Title: Transdisciplinary doctoral training to address global sustainability challenges

Authors: Zoie Diana,[1,2,3] John Virdin,[4] Michelle Nowlin,[5] Nishad Jayasundara,[3,6] Daniel Rittschof [2,3, 7,8]

1. University of Toronto, Department of Ecology and Evolutionary Biology, Toronto, Ontario, Canada
2. Duke University, Division of Marine Science and Conservation, Nicholas School of the Environment, Duke University Marine Laboratory, Duke University, Beaufort, North Carolina, USA
3. Integrated Toxicology and Environmental Health, Nicholas School of the Environment, Duke University, Durham, North Carolina, United States
4. Nicholas Institute for Energy, Environment & Sustainability, Duke University, Durham, North Carolina, United States
5. Duke University School of Law, Durham, North Carolina, United States
6. Nicholas School of the Environment, Duke University, Durham, North Carolina, United States
7. Duke University Microbiome Center, Durham, North Carolina, United States
8. Duke University Biology, Trinity College, Durham, North Carolina, United States

Non-peer-reviewed preprint submitted to EarthArXiv

Undergoing revisions for publication in *PLOS Sustainability and Transformations*

1. Introduction

Global sustainability challenges, such as climate change and the plastics crisis, converge across disciplines and involve diverse stakeholders. Given sustainability challenges' great magnitude, problem-solvers must be trained across disciplines. The United Nations Brundtland Commission's report "Our Common Future" articulated a definition of "sustainability" in the context of development: "…development that meets the needs of the present without compromising the ability of future generations to meet their own needs" [1]. Although interdisciplinary research teams are common, doctoral training traditionally focuses on gaining depth in a discipline, undermining the transdisciplinary nature of socio-ecological systems and environmental problems in the Anthropocene [2–4].

Sustainability science connotes a sole field with shared concepts and theories; however, the National Research Council and others employ "the science of sustainability" to describe the use of multiple disciplines to address a common question, which leads toward an established field [5]. In establishing sustainability science, the National Academy of Sciences notes that scientists must engage in dialogue and conduct research for environmental practitioners, from applied research to developing theory and concepts [6].

Sustainability science conflicts with traditional doctoral training, which cabins deep research in a narrow frame. Transdisciplinary research offers an alternative. Jean Piaget defined transdisciplinary scholarship in 1970 as research that "would not only

cover interactions or reciprocities between specialized research projects but would place these relationships within a total system without any firm boundaries between disciplines," [7].

Here we propose a roadmap for transdisciplinary doctoral training in the sustainability sciences. Transdisciplinary doctoral training is necessary to produce solutions-driven sustainability research, especially given that a 2015 Elsevier report notes that sustainability science is less interdisciplinary than the global average [6,8]. While calls for transdisciplinary research have increased [9,10], few discuss a practical approach to transdisciplinary doctoral training. The roadmap proposed here may help trainees to better contribute to the community of practice (*e.g.*, policymakers, nongovernmental organizations) while furthering sustainability science. We close by discussing the outcomes of transdisciplinary doctoral training on individuals, the academy, and society.

2. A roadmap for transdisciplinary doctoral training

The roadmap proposed highlights three pillars to structure Ph.D. training: research lenses, network, and quality control (**Figure 1**). These features are not unique to a transdisciplinary Ph.D., but the content varies significantly from a discipline-bound Ph.D. We refer to the research lenses as the disciplines that probe complex environmental challenges. The network includes the individuals with whom the trainee learns, formally and informally, within and outside the university. Quality control refers to the metrics

used to ensure adequate training and fulfillment of Ph.D. requirements outside of those defined by the university.

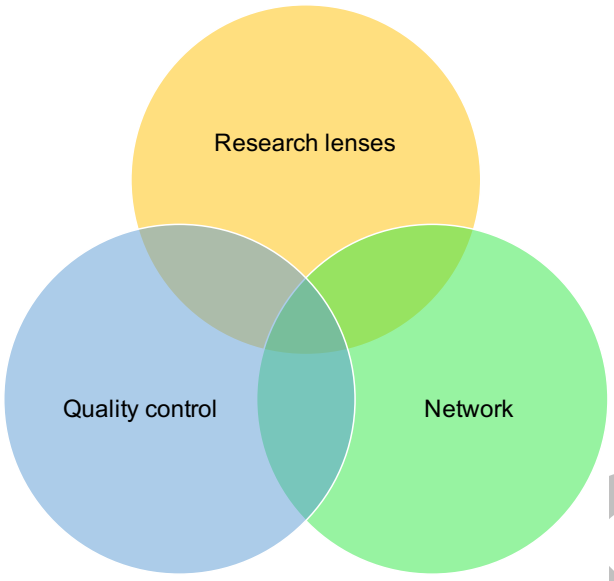

Figure 1. The pillars of transdisciplinary Ph.D. training in the sustainability sciences.

3. Discussion

3.1 Research lenses

Defining the research lenses used during the Ph.D. contributes to delineating learning and research goals. The research lenses identified vary based on the environmental problem that is the dissertation's focus. Defining the workspace enables trainees to select mentors, target coursework, and build skillsets. Initially, it may be helpful for trainees to produce a few disciplinary dissertation chapters. Synthesizing across disciplines takes fundamental knowledge and improves with experience. Including a

synthesis dissertation chapter refines transdisciplinary learning and furthers sustainability science.

3.2 Network

A cross-disciplinary network is critical. The Ph.D. committee should include members to guide the trainee in each research lens. One of the greatest challenges for transdisciplinary research is communication and respect between disciplines [2]. We suggest ensuring committee-wide interest and respect for transdisciplinary research as much as possible.

Expertise outside the academic committee is needed to ensure real-world applicability. Doctoral training should include direct research experience with practitioners engaging with the environmental problem that is the dissertation's focus. University centers may provide an avenue for this, as was the case in the author's experience with an environmental law clinic and policy center. Research with development agencies, businesses, or local organizations expands perspectives and provides organizations with academically-rigorous research.

3.3 Quality control

Most academics have not undergone transdisciplinary training, so ensuring quality may be difficult [11,12]. Quality control is the network's purview, including the doctoral committee and outside experts, which is no different in siloed Ph.D. training. The

perceived differences are due to difficulties in communication and respect across disciplines.

Although scientific publications in discipline-specific journals would be suitable for disciplinary competence, limiting outcomes to journal publications is a narrow metric. Understanding and evaluating non-traditional products (*e.g.*, policy reports, patents, transdisciplinary journal articles) is essential and may yield increased creativity in solutions-driven research [13,14]. Success metrics beyond scientific publications will broaden academia's reach and impact.

4. Outcomes

The Ph.D. is the beginning of the journey. Interdisciplinary doctorates in the United States are more likely to be non-tenure-track academics (from 2004 to 2005), obtain a postdoc, publish more articles than peers (regardless of employment sector), and identify as women [10]. Interdisciplinary scientists were more likely than disciplinary peers to create new firms, license or patent technology, co-produce research, and provide research services [13].

Incorporating non-traditional evaluation metrics (*e.g.*, Rao-Stirling diversity index, patents, social media shares) into promotion and tenure packets would aid in institutionalizing transdisciplinary research [6,14]. Due to the short-term nature of postdoctoral employment and low salary compared to the cost of living (in the U.S.) [15],

interdisciplinary[1] researchers may be dissuaded from pursuing academia [14] and pose risks to academia by losing these researchers to other sectors.

Conclusion

New funding opportunities call for transdisciplinary sustainability research. Conservation postdoctoral fellowships, such as the David H. Smith Conservation Research Fellowship and the Liber Ero Postdoctoral Fellowship, provide research experiences with practitioners. Other broad funding calls, such as the National Science Foundation's Convergence Research and Dear Colleague Letters, invite transdisciplinary research [14]. The South American Institute for Resilience and Sustainability and Accelerator at Stockholm University provide space for discipline-free encounters [6]. Transdisciplinary doctoral training equips scholars to creatively tackle the world's most urgent environmental problems [14] and will grow in necessity in the future.

Conflict of Interest

Z.T.D. is a Liber Ero Postdoctoral Fellow.

Funding

Research reported in this publication was supported by the National Institute Of Environmental Health Sciences of the National Institutes of Health under Award Number T32ES021432. The content is solely the responsibility of the authors and does not necessarily represent the official views of the National Institutes of Health.

[1] We use the term "interdisciplinary" here instead of "transdisciplinary" to reflect the language used by survey respondents in Hein et al., (2018).

Acknowledgments

Z.T.D. and D.R. would like to acknowledge the Oak Foundation for their support.

References

1. Brundtland GH. Our Common Future: Report of the World Commission on Environment and Development. Geneva; 1987.

2. Milman A, Marston JM, Godsey SE, Bolson J, Jones HP, Weiler CS. Scholarly motivations to conduct interdisciplinary climate change research. J Environ Stud Sci. 2017;7: 239–250. doi:10.1007/s13412-015-0307-z

3. Folke C, Polasky S, Rockström J, Galaz V, Westley F, Lamont M, et al. Our future in the Anthropocene biosphere. Ambio. 2021;50: 834–869. doi:10.1007/s13280-021-01544-8

4. Ostrom E. A General Framework for Analyzing Sustainability of Social-Ecological Systems. Science. 2009;325: 419–422. Available: http://www.jstor.org/stable/20536694

5. Clark WC, Dickson NM. Sustainability science: The emerging research program. Proc Natl Acad Sci USA. 2003;100: 8059–8061. doi:10.1073/pnas.1231333100

6. Paasche Ø, Österblom H. Unsustainable Science. One Earth. 2019;1: 39–42. doi:10.1016/j.oneear.2019.08.011

7. Darian-Smith E, McCarty P. Beyond Interdisciplinarity: Developing a Global Transdisciplinary Framework *. Transcience Journal. 2016;7.

8. SustainabilityScienceReport-Web.pdf. Available: https://www.elsevier.com/__data/assets/pdf_file/0018/119061/SustainabilityScienceReport-Web.pdf

9. Kiley M, Halliday DP. Candidate and supervisor experiences of doctoral study in a structured, interdisciplinary training environment. Innovations in Education and Teaching International. 2019;56: 663–674. doi:10.1080/14703297.2019.1570306

10. Millar MM. Interdisciplinary research and the early career: The effect of interdisciplinary dissertation research on career placement and publication productivity of doctoral graduates in the sciences. Research Policy. 2013;42: 1152–1164. doi:10.1016/j.respol.2013.02.004

11. Gardner SK, Jansujwicz JS, Hutchins K, Cline B, Levesque V. Socialization to interdisciplinarity: faculty and student perspectives. High Educ. 2014;67: 255–271. doi:10.1007/s10734-013-9648-2

12. Kovacic Z, Marcos-Valls A. Institutionalising interdisciplinarity in PhD training: challenging and redefining expertise in problem-oriented research. Environmental Education Research. 2023;29: 473–488. doi:10.1080/13504622.2023.2174252

13. D'Este P, Llopis O, Rentocchini F, Yegros A. The relationship between interdisciplinarity and distinct modes of university-industry interaction. Research Policy. 2019;48: 103799. doi:10.1016/j.respol.2019.05.008

14. Hein CJ, Ten Hoeve JE, Gopalakrishnan S, Livneh B, Adams HD, Marino EK, et al. Overcoming early career barriers to interdisciplinary climate change research. WIREs Climate Change. 2018;9. doi:10.1002/wcc.530

15. Sainburg T. American postdoctoral salaries do not account for growing disparities in cost of living. Research Policy. 2023;52: 104714. doi:10.1016/j.respol.2022.104714