scientific writing by students who had research experience (*6*). The typical 8- to 10-week summer research experience does not supply enough time to develop writing skills. However, a student who gets to participate in the manuscript authoring process should receive the experience and faculty attention that will result in increased ability to communicate through scientific writing.

Students who really become engaged in research frequently energize the faculty

member's commitment to the Teacher-Scholar Model (*13*, *14*). Although it is not simple or trivial to establish a research program that involves undergraduates, early evaluation of which research objectives match the needs and capabilities of undergraduates and which do not will bear the most fruit and minimize faculty and student frustration. The best experiences start with preplanning on the part of the faculty. The intellectual ownership on the part of the undergraduate will come later.

Publishing with undergraduates has an impact on society greater than simply the paper (*4*–*6*, *15*, *18*). Therefore, we encourage faculty to consider not only the impact of their research on the scientific community but also the impact that including undergraduates in the publishing and authorship process will have on the next generation of scientists and the general public. For academic faculty, first-author publications still impress, but working with students to author papers may be a more notable milestone in a faculty career.

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