

DAY ONE PROJECT

Forging 1,000 Venture Scientists to
Transform the Innovation Economy

Thane Campbell
Dominic Falcão

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Summary

The US innovation ecosystem is falling behind global players like China and India because our current Research and Development (R&D) landscape does not incentivize commercialization in university laboratories. The federal government should establish the Venture Science Doctorate (VSD) initiative to close this gap by training graduates to combine research and entrepreneurship in legacy sectors. The Biden-Harris Administration should support VSD to turn more metropolitan areas into innovation centers. Swifter shifts from theory to products are “crucial to our future prosperity” as a global leader¹ and as the *United States of America*, creating opportunities to mitigate rising economic inequality. Executing the VSD will require multiple agencies. The Office of Science and Technology Policy (OSTP) will coordinate the creation of demand-side policies that remove barriers to innovation in legacy sectors. The National Science Foundation (NSF) will coordinate a strategy of regional development through VSD programs, tracking their impact with state-level economic indicators. A multinational collaboration will widen access to talent and distribute US lessons in innovation policy among international regulators in the pursuit of truly global public goods. A stronger science innovation system will recover ground the US has lost to competitors and create compelling partnership opportunities for allies.

This proposal describes a scalable PhD program that brings sector-shaping technologies to market. By bridging NSF programs for scientist training (e.g. I-Corps) and company funding (e.g. Small Business Innovation Research, Small Business Technology Transfer), VSD will support the entire innovation ecosystem. By producing scientists and influencing undergraduate degree choices,² VSD will effect targeted and broad-based workforce expansion. By training graduates to create high-value manufacturing companies, job creation in this workforce and supporting sectors will soar. To do this, VSD will use mission-oriented research, complementing basic scientific research with DARPA³-like, combinations of training, R&D and commerce. These are the economic experiments our innovation system needs for growth and sustainability in legacy sectors like clean energy.⁴ But to share this prosperity we need to start with the states “left behind.”

¹ Ashish Arora et al., “The Changing Structure of American Innovation: Some Cautionary Remarks for Economic Growth,” *Innovation Policy and the Economy* 20, no. 1 (2020): 86. <http://doi.org/10.3386/w25893>

² Paul M Romer, “Should the Government Subsidize Supply or Demand in the Market for Scientists and Engineers?,” *Innovation Policy and the Economy* 1 (2000): 240–241. <https://doi.org/10.1086/ipe.1.25056146>

³ Defense Advanced Research Projects Agency

⁴ William B Bonvillian and Charles Weiss, *Technological Innovation in Legacy Sectors* (Oxford University Press, 2015): 1, <https://doi.org/10.1093/acprof:oso/9780199374519.003.0001>.

Challenge and Opportunity

University laboratories supply the scientific workforce, but they are not designed to train its entrepreneurs. Science-based entrepreneurship, unlike that based on software (e.g. 'lean start-up methodology'), depends more on forward-looking analyses of sector-scale opportunities than on customer development. Through specialized venture-building environments, hundreds of new tech stars could pour out of labs every year, giving their regions a fairer share of US innovation.

Large corporations historically provided much of the runway for US innovation. Before 1970, firms like DuPont, Xerox and AT&T prized basic research, but changing stakeholder composition and increased competition led to drastic R&D cuts.⁵ Since then, the sharpened divide between academia (research) and industry (development) has been slowing the US economy, despite increases in total spending on higher education R&D (6x),⁶ trained PhDs (2x) and research publications (7x).⁷ More product innovations now rely on acquiring inventions from universities and small firms (nearly 50% in the manufacturing sector).⁸ But market entry is not a priority for university researchers. Industry rewards the commercial utility of inventions, but academia rewards novelty – which is why academics are 23% less likely to file for a patent than industry for the same discovery.⁹ This incentives problem blocks market launch.

Manufacturing economies like China and India that are building innovation into all sectors have productivity growth rates two to three times that of the US.¹⁰ While reshoring manufacturing is necessary to rescue domestic supply chains, it is not sufficient. China is turning its trade deal revenues into innovation and productivity gains which cannot be reshored -- through massive investment in state-owned-enterprises (i.e. LinkDoc¹¹ and Jinko Solar¹²). This is why the International Trade Administration emphasizes that "[a] second essential component of a reshoring strategy is incentivizing inward investments in domestic manufacturing and R&D activities."¹³

⁵ Arora et al., "Changing Structure of American Innovation: Cautionary Remarks for Growth." 43

⁶ National Science Foundation, "National Center for Science and Engineering Statistics 2019. National Patterns of R&D Resources: 2017–18 Data Update.," *NSF 20-307* (Alexandria, VA., 2018), <https://ncses.nsf.gov/pubs/nsf20307>.

⁷ Ashish Arora, Sharon Belenzon, Andrea Patacconi and Jungkyu Suh, "Why the U.S. Innovation Ecosystem Is Slowing Down," *Harvard Business Review*, November 26, 2019, <https://hbr.org/2019/11/why-the-u-s-innovation-ecosystem-is-slowing-down>.

⁸ Ashish Arora, Sharon Belenzon, and Andrea Patacconi, "The Decline of Science in Corporate R&D," *Strategic Management Journal* 39, no. 1 (2018): 28. <https://doi.org/10.1002/smj.2693>.

⁹ Michaël Bikard, "Made in Academia: The Effect of Institutional Origin on Inventors' Attention to Science," *Organization Science* 29, no. 5 (2018): 818–36. <https://doi.org/10.1287/orsc.2018.1206>.

¹⁰ Charles Weiss and William B Bonvillian, "Complex, Established 'Legacy' Sectors: The Technology Revolutions That Do Not Happen," *Innovations: Technology, Governance, Globalization* 6, no. 2 (2011): 182. https://doi.org/10.1162/INOV_a_00075

¹¹ Catherine Sturman, "LinkDoc Receives \$151mn in Series D Funding," *Healthcare Global*, 2018, <https://www.healthcareglobal.com/medical-devices-and-pharma/linkdoc-receives-dollar151mn-series-d-funding>.

¹² Georgia Wilson, "Solar Module Manufacturer, Jinko Solar Co. Raises US\$458mn," *Business Chief*, 2020, <https://doi.org/http://dx.doi.org.ezproxy.is.ed.ac.uk/10.1111/etap.12095>.

¹³ Nazak Nikakhtar, "The China Challenge: Realignment of U.S. Economic Policies to Build Resiliency and Competitiveness," *For the Hearing: "The China Challenge: Realignment of U.S. Economic Policies to Build Resiliency and Competitiveness,"* (2020): 8. <https://www.commerce.senate.gov/2020/7/the-china-challenge-realignment-of-u-s-economic-policies-to-build-resiliency-and-competitiveness>

While conflicting national, industrial and institutional incentives limit our growth, competitors are gaining a strategic upper hand. As an International Trade Administration official told Congress in a hearing on the Chinese threat to American competitiveness, “China, by controlling America’s revenue stream, also controls America’s ability to earn income and fund R&D.”¹⁴ In the US, complex established legacy sectors (CELS) operate within well-defended technological, economic and political paradigms rooted in incentives, price structures, expert communities, political support, university curricula, and career paths built over decades.¹⁵ With these defences, incumbent firms and their aging technologies “resist any change that threatens their business models.”¹⁶ This results in hidden market imperfections like network dependence and non-appropriability -- wherein customers benefit more than investors -- that keep university spin-offs out of CELS. Thus, the incentives problem upstream and market imperfections downstream are major barriers to our innovation system’s productivity and scope.

CELS comprise 65% of the economy, and to foster innovation among them requires strategies that tackle market imperfections from day one.¹⁷ Universities could partner with an applied science program to dedicate scientists to CELS market launch throughout their training. But ultimately these visionary firms will need policy environments which more readily foster innovation in these sectors. Regulatory sandboxes -- spaces that allow for defined policy innovation -- should be accessible in VSD regions to remove barriers to technological testing and grant founders access to research labs. Funding, prizes and federal procurement can be used to promote truly innovative technologies to update CELS, while price structures can shift incentives around products that need to change (e.g. charging for carbon dioxide emissions).¹⁸ OSTP can coordinate these efforts and identify where the National Institute of Standards and Technology is required to produce metrics for cleaner and fairer innovation in future industries. Firms will benefit from the extension of these practices into global markets. Through multinational collaboration, the US could encourage other countries to similarly reshape their legacy sectors, learn from different approaches to CELS and engage with international science entrepreneurs keen to work in the US.¹⁹

With R&D incentivized for CELS market launch, the size of the scientific workforce becomes the long-term challenge for future innovation,²⁰ but also a potentially profound source of sustainable job creation.²¹ The science and technology (S&T) workforce is limited by the size of the cohort of S&T undergraduates. To increase the number of undergraduates, according to Paul Romer, “they must

¹⁴ Nikakhtar “Realignment of Policies to Build Competitiveness” 7.

¹⁵ Weiss and Bonvillian, “Complex, Established ‘Legacy’ Sectors,” 158.

¹⁶ Weiss and Bonvillian, “Complex, Established ‘Legacy’ Sectors,” 158.

¹⁷ Bonvillian and Weiss, *Technological Innovation in Legacy Sectors*, 2.

¹⁸ Weiss and Bonvillian, “Complex, Established ‘Legacy’ Sectors,” 164.

¹⁹ “Memo to Biden: in science, think global” Science Business, Accessed February 23, 2021. <https://sciencebusiness.net/news/memo-biden-science-think-global-survey-results>

²⁰ Claudia Dale Goldin and Lawrence F Katz, *The Race between Education and Technology* (harvard university press, 2009): 2. https://books.google.co.uk/books?id=yGICFqnakCoC&printsec=frontcover&source=gbs_ge_summary_r&cad=0#v=onepage&q=higher%20labor%20productivity&f=false

²¹ Ian Hathaway and Patrick Kallerman, “Technology Works : High-Tech Employment and Wages in the United States,” *Bay Area Council Economic Institute*, no. December (2012): 3. <http://www.bayareaeconomy.org/files/pdf/TechReport.pdf>

be convinced that this kind of degree can lead to better career outcomes than the dead-end postdoctoral positions that have become increasingly common.”²² With more appealing PhD outcomes, more categories of undergraduates are likely to pursue S&T. Furthermore, while traditional graduate programs recruit candidates high in individual achievement and academic career intentions, these are not the best indicators of potential for innovative venture development. From entrance tests to the types of graduate programs institutions cultivate, the educational system rewards individual achievement.²³ As a venture-focused graduate program, VSD needs team-orientated candidates who can enhance venture performance through interdisciplinary collaboration.²⁴ Finally, S&T graduates typically aspire to be academics: 80% of graduates view their PhD as the start of an academic career path.²⁵ Career ambitions matter because current methods of entrepreneurship training are largely ineffective in creating entrepreneurial intentions.²⁶ Recruiting more team-oriented aspiring entrepreneurs into the S&T workforce will thus stimulate the economy through the increase in companies created by these recruits. A dedicated career path would not only enhance supply to the S&T workforce, but would also transform colleges into the technology test beds CELS need.²⁷

Widening regional disparities not only constrain the S&T workforce, they spawn liveability, diversity and competitiveness crises as migrating workers flood superstar regions and “left-behind” regions stagnate.²⁸ 90% of the US is left out of the innovation economy as their college-educated talent moves to the top 5 metropolitan areas.²⁹ In a public-private partnership, comprehensive regional profiles could guide agile program replication in underrepresented communities. With the “heartlands” using 74% of federal R&D investment to generate 76% of basic research PhDs, there’s a compelling case for innovation-driven growth outside of California, Massachusetts and New York.³⁰ Moreover, 35 metropolitan areas are primed to become self-sustaining growth centers, which will alleviate the negative externalities of highly-concentrated innovation like spiralling home prices and increasingly non-competitive wages in superstar regions,³¹ diversifying the tech workforce across regions.³² Indeed, the costs of elite tech hubs are so exorbitant that, in the absence of a well-distributed domestic ecosystem, investments increasingly flow into lower-cost hubs in Shanghai,

²² Romer, “Should Government Subsidize Supply or Demand?,” 241.

²³ Daniel Boden, Maura Borrego, and Lynita K Newswander, “Student Socialization in Interdisciplinary Doctoral Education,” *Higher Education* 62, no. 6 (2011): 752. <https://doi.org/10.1007/s10734-011-9415-1>

²⁴ James E. Driskell, Eduardo Salas, and Sandra Hughes, “Collective Orientation and Team Performance: Development of an Individual Differences Measure,” *Human Factors* 52, no. 2 (2010): 317, <https://doi.org/10.1177/0018720809359522>.

²⁵ Chris Woolston, “Graduate Survey: A Love-Hurt Relationship,” *Nature* 550, no. 7677 (2017): 522. <https://doi.org/10.1038/nj7677-549a>.

²⁶ Tae Jun Bae et al., “The Relationship between Entrepreneurship Education and Entrepreneurial Intentions: A Meta-Analytic Review,” *Entrepreneurship Theory and Practice* 38, no. 2 (2014): 217. <https://doi.org/10.1111/etap.12095>

²⁷ Weiss and Bonvillian, “Complex, Established ‘Legacy’ Sectors,” 178.

²⁸ Robert D Atkinson, Mark Muro, and Jacob Whiton, “THE CASE for GROWTH CENTERS,” no. December (2019): 5. <https://www.brookings.edu/research/growth-centers-how-to-spread-tech-innovation-across-america/>

²⁹ Atkinson, Muro, and Whiton, “THE CASE for GROWTH CENTERS,” 22. <https://www.brookings.edu/research/growth-centers-how-to-spread-tech-innovation-across-america/>

³⁰ “What We Bridge” Research Bridge Partners, Accessed October 1, 2020 <https://www.researchbridgepartners.org/what-we-bridge/>

³¹ Atkinson, Muro, and Whiton, “THE CASE for GROWTH CENTERS,” 8. <https://www.brookings.edu/research/growth-centers-how-to-spread-tech-innovation-across-america/>

³² Bhaskar Chakravorti “To Increase Diversity, U.S. Tech Companies Need to Follow the Talent” *Harvard Business Review*, October 4, 2020, <https://hbr.org/2020/12/to-increase-diversity-u-s-tech-companies-need-to-follow-the-talent>

Taipei and Bangalore.³³ Feeding global competitors by draining regional talent pools puts the US innovation economy in an untenable position. A science entrepreneur program can sustainably grow regional tech ecosystems, workforce first, to give relocating firms options in the US. And where positive externalities accrue internationally, they should accrue to US allies.

Tech-based workforce development efforts can reach critical mass through the education system. To promote regional productivity growth, VSD will implement the scaling principles of basic scientific research by: a) handing decision-making tools and frameworks to founders; b) encouraging management structures in which research is quality-assured by sector experts; c) partnering more junior candidates with existing, fully trained founders to create mixed teams; and d) expanding talent reservoirs via training program replication with maximal access to the best foreign-born graduates. These principles, combined with the program's company-formation focus, favor the growth of high-tech companies that will create high-paying, recession-resistant skilled manufacturing jobs throughout the country.

More than 40% of US S&T graduates are foreign-born, and they show the greatest capacity for expanding the S&T workforce.³⁴ Initially launching from the US, UK and EU, VSD will implement recommendations for US technology leadership by enabling partnered research with allied R&D investors.³⁵ As the program scales, the hiring of 120 sector experts will support company formation for 1,000 graduates annually. This will raise the US PhD total by 2.9%³⁶ and produce hundreds of mission-oriented science companies each year, even with modest spin-off rates and limited replication. Verge Genomics, Recursion Pharma, Ginkgo Bioworks, Ziylo and others prove that graduate-founded firms can exceed valuations of \$500 million and stimulate the innovation economy. By institutionalizing proven entrepreneurship pedagogy, more companies like them will emerge. Should just one graduate-founder start a \$1 billion company, the return on investment to the US economy is likely a very significant multiple of the initial VSD program cost.

Examples of companies formed through an analogous process run by Deep Science Ventures include:

- XONAI, Artificial Intelligence. How can quantum computing become an accessible product when it requires supercooled environments? After testing 5 approaches, XONAI applied mathematical mapping for room temperature, quantum computing hardware.

³³ Atkinson, Muro, and Whiton, "THE CASE for GROWTH CENTERS," 6. <https://www.brookings.edu/research/growth-centers-how-to-spread-tech-innovation-across-america/>

³⁴ National Science Board, "Foreign-Born Students and Workers in the U.S. Science and Engineering Enterprise" (National Science Board, 2020). <https://www.nsf.gov/nsb/sei/one-pagers/Foreign-Born.pdf>

³⁵ Rush Doshi, "The United States, China, and the Contest for the Fourth Industrial Revolution," *For the Hearing "The China Challenge: Realignment of U.S. Economic Policies to Build Resiliency and Competitiveness,"* (2020): 2. <https://www.brookings.edu/testimonies/the-united-states-china-and-the-contest-for-the-fourth-industrial-revolution/>.

³⁶ National Center for Science and Engineering Statistics National Science Foundation, "Doctorate Recipients from U.S. Universities: 2019," NSF 20-308. (Alexandria, VA., 2019), <https://nces.nsf.gov/pubs/nsf21308/>.

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- Mission Zero, Climate Positive Technologies. Carbon capture is un-investable unless chemical approaches can be proven at scale. Within 9 months, Mission Zero's 1-ton carbon capture process was cheap enough to demonstrate, acquire customers, and scale.
- Reflection TX, Drug Discovery. With 200+ failed Alzheimer's trials, the standard neurodegenerative disease models seem inadequate. Reflection TX has preclinically resolved inflammation precisely at nerve-endings, a result with the potential to treat Alzheimer's, Motor Neuron Disease and Parkinson's.

XONAI, Mission Zero and Reflection TX prove what a rigorous approach to science company design can achieve: each represents the inception of a novel industrial system. Increasing high-tech spin-off productivity makes for powerful regional economic development. Our own research (see FAQ) shows that programs with an explicit company-formation focus spin off 7-8 times more companies per applicant than alternative entrepreneurship training for scientists. Compared to other private sector industries, high-tech jobs are more resilient during economic downturns, pay more and show more potential for continued growth.³⁷ Each manufacturing job creates 1.4 more jobs in supporting industries, but each high-tech job creates 4.3 additional jobs.³⁸ If only 200 graduates each make 3 hires, VSD (26.9k jobs per \$1bn federal investment – a *modest estimate*) exceeds large-scale construction (20.3k jobs per \$1bn federal investment) in job creation.³⁹

The S&T workforce can be trained to create more jobs and produce more technologies. Mission-oriented VSD companies will exist to do what their industries still cannot. Running at scale, the program will demonstrate what works for CELS innovation by offering the opportunity to conduct comparative studies across R&D, prototyping and test bed analysis. By distilling innovation economics, scientific research and spin-off pedagogy into VSD firms, a consolidated process of innovation emerges with novel learning opportunities. Combinations of individuals, teams and R&D systems can be hypothesized and tested for CELS growth. And this intervention is holistic: stronger applicants will leverage everything from entrepreneurial fellowships to NSF programs to greater effect for their regions. Founding science companies faster and in more sectors will transform US innovation.

Research institutes produce the S&T workforce, but they lack the incentives and market-focus science entrepreneurs need. Deep Science Ventures' companies bring sector-shaping technologies into CELS through a systematic approach to mission-orientated research, prioritising design-led super-forecasting, technical risk, intellectual property and collective action for science entrepreneurship. With federal support, a specialized innovation program with the strengths of both could transform promising metro areas into artificial intelligence, climate positive and healthcare innovation centers.

³⁷ Hathaway and Kallerman, "High-Tech Employment and Wages in the US.," 26.

³⁸ Hathaway and Kallerman. "High-Tech Employment and Wages in the US.," 5.

³⁹ Casey J Bell, "Understanding the True Benefits of Both Energy Efficiency and Job Creation," *Community Development Investment Review* 10, no. 1 (2014): 111. <https://ideas.repec.org/a/fip/fedfcr/00039.html>

Plan of Action

To close the gap in tech innovation and create regional economic growth, the Biden-Harris Administration should launch the Venture Science Doctorate to train S&T graduates to combine research and entrepreneurship. Over a 2-year launch period, it should invest an initial \$236 million in training 2000 graduates. The VSD will be conducted in collaboration with UK and EU initiatives to leverage global talent for the growth of American high-tech industries and the strengthening of its allies. Reporting to NSF, Deep Science Ventures (DSV) will deliver the Venture Science Doctorate to incentivize and train graduates for spinning off into high-tech firms in CELS. DSV would leverage its expertise in founding innovative firms in CELS, raising capital, and training scientists to conduct mission-oriented research.

Pilot Execution and Data Analysis

The Biden-Harris Administration should invest 66% of the initial \$358mn (see FAQ) required for a 2-year, international VSD launch, leaving 33% to be raised through launch partner match funding. A preliminary VSD should include a 4-month pilot to develop constraints for the initial training environment. The venture-integration pilot will be launched in Fall 2022, combining scientific, personal performance and venture design training through established pedagogy from science venture-building environments. Virtual and decentralised, the pilot will train 16 individuals, using scalable components capable of supporting 1,000 candidates per year. Unlike traditional graduate programs, recruitment will target entrepreneurial intention and social skill. Graduates will systematically identify, construct and lead their research ventures within collaborating research teams. Multidisciplinary research teams (~5 members) will conduct autonomous but coordinated investigations, following set frameworks, processes and guidelines. Program design will draw on and expand the methodology designed at Deep Science Ventures to identify high impact interfaces between disciplinary silos. It will further build on insights from predecessor programmes such as ConceptionX, I-Corps, iCURE, the Medtech Superconnector, Stanford's Biodesign and others. The potential for this program to scale a diversified S&T workforce is substantial. Deep engagement with minority-serving institutions and key states will be crucial to program replication in underrepresented communities. The Department of Homeland Security's Minority Serving Institutions Program and the Aspire Alliance for inclusive and diverse STEM faculty highlight models for inclusive training, and over 40 post-secondary institutions advancing diversity in education. High achieving applicants will be able to access VSD regardless of economic status through comprehensive stipendiary support (\$31k/year) and research funding (\$25k/graduate).

Instigating Key Venture-Focused Partnerships

The Office of Science and Technology Policy can coordinate demand-side initiatives to support innovators. These may include government procurement of new technologies; renewable energy requirements; enabling commercial use of academic labs; and convening thought leaders, philanthropic funders and corporate executives who can support the initiative. Through an ongoing

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search for research partners, the University of Edinburgh (UK) has been identified as an academic partner ready to immediately spearhead the initiative. OSTP should identify US industrial partners with corporate values and research capabilities suitable for spearheading the initiative.

OSTP should convene national medicine, agriculture, clean energy and artificial intelligence (AI) stakeholders to commit to both 20-year goals for their industries and weakening systemic barriers to CELS innovation. Convention proceedings could summarize the positions and aspirations of industry incumbents, investors, VSD firms, and the National Institute of Standards and Technology (NIST). VSD firms can raise concerns with sector stakeholders, collaborate and generate corporate interest in their regions. VSD firms could use their experiences in driving sectoral change to form an industry reform advisory group that reports to NIST and OSTP, describing barriers to innovation and regional workforce retention while contributing to demand-side initiatives.

National Science Foundation Scale-up across the American Southeast and Midwest

NSF support will be instrumental in identifying metropolitan areas where science companies can leverage basic research, industry and funding for sustainable economic development. Federal data and priorities will be instrumental in conversations with stakeholders of “heartland” regional development such as Research Bridge Partners, the Brookings Institution and the Information Technology Innovation Foundation. NSF should work with these organizations and OSTP to identify 3+ research partners best situated to promote regional economic development. Furthermore, NSF established the National Research Traineeship at hundreds of institutions with industrial partnerships across the country. Revisiting networks of ambitious research partners and their strategies for successful adoption of the National Research Traineeship will expedite national VSD uptake. Deep Science Ventures will report to NSF to track VSD impacts like S&T undergraduate and workforce population sizes, state-level economic indicators and novel predictive indicators, measured during VSD, correlating the training process with regional outcomes.

Conclusion

In the United States, complex established legacy sectors such as healthcare delivery, agriculture and clean energy are falling behind the global innovation frontier. These sectors cannot grow while the R&D incentives problem and market imperfections restrict the productivity and scope of US innovation. Solving these problems will bring innovation into CELS, creating jobs cost-effectively and at an exponential rate while securing global competitiveness. We can do this sustainably -- through higher education -- and equitably -- harnessing the ingenuity of Americans in areas left behind. With federal support, VSD will be broad enough for regional economic development and deep enough to sustainably grow the workforce that creates technologies. Aligning science and market launch through this scalable program will inspire founders and researchers across the US and allied countries to create global public goods.

Frequently Asked Questions

Why should the VSD be implemented and run by Deep Science Ventures?

DSV's existing opportunity areas and sector structures offer a set of teams and a culturally entrepreneurial microcosm for PhD candidates. DSV's existing methodologies for selecting recent graduates and training them to become founders is directly applicable. Indeed, it was through running training and workshops for postgraduate and postdoctoral training centers at top universities around the world that we began thinking about a PhD program.

At Deep Science Ventures, mission-oriented company creation begins with a 5-15 year vision of what a high-tech firm ought to be. Our research and training methods have been validated through founding 30 firms, raising \$35 million in funding (leveraging DSV's own funding >10x) and creating over 100 jobs. Importantly, our science entrepreneurs pursue technical and market-entry targets in parallel, to innovate in CELS. Training scientists to investigate neglected problems, we approach the crises that industry incumbents don't resolve, such as surgical "never events" (surgical tools accidentally left in the patient's body) and adhesive toxicity (hazardous chemicals in a wide variety of glues). Behind such industrial crises are unresolved scientific questions. Our investigations turn up fundamental challenges ripe for mission-oriented research.

Why should a British company run the Venture Science Doctorate, rather than an American one?

The US has a track record of attracting novel concepts and innovative firms from abroad, with DARPA, Advanced Research Projects Agency-Energy (ARPA-E) and other agencies having demonstrated the benefit of funding firms from abroad pioneering new approaches. Indeed, it is one of the arguments advanced in this proposal that focusing on catalyzing innovation from abroad offers greater rewards than a pure domestic focus, which no longer seems controversial. In particular, an international PhD program focused on attracting talented foreign-born individuals may stand to benefit from a center of gravity outside the US. Collaborating with a British firm on the VSD furthers an American legacy of attracting first-in-class pilots for novel training and innovation schemes from other regions.

Why would a public-private partnership be preferable to a government run program?

Superficially, there is a sense of internal consistency in the idea of a venture-focused PhD being coordinated by a for-profit entity, in the sense that the interests and missions of both the new companies created and the coordinating body would be aligned: the use of profit to expand and grow high-impact technologies. Specifically, a firm with a venture capital business model, like DSV, profits when it successfully trains high quality entrepreneurs and these entrepreneurs in turn start high impact, high growth companies. This is in contrast to other possible education providers, who have somewhat less clear incentive structures. Allowing publicly funded entities

to share in the reward from this entrepreneurial activity makes the provision of higher risk research sustainable and provides a return on investment to taxpayers. Nevertheless, it may be advantageous to pilot a government-run program in parallel with a DSV-run public-private partnership, an 'A-B test' as part of the overall mission of investigating the ideal circumstances for innovation.

How will funding be allocated?

The majority of the budget will go into the full-time, graduate-founders bringing sector-shaping research and high-value jobs to their regions. To minimize costs and lower barriers to participation for host laboratories and industrial partners they will be reimbursed for their time and use of facilities.

| Component | Units/Year | Year 1 Cost (\$M) | Year 2 Cost (\$M) |
|---|------------|-------------------|-------------------|
| PhD salaries | 1000 | 93 | 93 |
| PhD research budgets | 1000 | 25 | 25 |
| Decentralized, part-time, academic and industrial faculty | 500 | 36 | 36 |
| Managerial Overheads | 200 | 20 | 20 |
| Venture investments (assuming 1 in 10 graduates) | 100 | 5 | 5 |
| Pilot | 1 | 0.348 | |
| Total | | 179.348 | 179 |

What 'Opportunity Areas' will candidates be able to apply to?

| | |
|-------------------|---|
| Pharmaceuticals | <ul style="list-style-type: none"> Oncology - Synthetic Lethality (1 approach) Oncology - Oncolytic Viruses (1 approach) Oncology - The Tumor Microenvironment (1 approach) |
| Energy and Carbon | <ul style="list-style-type: none"> Climate Finance - The Planet Positive Economy (4 approaches) Carbon - Negative Emissions Technologies (3 approaches) Carbon - Carbon Negative Fuels (2 approaches) Carbon - Catalysing Clean Energy Underground (2 approaches) |

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Agriculture Regenerative Aquaculture - Plants (1 approach)
 Regenerative Aquaculture - Fish (1 approach)
 Pollinator Reinforcement (2 approaches)
 Controlled Environment Agriculture (3 approaches)

Computation Optimizing Hardware (1 approach)
 Room Temperature Quantum (1 approach)
 Cybersecurity (1 approach)

How has the curriculum of the Venture Science Doctorate been designed?

Our program design expands the methodology designed at DSV to identify high-impact interfaces between disciplinary silos. It further builds on insights from predecessor programs, such as ConceptionX, iCorps, iCURE, the Medtech Superconnector, Stanford's Biodesign, Imperial's Innovation Design Engineering and others. We will form doctoral-level founders by focusing on the Venture Scientist's head, heart and hands.

Head: Fostering the development of independent technical experts

The program will train participants to rapidly comprehend the state of the art, draw knowledge of technical and commercial constraints from previous product launches, map pathways to an ideal intervention and hypothesize winning combinations of technology and business models. Participants will blend research fields, developing their technical expertise at the interface between them. They will engage with the literature of technologically relevant fields to develop supervised research projects, rigorously and relentlessly closing the gap between their understanding at entry and that of an industrial expert.

Heart: Curating experiences to promote leadership through self-mastery

To lead in uncertain environments, participants will learn to interpret key relationships between personality, habit-formation and performance. They will understand how to seek clarity, generate energy, deepen resolve, increase productivity, demonstrate courage and develop influence. These six practices create a matrix for adapting beyond the individual's "natural" strengths to create "antifragile" organizations which strengthen under pressure.

Hands: Teaching deeptech-tailored venture creation and scaling

Science entrepreneurship is qualitatively distinct from software entrepreneurship (e.g. lean startups). In this context, forward-looking analysis of sector-scale opportunities becomes more important than customer development or the urgent unmet needs of the status quo. The required approach is more akin to design-led super-forecasting. Candidates will use an optimized market research framework and develop commercial and technical hypotheses (value capture economics, freedom to operate, defensibility) in parallel, focusing on the interplay between market, business model, technology and scale strategy.

Is there a career trajectory for Venture Scientists produced by VSD?

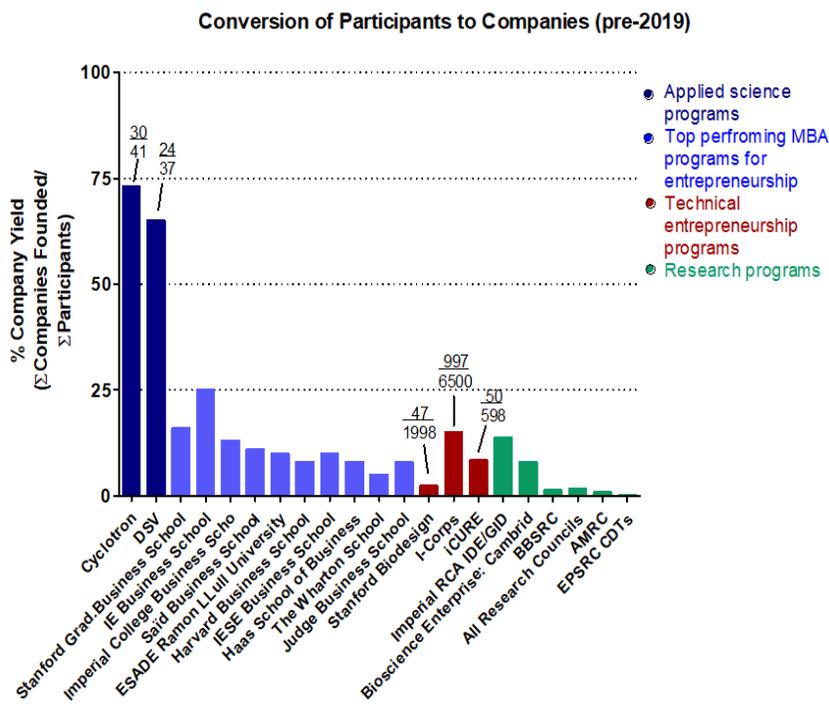
As well as the opportunity to start their own companies during the program itself, many Venture Scientists will flow into programs suggested in other Day One proposals, leading and co-founding companies at MIT's Engine, Activate and the Crick's Applied Biotechnology Lab; into universities as Entrepreneurs in Residence; and translational research team-leaders as engines for new spin-offs worldwide. Through this intervention, Venture Scientists will become the foundation of a new infrastructure for the innovation economy.

Does applied science displace basic science?

No, in fact the opposite is true. As basic research matures into technology, commercialization creates a compelling argument for continued basic research investment. Applied science acts as a final test of basic research theories, generating new fundamental questions.

How do types of entrepreneurship training relate to spin-off productivity?

Research conducted at DSV has found that dedicated programs consistently achieve better outcomes than MBAs and translational research programs. The average across the top MBA programs in the world for entrepreneurship was a conversion of 11.4% of participants to founders, and 8.9% for technical entrepreneurship programs. In DSV's own programs and those of Cyclotron Road, programs which almost exclusively draw on PhDs and postdoctoral fellows, conversion rates are $\geq 65\%$. We believe a hybrid program can maximize conversion, at scale, through PhD education.



Are there comparable venture creation programs in other countries?

The idea of a vocational PhD which explicitly points outside of academia from the beginning is in itself a relatively rare phenomenon. To our knowledge, there are no programs where PhD students combine scientific disciplines with the design and launch of science ventures. It's difficult for PhD programs to become the sites of market launch with public expectations of the PhD as an academic career entry-point⁴⁰ and perverse institutional incentives⁴¹ defending the old models. China and India rely on industrial clusters and technology business incubators to create science entrepreneurs for economic development. (China has 896, 344 of which are state-owned, while India has 120.)⁴² These models rely on a minority of entrepreneurs coming through the scientific educational system. VSD represents a more efficient model by 1) saving time and costs in science and entrepreneurship training, 2) adding science entrepreneurs to the workforce and 3) targeting low innovation-yield sectors. The idea of an internationally distributed, capital expense-light innovation cluster is also relatively new, and the VSD is a pilot of this concept too.

Can you elaborate on the examples of the DSV methodology?

Example 1: XONAI. What is the fastest route-to-market for quantum computing? DSV identified the key constraints (scaling in absolute zero environments), generated 5 approaches, and chose the optimum (photonic modes 'squeezed' light, a tangential field of physics). Taking our techno-economic analysis further showed that even at room temperature, the real customer problem was linking quantum architectures to existing software. Knowing this, DSV joined up the stack by finding an approach from a neglected field of mathematics to map software functions into an abstract domain that could be universally mapped to the fastest existing hardware. This would allow rapid integration of hardware such as room temperature quantum systems, in the same architecture as novel emerging forms of specialised computation for graphics and 'in-memory' computation. The academic team brings together diverse fields and regions from Philadelphia in the US (SRAM fabrication), Oxford University in the UK (continuous variable computation) and Israel (Hilbert space mapping) and the solution is now in testing with software companies and database providers.

Example 2: MISSION ZERO. Carbon capture technologies have until now had higher costs to capture the carbon than it can be sold for. This is an area of research that has received substantial funding, but with much of this being split between legacy industrial chemistry or more speculative, blue skies work in chemistry. One universal route-to-market challenge that new chemicals companies experience is achieving commercial traction before achieving minimum efficient scale, making it challenging for even high-potential new technologies to displace incumbent, highly-optimized processes. DSV therefore constrained the solution space to

⁴⁰ Woolston, "Graduate Survey: A Love-Hurt Relationship," 522

⁴¹ Julie Gould, "How to Build a Better PhD," *Nature News* 528, no. 7580 (2015): 23; <http://doi.org/10.1038/528022a>
Jody D Nyquist and Bettina J Woodford, *Re-Envisioning the Ph. D.: What Concerns to We Have?*, vol. 1 (University of Washington Washington, 2000). 13. <https://depts.washington.edu/envision/resources/ConcernsBrief.pdf>

⁴² Mingfeng Tang et al., "Technology Business Incubators in China and India: A Comparative Analysis," *Journal of Global Information Technology Management* 16, no. 2 (2013): 41-45. <https://doi.org/10.1080/1097198X.2013.10845635>

technologies which could capture carbon dioxide at less than \$100 /ton even at very small scales. Focusing on this new design space, the team at DSV generated 7 novel scientific approaches (utilizing various insights from chemical engineering, synthetic biology and material informatics) to significantly reduce the cost. One of those approaches surpassed the pre-assigned technical and commercial constraints, combining both chemistry and biology intellectual property with academic expertise to create a mechanism that meets the \$100 / ton market viability point and proving that viability in the market with 6 initial customers. Finally, DSV built a specialist founding and advisory team, including early academic advisors of Carbon Engineering and early commercial advisors from Climeworks and incorporated the new company with seed funding. This was all achieved within 9 months.

Example 3. REFLECTION TX. Over 200 Alzheimer's trials, based on essentially the same 'amyloid' hypothesis, have failed so far. The team at DSV analyzed the failure cases to understand why this track record had not dissuaded continuing funding and academic effort to be spent on the amyloid hypothesis. It became apparent that all of these failed approaches showed promising data in very similar animal models, which had become a standard, but were not representative of human biology in several crucial respects. The approach ultimately chosen borrowed from the fields of immuno-oncology (with Cambridge University) and synthetic biology (with University of California) to create a system that very selectively resolves inflammation at the sight of the damaged synapse, and tested this in combination with more representative models from motor neurone disease with academics at King's College London. This work is currently in the pre-clinical phase and has the potential to address Alzheimer's, Parkinson's, and motor neurone disease. To date the company has raised just under £1 million in a mix of dilutive and non-dilutive capital, and the technology has been proven in vitro with in vivo results expected in Q1 2021.

What are the core operational components that allow VSD to scale?

Knowledge model: This is an outcome-centric model which schedules research and execution tasks according to their impact on other work across the combined technical and commercial landscape, matching "desired outcome" to "possible technology." DSV's current build is a manually-tagged database, partially defining each concept through its relation to other concepts ("a relational database") made up of hundreds of pages of "constraints" (factors known to represent some limit to innovation or risk) and synthesized literature, assessed and progressed approaches, constantly being co-created through the collaboration of a small group of dedicated chemists, engineers, physicists, computer scientists, economists and biologists. Rather than decisions being made by a centralized, generalist investment committee, progression decisions are made continuously according to performance against these constraints and judged by cutting-edge specialists.

Talent graph: One of the 'hard' parts of deep tech is talent. Roughly 30% of DSV's current founders come via referral, but a process which scales faster was needed. DSV has built a behavioral and technical capability assessment framework, implemented in software, that

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performs high-specificity searches and return hundreds of prioritized candidates in minutes, with greater than 20% response rates from cold contact. DSV is also building a system in which reputation of individuals (founders, funders, experts) accrues in a non-gameable way and aligns incentive structures to long-term rewards, inspired by trust protocols in decentralized systems and adapting models of productive communities like StackExchange. DSV currently already use this to match and combine individuals into small, agile teams, and direct the allocation of resources.

This system has allowed DSV to actively target the creation of more diverse teams, meaning that DSV has (for example) four times as many mixed gender teams as in the general spin-off population in the UK. By carefully reviewing evidence of achievement and technical expertise, such systems can start to look 'through' standard biases, ignoring the names of universities, the color of skin and the gender of names.

Incentivization ruleset: Though the core, permanent team of DSV is small, we currently work with a distributed, full-time network of around 50 people from Chile to Australia. We are currently designing a set of rules which will govern the way individuals are incentivized on a more granular level; an "incentivization ruleset." Such a ruleset would reward collaboration across the boundaries of sectors, companies and geographies for actions such as solving technical problems, identifying critical hires and investment, allowing founders from different companies to support each other, and for those unattached to any particular company to share their expertise without needing to create and track a large number of fixed contracts. The incentivization ruleset also represents the core value-set of the organization, directly integrating values of climate impact, the well-being of target populations and demographics, and our ethical framework.

About the Authors



Thane Campbell holds a PhD in Optical Immunology for combining biochemistry, live cell imaging and neural networks to predict immune responses, with GlaxoSmithKline. His research supported PROTEUS, a 3-university, interdisciplinary collaboration to build a fiber microscope for imaging inside human lungs. Thane learned about science venture design at Deep Science Ventures, where cohorts of scientists use first principles to explore the “impossible” challenges that lead to sector-dominating technologies. At Edinburgh Innovations he helped to rapidly establish Scotland’s first Agri-tech venture builder, DSV FAST, and his work to encourage research commercialization won the BBSRC Recognizing Excellence in Knowledge Transfer Award.



Dominic Falcão is a founding Director of Deep Science Ventures, an organization synthesizing knowledge, talent and capital into optimal science companies. He studied Politics, Philosophy and Economics, focusing in particular on the fundamental drivers and assumptions underlying welfare and wellbeing and went on to run Imperial College London’s flagship accelerator program, graduates of which have been acquired by Google, Facebook and Apple.



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