The Scientific Workforce Policy Debate: Do We Produce too Many Biomedical Trainees?

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The number of trainees that the biomedical research enterprise produces currently far exceeds the number of academic PI positions available. Although calls for increased funding of research are routine, relatively few in the scientific community have asked the question, “Are we producing too many trainees?” Here, I review current thinking on this issue in the literature and summarize the arguments for both the “yes” and “no” sides. Some have argued that the surplus of trainees acts as a deterrent for talented individuals considering a career in research, and that radical structural reforms to the current system are needed to uncouple “training” and “work”. Others have countered that competition is an essential feature of the biomedical research engine, and that the solution lies in legitimizing non-academic “alternative” career paths for scientists. This is a debate that requires the scientific community to re-examine fundamental questions regarding the nature of PhD and postdoctoral training.
Figure 1 | Current biomedical science career “bottleneck.” Overproduction of trainees is currently an inherent structural feature of the research enterprise. The number of trainees accepted into the pipeline responds to signals from government funding agencies, which create “demand” for personnel by funding PIs’ research grants. This number far exceeds the number of academic PI positions available and is unconnected to the demand for PhDs in the external labour market. As trainees travel along the pipeline, they produce research at low cost. Most trainees voluntarily or involuntarily exit the pipeline to resume their careers in a different discipline either after their PhD or after a “holding pattern” of postdoctoral studies. All of the stakeholders (individual PIs, universities, funding agencies, and the public) have an incentive to maintain this system because they all benefit from the large pool of inexpensive labour it provides.

Do we produce too many biomedical trainees? Yes — the surplus acts as a powerful deterrent to talented individuals considering a career in research. Radical structural reforms to the system are needed.

Current structure of the biomedical research engine. The large number of biomedical trainees is an inescapable feature of how the research enterprise is currently structured. Research is an industry that is unusual in that the production of trainees (graduate students and postdocs) and the generation so that it now exceeds the number of postdocs that are U.S. citizens (Garrison et al., 2005).

Although calls from the scientific community for increased funding of research are common, relatively few have asked the question, “Are we producing too many scientists?” (Collins, 2007; Cottingham, 2002; Indentured, 2007; Martinson, 2007; Olds, 2001; Perutz, 1999). Here, I review current thinking on this issue in the literature and summarize the arguments for both the “yes” and “no” sides in “point-counterpoint” format.
of product (science) are inextricably linked. As a consequence, increases in scientific output are heavily reliant on increasing the flux of trainees through the system regardless of whether jobs exist for them in the external labour market (Juliano and Oxford, 2001; Listening, 2001; Marincola and Solomon, 1998a; Massey and Goldman, 1995; Perutz, 1999; Stockpiling, 1999).

Because the majority of trainees are supported by PIs' research grants rather than individually-awarded scholarships or fellowships (Canadian Association for Graduate Studies, 2001; Garrison and McGuire, 2007; Singer, 2004), increasing public funding for research has a perverse secondary effect of creating a “false” demand for trainees — “false” in that it is strictly internal to research labs and has no connection to the external economy.

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Negative consequences of the scientist surplus. The inevitable consequence of a trainee surplus is degradation in the quality of compensation, working conditions and training. The scientific community has produced a vast quantity of literature in the last decade lamenting the situation of postdocs: their low pay, arduous working...
conditions, limited prospects for professional development, and entrapment in a "holding pattern" of short-term contracts.

Paradoxically, while research aims to recruit rational individuals, research may not be a rational career choice.

while they search for an academic position (Davis, 2005; Dilion, 2003; Gannon, 2005b; Kreeger, 2004; Ledford, 2007; Mason, 2004; National Academy of Sciences, 1995, 2000; National Research Council, 2005; Nerad and Cerny, 1999; Postdoctoral, 2002; Pulling, 2006; Russo, 2003; Singer, 2004; The Role, 2003; Value, 2001; Young, 1998). Although progress has been made in improving wages and working conditions (Aschwanden, 2006; Pulling, 2006), the scarcity of academic positions remains a cold reality. Some are skeptical of whether the "alternative" careers that these individuals eventually find truly require their advanced research skills (Breithaupt, 2004; Juliano, 2003; Juliano and Oxford, 2001; Marincola and Solomon, 1998a; National Research Council, 1999). Excessive competition caused by a scientist surplus also has negative effects on research in general: low morale and scientific conservatism due to falling success rates for funding grants and fellowships (Couzin and Miller, 2007; Giles and Wadman, 2006; Martinson, 2007; Mervis, 2004; Nurse, 2006; Zerhouni, 2006); secrecy and unwillingness to talk openly about data (Pearson, 2003; Walsh and Hong, 2003); and in some cases, unethical behaviour (Breitling, 2005; Martinson et al., 2005). Furthermore, intense competition necessitates maximum productivity at all times during a scientific career — an imperative that is often incompatible with child-care responsibilities requiring a leave of absence or reduction in working hours (Gannon, 2005a; Gewin, 2005). The loss of competitiveness incurred by women, whose childbearing years coincide with the critical postdoc-to-PI transition period, is a major factor contributing to female underrepresentation in the upper ranks of academia (Ledin et al., 2007).

The current system risks repelling the "best and brightest": Science, like any other profession, attempts to attract the "best and brightest" of every cohort. The danger of the current system is that talented but well-informed individuals will recognize the disincentives associated with a career in research and opt for a different occupation (Freeman, 2004; Freeman et al., 2001; Gannon, 2002a; Gerbi et al., 2001; Indentured, 2007; Juliano and Oxford, 2001; Marincola and Solomon, 1998a; Moore, 1998; National Research Council, 1998, 2005). Other education-intensive disciplines like medicine and law present chances of employment as a doctor or lawyer that are considerably higher than 20% and offer significantly higher lifetime earnings compared to research (Freeman et al., 2001; Parker, 2002). Paradoxically, while research aims to recruit rational individuals, research may not be a rational career choice (Davis, 2005; Gerbi et al., 2001).

Radical structural reforms are needed.

Bringing the present system into equilibrium requires that the scientific workforce
be “professionalized” just like any other workforce — in short, training and work must be uncoupled (Gerbi et al., 2001; Juliano and Oxford, 2001; Marincola and Solomon, 1998a, b). The total number of graduate students and postdocs should be drastically reduced, leaving an elite group of truly talented individuals to travel down the career pipeline (Figure 2). The current funding system should be altered such that these trainees are largely or exclusively supported via portable scholarships and fellowships awarded to individual trainees instead of PIs’ research grants — this would unambiguously define the supervisor-trainee relationship as one of “master-apprentice” rather than “employer-employee” (Freeman et al., 2001; Juliano and Oxford, 2001; National Research Council, 1998). In the absence of numerous trainees, the bulk of the “work” of research would be performed by permanent employees with pay and benefits commensurate with their age and experience —

**Figure 2** | Proposed structure of a reformed biomedical science career pipeline that uncouples training and work. A smaller number of elite trainees travels down the career pipeline, supported largely or exclusively via portable scholarships and fellowships instead of PIs’ research grants. Most of the “work” of research is performed by a professional workforce of permanent employees — technicians with a BSc or MSc, and “staff scientists” with a PhD or postdoctoral experience. Most trainees reach the end of the pipeline and become an academic PI. The cost of producing scientific research is increased, in exchange for higher-quality training for trainees and improved conditions for the entire scientific workforce.
technicians with a BSc or MSc, and “staff scientists” with a PhD or postdoctoral experience (Freeman et al., 2001; Gerbi et al., 2001; Juliano and Oxford, 2001; Marincola and Solomon, 1998a; National Research Council, 1998). The latter would provide a badly-needed career niche to talented postdocs who would prefer to continue using their skill at the bench instead of moving into positions focused upon management and grant-writing that the current “up or out” system offers (Breithaupt, 2004; Freeman et al., 2001; Gerbi et al., 2001; Juliano and Oxford, 2001; Korn, 2004; Moore, 2004; Value, 2001).

Summary. These systems reforms will be painful in the short term, as reliance upon a professional workforce to advance scientific knowledge will necessarily be more expensive than extracting cheap labour from an army of trainees. Nevertheless, such changes are the only way to reach a steady-state condition that ensures the long-term health of the research enterprise.

Do we produce too many biomedical trainees? No—competition is an essential feature of the research engine. The solution lies in legitimizing non-academic “alternative” career paths and adjusting training accordingly.

Competition is a key feature of the research engine. Although a lower proportion of PhDs now follow the traditional student-postdoc-PI career path, limiting the number of trainees is a misguided reaction that fails to recognize that competition is an essential feature of the research enterprise. Research fits a model known among economists as a “tournament” structure (Freeman et al., 2001). In the biomedical career tournament, the “prize” to which entrants aspire is prestige and/or reward for
important contributions to their field and (for some) a tenure-track position as an academic PI. Competition is stimulated in this system by mechanisms that magnify small differences in output into large differences in reward or penalty (Freeman et al., 2001). For example, completing a 5-year series of experiments 1 week earlier than a competitor can make the difference between a career-launching paper in a prestigious journal and no paper. There are two critical features of the tournament structure. Firstly, it generates a high degree of productivity from all entrants and is thus a very efficient way of producing biomedical research (Freeman et al., 2001). The public is overwhelmingly the main funder of biomedical research and this system provides the maximum return for its tax-dollar investment (Indentured, 2007). Secondly, the Darwinian selection process ensures that the most successful individuals in the tournament who become independent PIs are the most talented and hard-working candidates available (Benderly, 2005).

**Academic PI is just one of many legitimate career paths.** The assertion that too many trainees are being produced rests on the premise that replication of the academic PI is the only “successful” outcome of training. The solution lies in recognizing the merit of “alternative” career paths (Bogan and Bogan, 1998; Gannon, 2002a; Kerr, 1995; Mainstreaming, 2006; National Academy of Sciences, 1995; National Research Council, 1998; Nyquist and Woodford, 2000; Olds, 2001; Pulling, 2006; Stockpiling, 1999). In 2002, scientific funding agencies from around the world (including Canada) collectively put forward a new paradigm for training in the biomedical sciences that aimed to replace the traditional model of the career pipeline with that of a branching tree (Krotosky et al., 2002; Wiesel and Banda, 2002) (Figure 3). The arms of the tree represent different academic and non-academic careers that are all of inherently equal value. Although the legitimization of such non-traditional career paths requires overcoming a phenomenon that has been dubbed the “passion of mentors to clone themselves professionally” (Kerr, 1995), the more widespread dispersal of scientists into other sectors of the economy can only be beneficial to society (Adams, 2004).

**Training should be adjusted to better reflect eventual employment.** Rather than limiting enrolment, we should modify the nature of PhD and postdoctoral training to reflect the realities of the job market (Alvarez, 2007a, b; Demers and Desai, 2002; Indentured, 2007; Kerr, 1995; Listening, 2001; National Research Council, 1998; Nicolas, 2008; Nyquist and Woodford, 2000; Stockpiling, 1999). Essentially, a strict focus on research skills is no longer appropriate and training should be widened to include topics such as project management, leadership, teaching, proposal writing, and exposure to ... a strict focus on research skills is no longer appropriate and training should be widened to include topics such as project management, leadership, teaching, proposal writing, and exposure to non-academic career paths.
non-academic career paths. There is some debate as to whether this additional training should be incorporated as an integral component of the curriculum (Andreson, 2006; Mainstreaming, 2006; National Academy of Sciences, 1995), or whether it should be made available on an optional basis so as not to dilute the intensive research experience for those destined to become PIs (Gannon, 2006, 2007; National Research Council, 1998). Ultimately, trainees must take responsibility for their own careers by acquiring a realistic understanding of their post-PhD employment options and expanding their skill set accordingly (Benderly, 2005; National Academy of Sciences, 1995; National Research Council, 1998).

Albeit the current system may appear non-ideal from the perspective of trainees, they may simply be receiving a return that is proportional to the size of the economic investment they make in their training.

Imposing artificial constraints on trainee numbers is dangerous and unnecessary. Because future labour-market demand for scientific workers is famously hard to predict (Garrison and Gerbi, 1998; Mervis, 2003), arbitrary limits on the number of PhDs could lead to a shortage that would cause serious damage to a knowledge-based economy (Canadian Association for Graduate Studies, 2001; Industry Canada, 2002, 2007; National Academy of Sciences, 2005; National Science Foundation, 2003). The permanent employees required to replace lost trainees would also incur higher costs (Marincola and Solomon, 1998a), leading to a decline in total research output per dollar invested. Furthermore, despite profuse “hand wringing” in the scientific community regarding the plight of biomedical postdocs, PhD-level workers enjoy considerably higher salaries and lower unemployment rates than the general population (McKenzie, 2007). Studies consistently show that life scientists from all employment sectors report high levels of job satisfaction (Austin, 2006; Holden, 2001, 2004). As one might expect, intellectual fulfillment is more important to many scientists than monetary reward (Marincola and Solomon, 1998a). Finally, there is no reason to presume that outside intervention is required to stabilize the number of trainees at an equilibrium level (National Academy of Sciences, 1995; National Research Council, 1998; Olds, 2001). If pursuing a career in research were truly an unattractive option, we would observe a decrease in the number of entrants and a self-correcting increase in wages and benefits. The fact that this career path remains popular may imply that research satisfies a deep human need for intellectual autonomy and discovery that supercedes cold economic calculations.

Summary. Thus, it is not the number of biomedical trainees that must be changed, but the nature of the training they receive. Restricting the number of people pursuing a career in research could damage a system
that is a resounding success as evidenced by the rapid expansion of scientific knowledge and resulting gains in human health.

Discussion
Faced with a system that provides intensive training for an occupation that only 20% of postdocs will eventually adopt, the two positions argued above outline different plans of action. The first position advocates a radical restructuring of the training system to reduce the number of trainees, while the second position retains the basic structure of the current system but advocates expansion of the scope of training beyond research skills. While leaving the reader to judge the relative merit of their arguments, several general observations can be made.

Perhaps the current system requires no reform. Inherent in both of the viewpoints argued above is the assumption that the current system requires reform. However, one might suggest a third possibility: the system is fine, and no action is needed. In reviewing the literature on a topic such as this, it is difficult to exclude the possibility that only a disgruntled minority is investing the effort to write about their dissatisfaction with the status quo — the silent majority may believe that the current system is perfectly acceptable. Certainly, the disconnect between the number of trainees and the number of academic PI positions has been written about for over a decade without any substantive action being taken to address it. Meanwhile, PhDs and postdocs exiting the pipeline have found employment, even if not as a PI as they had originally envisioned. In addition, the intake of new trainees has remained stable or increased, suggesting that new entrants are either unaware of the concerns associated with the current system, or have judged them to be outweighed by the positive aspects of pursuing a career in research. Whether the pool of new trainees, although stable in number, is depleted for the “best and brightest” — who may be choosing other disciplines — is unknown. In any event, a skeptic might argue that there is in fact little evidence that the current training system is in crisis.

The interests of trainees must be weighed against the interests of society. An underlying theme in the arguments presented above is the fundamental tension between the interests of trainees and the interests of society at large. The goal of society is to have the biomedical research engine drive advances in technology and medicine that enhance the quality of life of all its citizens, by producing the maximum amount of scientific knowledge for the lowest cost. In a purely utilitarian sense, society's strategy should be to improve the situation of biomedical trainees by the minimum amount required to retain and attract talented individuals (and thus keep productivity high). However, there currently appears to be no shortage of new trainees eager to work long hours in Darwinian competition with their peers, for low pay and a 20% chance of becoming a PI — consequently, society has little rationale for altering the existing system. On the other hand, the goal of trainees is to obtain training that maximizes their chance of securing a position in their desired occupation, and to minimize the amount of time and expense required. Although the present system may seem non-ideal from the perspective of trainees, they may simply
be receiving a return that is proportional to the size of the economic investment they make in their training. In this respect, it is informative to compare science with other disciplines with an extended training period, like law and medicine. Trainees in these fields incur a net loss of tens of thousands of dollars during their training program, in exchange for high rates of employment as a doctor or lawyer upon completion. In contrast, graduate students and postdocs receive a net financial gain due to a modest stipend during their training, in exchange for a 20% chance at becoming an academic PI (and considerably lower earning potential than a doctor or lawyer if they succeed).

Outlook
Answering the question of whether we are producing too many trainees ultimately requires us to address even more fundamental questions. Is the purpose of PhD training to select and cultivate the most promising future PI candidates or to provide a foundation for multiple career paths? Is the goal of the system to create science or scientists? If the current system is flawed, why does the intake of new trainees remain robust? How can we strike a balance between the interests of the trainee and the interests of society? The arguments presented herein represent the starting point for a discussion that we, in the scientific community, should energetically undertake — one that is arguably long overdue.

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