

Training in scientific manuscript writing

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Graduate programmes require their doctoral students to write as scholars and experts who publish their findings in quality, peer-reviewed journals. However, since not all programmes require a formal writing course and uniformity in explicit instructions from supervisors is not possible, variability in the preparedness of trainees for scientific manuscript writing is likely. Indeed, results from a self-reported survey of doctoral and postdoctoral researchers that we conducted confirm this uneven preparation, and reinforce the clear need for formal training in disciplinary writing. We review some initiatives, whose implementation should prove profitable in formalizing the instruction of pre- and postdoctoral researchers in the practical skills required to write dissertations and scientific manuscripts, the cornerstone for archiving and transferring disciplinary knowledge.

Keywords: Disciplinary writing, formal training, graduate programmes, postdoctoral research, scientific manuscripts.

‘If your research does not generate papers, it might just as well not have been done.’

– G. M. Whitesides¹

NEW knowledge that results from research needs to be disseminated to other scientists and the public, and to do so effectively is a learned skill. Despite efforts dating back to the 1960s to impart formal training to doctoral students in scientific writing^{2–4}, historically this learning has been a process of trial and error, mainly during an apprenticeship with his/her mentor^{5,6}. By the end of their training, graduate students are in fact expected to independently write papers and grant proposals (see Box 1 for some examples). Such doctoral requirements have been inspired in part by the realization that clear and persuasive writing is a reflection of logical thinking and the ability to develop scientific arguments – thus writing papers is not merely an archival effort but fundamental to developing the ability to think vigorously about what constitutes scientific proof and how to express scientific findings precisely². Writing is thus an integral part of the initiation into a discipline, as it promotes the identity of a new researcher through specific contributions to the knowledge-making practices of his field⁷.

Some students, especially those for whom English is the native language, are already good writers when they

start their graduate work and they further develop their skills during graduate courses in which there is a major writing component. However, given the diverse writing skills of incoming graduate students, writing a scientific paper requires additional formal training, one that includes an elaboration of discipline-specific practices and not merely an enumeration of general effective writing tools. Since such courses in scientific writing are not a universal feature of graduate curricula (see Box 2 for some current offerings), we were curious to know how the challenging goal of writing papers might be fulfilled. To gain insights in this regard, we conducted surveys of graduate students and postdoctoral researchers. Our findings should motivate graduate programme faculty and students to consider the desirability of and strategies for incorporating methodical training in effective scientific writing into the education of young scientists.

Objectives of the surveys

To determine the attitude of graduate students and postdoctoral fellows towards their experiences, perceived skill levels and aspirations with respect to writing scientific manuscripts, we conducted two surveys. We distributed an eight-item survey to graduate students in their third or later year in three life-sciences programmes at the Ohio State University, USA – the demographics of the 73 students who returned completed surveys are shown in Figure 1a. We sent a similar 11-item survey electronically to several postdoctoral researchers, who had their graduate education in universities, both within the US and abroad. We also posted our survey on a professional networking site of the National Postdoctoral Association (www.nationalpostdoc.org) – the demographics of the 185 postdoctoral scholars who returned completed

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Box 1. Samples of graduate programme expectations on research publications.**Case Western Reserve University, School of Medicine**

'By completion of the PhD, we expect graduates of Case biomedical graduate doctoral programs at the School of Medicine to have two or more first-authored primary research publications in peer-reviewed scientific journals.' <http://casemed.case.edu/gradprog/pubpolicies.html>

University of South Carolina, Integrated Biomedical Sciences

'Students are unequivocally encouraged to publish their dissertations. The student should be the first author of the publication but others who have made substantive contributions to the work may be assigned as co-authors. Although it is expected that the student's work will merit publication in a journal of national or international standing, it is not a prerequisite of graduation that the student have a first author paper accepted or published.' <http://pathmicro.med.sc.edu/graduate/dissertation.htm>

University of Massachusetts, Graduate School of Biomedical Sciences

'The GSBS Dean will review each student's publication record prior to approval of admission into Dissertation Defense. It is our expectation that by the time of completion, each student has developed sufficient original research material to justify submission as one or more research articles in which the student is the primary author.' <http://www.umassmed.edu/uploadedFiles/gsbbs2/Students-Faculty/Student%20Handbook.pdf>

Vanderbilt Brain Institute, Neuroscience Graduate Program

'The program requires that the student have a first-authored publication (or manuscript in press) in a peer-reviewed scientific journal prior to defending their dissertation.' <http://braininstitute.vanderbilt.edu/graduate/pdfs/2013-studenthandbook.pdf>

Box 2. Sample courses and workshops on scientific writing.

Scientific writing course, Department of Surgery, UC San Francisco; <http://sciencepubs.surgery.ucsf.edu/scientific-writing-course.aspx>

Writing in the sciences, Stanford University (through Coursera); <https://www.coursera.org/course/sciwrite>

Writing workshops, Office of Intramural Training and Education, NIH; https://www.training.nih.gov/writing_courses

Writing for scientific research, Veterinary Medicine and Biomedical Sciences, Texas A&M University; <http://writingcenter.tamu.edu/course/vibs-489-writing-for-scientific-research/>

Writing an effective scientific research article, Princeton Writing Program, Princeton University; <http://www.princeton.edu/writing/wse/graduate/>

surveys are shown in Figure 2 *a*. These researchers were asked to comment on their skills at the time they began their postdoctoral tenure to reflect the kind of training they had obtained during their graduate studies.

Recurring themes in the two surveys

The majority of graduate students (67%) and postdoctoral researchers (59%) reported that they did not have well-

developed writing skills and that they considered writing a scientific manuscript as not an easy task (Figures 1 *b* and 2 *b*). The overwhelming consensus among respondents was that knowing how to write a scientific manuscript is just as important as knowing how to design and execute a research project (93% graduate students; 98% postdoctoral fellows). However, close to 40% of the graduate students and 70% of the postdoctoral fellows agreed that their mentors did not set aside adequate time to guide them about how to transform their research results into a manuscript suitable for publication in a peer-reviewed journal. Interestingly, nearly two-thirds of all respondents agreed with the statement, 'My research mentor would encourage me to take a manuscript-writing course if one were available, even though it would take me away from the laboratory bench.'

Insights into graduate training from a survey of postdoctoral researchers

We asked the postdoctoral researchers to identify one of several scenarios in writing scientific manuscripts that they might have encountered during their graduate training – informal training by their thesis advisor; a mandatory course/workshop; and an optional course/workshop. They could also choose from options that entailed combinations of these training activities (Table 1).

Among the postdoctoral researchers who responded to our survey, 54% had received only informal mentoring from their thesis advisor, 8% had participated in a mandatory or optional course/workshop, 21% had received two

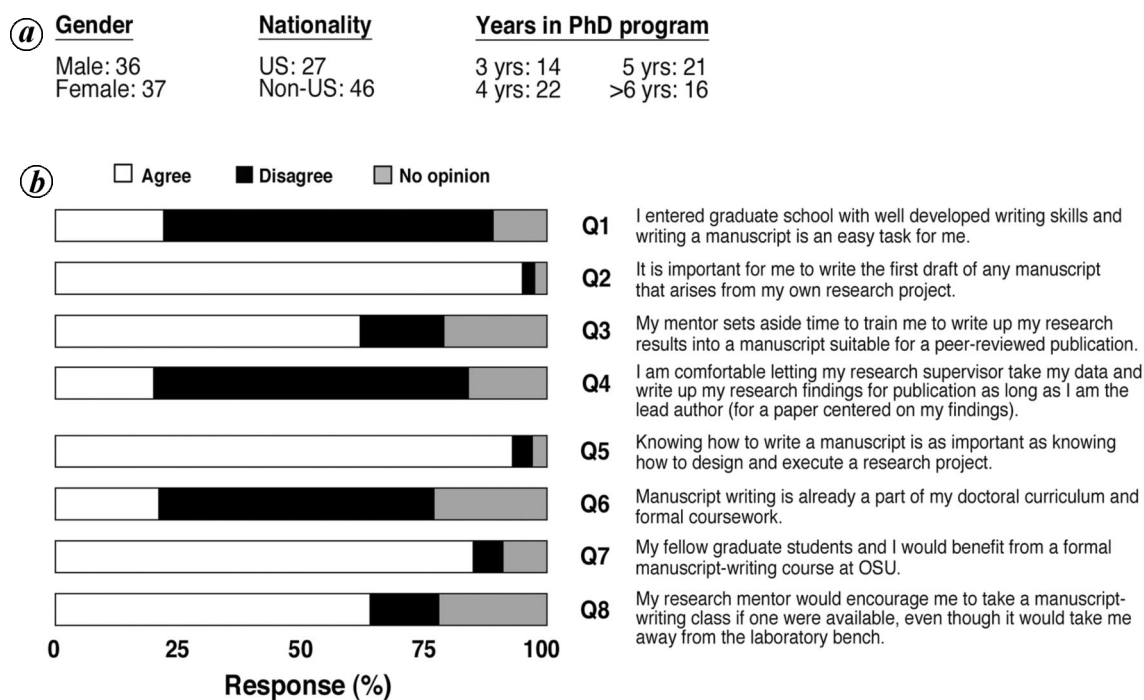


Figure 1. Results from the survey of graduate students. *a*, Demographics of students ($n = 73$), including gender, nationality and years in PhD programme. *b*, Summary of responses from graduate students. While the survey provided ‘Strongly agree’ and ‘Agree’ as possible responses, the two have been merged here into one header for the sake of simplicity. Likewise for the ‘Disagree’ option.

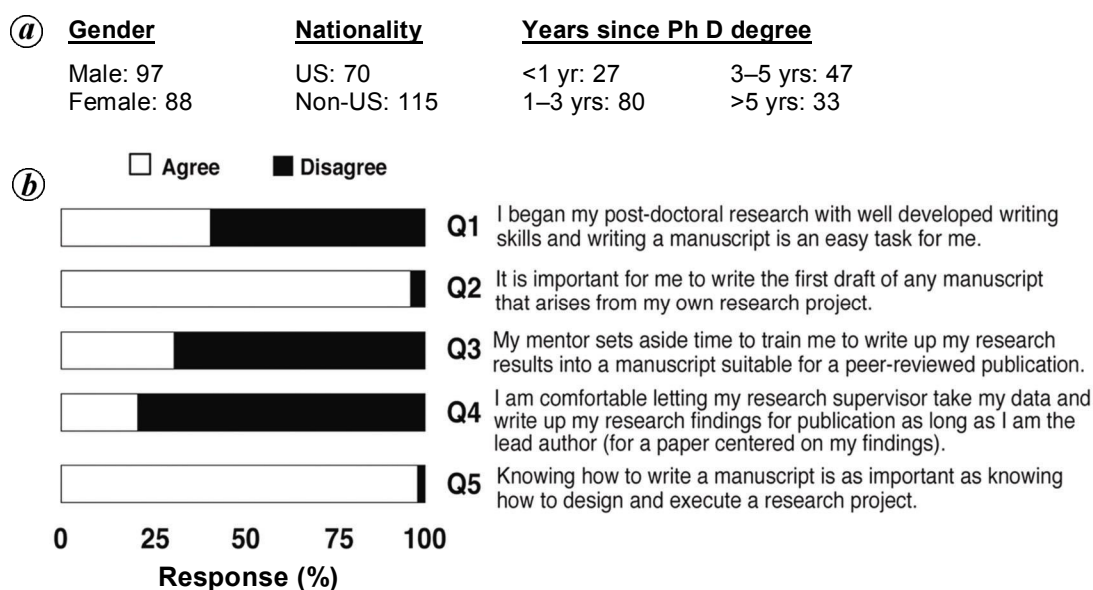


Figure 2. Results from the survey of postdoctoral researchers. *a*, Demographics of postdoctoral researchers ($n = 185$), including gender, nationality and years since obtaining the Ph D degree. *b*, Summary of responses from postdoctoral researchers.

types of training, a very small percentage – a mere 5% – had received all three kinds of training, and 12% had received no training at all. We note that 13% of all respondents had no access to any writing workshop or course during their graduate education. Furthermore, it did not matter whether they had been in graduate school within

or outside the US, and only 15% of respondents indicated that they had been required to take a mandatory formal course or workshop on writing scientific manuscripts.

Irrespective of the kind of training in scientific writing that the postdoctoral researchers had received during their graduate education, 59% of the respondents indicated that

Table 1. Analysis of results from the survey of postdoctoral researchers ($n = 185$). **a**, Distribution of postdoctoral researchers based on the nationality and location of Ph D granting institution. **b**, Further classification of respondents in (**a**) based on different types of training in scientific writing they obtained during graduate education: I – Informal mentoring by Ph D advisor only; M – Mandatory course/workshop only; O – Optional course/workshop only; All – I + M + O. The filled circle (●) and square (■) indicate those who chose ‘Yes’ and ‘No’ responses respectively, for the question pertaining to well-developed writing skills (Figure 2, Q1)

a Q1 (from Figure 2) – I began my post-doctoral research with well-developed writing skills and writing a scientific manuscript is easy for me		Yes	No
		●	■
US citizens with Ph Ds from US graduate schools		34	34
US citizens with Ph Ds from non-US graduate schools		0	2
Non-US citizens with Ph Ds from US graduate schools		13	27
Non-US citizens with Ph Ds from non-US graduate schools		28	47
Total		75	110

Category of postdoctoral researcher	Different types of training							None	Total
	I	M	O	I + M	I + O	M + O	All		
US citizens with Ph Ds from US graduate schools ($n = 68$)									
●	21	–	–	5	3	–	1	4	34
■	20	–	3	1	8	–	–	2	34
US citizens with Ph Ds from non-US graduate schools ($n = 2$)									
●	–	–	–	–	–	–	–	–	0
■	–	–	1	–	1	–	–	–	2
Non-US citizens with Ph Ds from US graduate schools ($n = 40$)									
●	6	1	–	2	3	–	1	–	13
■	11	–	3	2	5	–	3	3	27
Non-US citizens with Ph Ds from non-US graduate schools ($n = 75$)									
●	15	1	–	3	2	–	4	3	28
■	26	2	4	1	3	–	1	10	47
Total	99	4	11	14	25	0	10	22	185

they still lacked necessary writing skills when they began their postdoctoral career. This response rate was unexpected given that ~80% had received some informal training from their Ph D mentors in the preparation of scientific manuscripts. Failure to uncover correlative relationships in our data might stem from various reasons, which were not directly assessed in our surveys. First, exposure to long-term pedagogical approaches to writing in English might have better prepared some of them for writing scientific manuscripts. Indeed, among those who received a Ph D from a graduate school in the US, 50% of the US citizens surveyed expressed preparedness for scientific writing compared to 30% of the respondents from other countries. Second, training from mentors and or courses/workshops is likely to be variable. Lastly, co-authoring multiple papers possibly resulted in reinforcement of writing skills for a select few. However, the overall message is clear: graduate-level training in scientific writing is inadequate.

Moving forward

Our surveys reveal that most trainees recognize that they lack some of the skills required to write an acceptable

scientific manuscript. It is beyond the scope of this article to discuss the extensive research on either the pedagogical practices that doctoral supervisors must embrace or the best strategies for doctoral students to learn disciplinary writing. We merely emphasize that results from our surveys indicate that students are motivated to enhance their writing skills via one-on-one guidance from their research mentors and to supplement that informal training with participation in a formal writing programme, a central finding that mirrors commentaries based on interviews with students and advisors^{7,8}. Informal training by mentors is a labour of love, undertaken by conscientious, caring and patient advisors who believe that teaching students to write is just as important as teaching them to do research. However, this informal training and intimate dialogue does not ensure uniform outcomes, as can be inferred from our surveys – perhaps, this outcome is not unexpected since supervisors do not have formal training in how to teach scientific writing to their apprentices^{6,8}. It is clear then that a formal manuscript-writing programme with common standards should be an essential component of any graduate curriculum. Such a recommendation was advocated nearly five decades ago when a committee led by Woodford examined initiatives to improve the standard

of scientific writing in the US⁹. As a result, the Council of Biology Editors published a book entitled *Scientific Writing for Graduate Students: A Manual on the Teaching of Scientific Writing*. Several universities used this book in the 1970s, either in an extended 15-week course or an abbreviated 5-day workshop format⁹. Given our survey results, such courses built around the preparation of a research article need to be resuscitated and modified to meet the new challenges and opportunities associated with the growth of the internet and multimedia publishing platforms/services.

Scientific writing is a skill that can be taught just as critical reasoning and the design of experiments can be taught. In fact, this reasoning is the basis for courses on writing that are currently offered (Box 2). We share some personal experiences while teaching a course entitled 'How to write a scientific manuscript in the biomedical sciences' at the University of New Mexico (UNM) by one of us (R.H.G.). The one-semester course at UNM consists of 14 two-hour weekly sessions. The only prerequisite for participation is that each student must bring to the first session three or more tables and figures that contain high-quality informative data that have been generated by the student's own efforts. The expectation is that by the end of the course every student will have a draft of a manuscript suitable for submission to a respected journal. The curriculum focuses on the structure and organization of a scientific paper, and the content of each part (abstract, introduction, materials and methods, results, discussion, etc.). Trainees quickly recognize that while rhetorical devices and elegant diction are important, the highest priority is constructing compelling scientific arguments to present and interpret key findings. The course includes advice about streamlining the process of writing, such as when and where to write and even how long to write at a single sitting.

Feedback from participants in the above-described course and workshops emphasized their appreciation of the highly interactive nature of each session. All participants benefited from reading aloud the materials that they had worked on since the previous session and appreciated the constructive evaluation and criticism that they received. They learned not only how to improve their own manuscripts but also how to offer criticism and advice to colleagues in a constructive and sensitive manner. They also learned that initial drafts can always be improved by input from peers and colleagues. In fact, such open discussions have been advocated as effective mechanisms for students to receive feedback in a (non-intimidating) working group setting and improve their writing skills⁸.

The syllabus for the course at UNM is available on the internet¹⁰, and several excellent books, e-books and articles on scientific writing are also available^{1,4,11-13}. A new instructor and his/her trainees will undoubtedly benefit from these books and articles that distill the advice for

the writing process, including strategies that take into account the reader's expectations. However, given the explosion of the internet and multimedia-driven web technologies that are driving changes in the nature of scientific publishing from the traditional model, new multi-literacy training paradigms need to be incorporated into these scientific writing courses and workshops to address such ongoing changes. All scientific publications in the near future will likely include audio-visual narratives (e.g. 'PaperFlicks', Cell Press), interactive features, videos and animations. Moreover, given the large datasets resulting from 'omics' and systems biology approaches, best practices in statistical analyses and visualization/reporting also merit inclusion. Trainees should be made aware of several internet resources that could serve as supplementary guides. For example, tools like Scientific Writing Assistant (SWAN)¹⁴ help writers improve their manuscripts by providing feedback that makes the text more reader-friendly; similarly, the Academic Phrasebank (<http://www.phrasebank.manchester.ac.uk/>) offers a catalogue of phrases with contextual examples to help the writer choose a phrase, which with some adaptation will best convey his/her scientific argument.

Rising concerns and additional initiatives

While some graduate curricula in the sciences include formal training in writing and publishing a scientific paper, the absence of such training has unintended but avoidable consequences. When a student's writing skills are inadequate, his/her mentor might be forced to write an entire manuscript or to spend considerable time correcting the student's draft. Collaborative projects are gradually becoming the norm, and they result in predominantly multi-author publications where the actual writing contributions of individual graduate and postdoctoral researchers are not always clear. There is also increasing use of commercial correcting or editing services, some offered or endorsed by reputed journals. In all these cases, where the student ends up as the first author (or a co-author) on a paper, the student may have learned little about writing a paper and more importantly, lost a vital opportunity to establish his/her identity in a discipline. Equally troubling are the ethical issues, whose significance cannot be understated in an increasingly competitive environment where hiring and funding decisions are coupled to authorships in papers¹⁵. To address these issues and to ensure that students embrace uniform standards of scholarship, we offer the following proposals.

Occasionally, some students include in their thesis without proper attribution the entire text of manuscripts written, at least in part, by their mentors, co-workers and/or professional editors. In this regard, the Scandinavian thesis model warrants attention (http://www.globalstudies.gu.se/english/education_student/third_cycle-postgraduate_studies/

[about-the-doctoral-thesis/](#)). In Scandinavia, one form of the doctoral thesis is built around a core of published articles, accompanied by an introduction and concluding remarks that are written by the candidate. The published articles, clearly distinguishable from the candidate's personal contribution to the compilation thesis, may have benefited from inputs from the student's advisor, colleagues and peers. The introduction and concluding remarks are, by contrast, exclusively the student's own work. They reflect the student's grasp of the field and of the relevance of the experimental results, as well as his/her writing skills. Such an approach offers a mechanism for evaluating the student's independent writing skills and the ability to place the thesis in a broader context.

The curricula of doctoral programmes should include a multi-phase approach that is integrated into different stages of graduate training. At enrollment or registration, all graduate students should be required either to participate in a discussion of, or watch, a video about the definition and ramifications of misconduct (e.g. plagiarism) and the consequences of academic dishonesty (e.g. <http://ori.hhs.gov/thelab>; http://ccnmtl.columbia.edu/projects/rcr/rcr_authorship/). In years 2 or 3, graduate students who have generated sufficient data for a paper should enroll in a manuscript writing course that also "examines the roles of writing and discourse in the production of knowledge, research identity, and disciplinarity"⁷. If teaching resources are limited, graduate programmes should at least consider taking advantage of on-line courses that teach the principles of good scientific writing (<https://www.coursera.org/course/sciwrite>). We realize that disciplinary writing requires additional training (see below), but at least basic writing skills can be developed through participation in such on-line courses.

"Academic disciplines are complex communities with contested terrain, competing theories, historical rifts, methodological rivalries, and hostile factions."⁸ This perspective exemplifies the unique task of the supervisor in preparing trainees for scholarly discourse in a specific discipline. Such tacit expectations of the doctoral advisors in imparting specialized training can be met only if universities strive to develop the pedagogical repertoire of their faculty¹⁶, a goal that might be accomplished effectively through structured writing retreats¹⁷. Until such formal preparation becomes the norm, the educational trajectories of doctoral trainees should include mechanisms that promote disciplinary writing and researcher identity. For example, new opportunities such as the 'Journal Club' articles in the *Journal of Neuroscience* deserve serious consideration (http://www.jneurosci.org/site/misc/ifa_features.xhtml). These submissions are meant to encourage group efforts by Ph D students and postdoctoral researchers, wherein they present a scholarly, well-reasoned review of a recent article in the *Journal of Neuroscience*. Alternatively, many graduate programmes

now include a grant-writing exercise. The ability to express conceptual or technological innovations while providing a historical context of the field is indeed a rite of passage for an independent scientist, and affords an intellectual identity. From the above palette of options (or similar ideas), each graduate programme should draw a list of degree requirements that make writing a key element in doctoral education.

Envoi

When participants collaborate in writing a manuscript during a course or workshop, they overcome their fear of the review process and learn to appreciate the fact that even an experienced writer, such as the teacher of their course, can have trouble finding an appropriate word or phrase. Early exposure to constructive peer review fosters recognition of the fact that initial drafts of a paper are almost always subject to copious revisions prior to submission. Students will also learn to view comments by a journal's reviewers not merely as criticism, but as opportunities to improve their work. Thus, with appropriate training, young scientists can begin to view the writing, submission and revision of a manuscript as a straightforward exercise and not an insurmountable hurdle.

1. Whitesides, G. M., Whitesides' group: writing a paper. *Adv. Mater.*, 2004, **16**, 1375–1377.
2. Woodford, F. P., Sounder thinking through clearer writing. A graduate course on scientific writing can, if appropriately designed, strengthen scientific thinking. *Science*, 1967, **156**, 743–745.
3. Committee on Graduate Training in Scientific Writing of the Council of Biology Editors. *Scientific Writing for Graduate Students; A Manual on the Teaching of Scientific Writing* (ed. Woodford, F. P.), Rockefeller University Press, New York, 1968.
4. O'Connor, M. *et al.*, *Writing Scientific Papers in English: An ELSE-Ciba Foundation Guide for Authors*, Elsevier, North Holland, 1975.
5. Galipeau, J. *et al.*, Systematic review of the effectiveness of training programs in writing for scholarly publication, journal editing, and manuscript peer review (protocol). *Syst. Rev.*, 2013, **2**, 41.
6. Maher, M. A., Feldon, D. F., Timmerman, B. E. and Chao, J., Faculty perceptions of common challenges encountered by novice doctoral writers. *High. Educ. Res. Dev.*, 2014, **33**, 699–711.
7. Starke-Meyerring, D., The paradox of writing in doctoral education: student experiences. In *Supporting the Doctoral Process: Research-based Strategies for Doctoral Students, Supervisors and Administrators* (eds McAlpine, L. and Amundsen, C.), Springer, New York, 2011, pp. 75–95.
8. Paré, A., Speaking of writing: supervisory feedback and the dissertation. In *Supporting the Doctoral Process: Research-based Strategies for Doctoral Students, Supervisors and Administrators* (eds McAlpine, L. and Amundsen, C.), Springer, New York, 2011, pp. 59–74.
9. Woodford, F. P., Experiences in teaching scientific writing in the USA. *J. Biol. Edu.*, 1972, **6**, 9–12.
10. Glew, R. H. *et al.*, How to write a manuscript in the biomedical sciences. University of New Mexico, USA, 2009; <https://repository.unm.edu/handle/1928/9953>

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11. Gopen, G. D. and Swan, J. A., The science of scientific writing. *Am. Sci.*, 1990, **78**, 550–558.
12. Zeiger, M., *Essentials of Writing Biomedical Research Papers*, McGraw-Hill, Health Professions Division, New York, 2000.
13. Kallestinova, E. D., How to write your first research paper. *Yale J. Biol. Med.*, 2011, **84**, 181–190.
14. Kinnunen, T., Leisma, H., Machunik, M., Kakkonen, T. and Lebrun, J., SWAN – Scientific Writing AssistaNt: a tool for helping scholars to write reader-friendly manuscripts. In Proceedings of the EACL 2012, 13th Conference of the European Chapter of the Association for Computational Linguistics, Avignon, France, 2012, pp. 20–24.
15. Lozano, G. A., Ethics of using language editing services in an era of digital communication and heavily multi-authored papers. *Sci. Eng. Ethics*, 2014, **20**, 363–377.
16. Cotterall, S., Doctoral students writing: where is the pedagogy? *Teach. High. Edu.*, 2011, **16**, 413–425.
17. MacLeod, I., Steckley, L. and Murray, R., Time is not enough: promoting strategic engagement with writing for publication. *Stud. High. Educ.*, 2012, **37**, 641–654.

ACKNOWLEDGEMENTS. We thank Dr Ann Körner Altman for advice and manuscript editing; Dr Lien B. Lai [Ohio State University (OSU), USA] for critical comments and valuable insights; Dr Edward J. Behrman (OSU) for useful discussions; Dr Erin Dolan (University of Texas, Austin, USA) for bringing to our attention research publications pertaining to discipline-specific writing. We thank the doctoral students at OSU and postdoctoral researchers across the US who enthusiastically participated in the survey. We thank the directors of various graduate programmes at OSU (Drs Charles Bell and Ralf Bundschuh, Biophysics; Dr David Bisaro, Molecular Cellular and Developmental Biology Program; Dr Jill Rafael-Fortney, Ohio State Biochemistry Program) for their interest and kind consent to the survey. We also thank Dr Philip Clifford (previously at Medical College of Wisconsin, USA) and moderators of the National Postdoctoral Association (NPA) discussion forums for their efforts to enhance survey participation.

Received 5 August 2014; accepted 14 August 2014
