Design for Impact: A Development Engineering Graduate Program at UC Berkeley

David I. Levine
Haas School of Business, University of California, Berkeley, Berkeley, CA 94720

Alice M. Agogino
Department of Mechanical Engineering, University of California, Berkeley, Berkeley, CA 94720

Martha A. Lesniewski
UC Berkeley - UC San Francisco Graduate Group in Bioengineering, University of California, Berkeley, Berkeley, CA 94720 and University of California, San Francisco, San Francisco, CA 94143

Abstract
"Development engineering" is a new interdisciplinary field that we define as creating solutions that improve human development at scale in low-resource settings. In a new minor for Ph.D. students at UC Berkeley, we couple human-centered design with development applications to emphasize: 1) Incorporating development goals, constraints and opportunities; 2) Scaling for impact; and 3) Integration of novel sensors, experiments, and large datasets. This editorial describes the Development Engineering graduate program at UC Berkeley, motivates its multidisciplinary foundation and provides lessons learned from the first offering of the program's core course.

Keywords: design for development, development engineering, human-centered design

1. Introduction

UC Berkeley's new interdisciplinary Development Engineering (DevEng) minor [1] invites doctoral students from any discipline whose research includes technologies for social and economic development. The goal of our development engineering research and teaching program is to train students to accelerate innovations that enhance opportunities, improve access to affordable health care, clean water and sanitation and energy solutions, and improve living standards and quality of life. Through coursework, mentoring, and professional development, the program prepares students to develop, pilot, and evaluate technological interventions. The program is overseen by a group of over 20 faculty members from 13 departments ranging from bioengineering to economics.

DevEng students must take a core course (Design, Evaluate and Scale Development Technologies), a research seminar, and three electives from at least two of three thematic modules: Project Design; Evaluation Techniques and Methods for Measuring Social Impact; and Technology Development [1]. The core course is co-taught in the fall term by one technologist and one social scientist, with instructors rotating. The course is organized around analysis and application of case studies by multidisciplinary student teams in three modules:

- **Understanding the Problem, Context, and Needs** explores, via human-centered design processes, the integration of quantitative and qualitative needs assessment techniques such as observation, in the process of user identification, persona creation, insight communication, and question formulation.

- **Prototyping Solutions** investigates concept generation techniques and methods of low- and medium-fidelity prototyping with attention given to an iterative process of hypothesis testing, data evaluation and continuous improvement.
- **Rapid Improvement** extends this iterative process with examination of pilot tests in the lab and field, technologies for monitoring and testing, business modeling, rigorous impact evaluation, and financially sustainable scaling.

The goal of the core course is to provide students with the skills to address complex problems and design challenges in development engineering. To practice DevEng skills, students form four- or five-member multidisciplinary teams to develop a capstone project throughout the semester. The project deliverable is a modified USAID Development Innovation Ventures (DIV) proposal [2].

2. Framing Development Engineering

The framework for Development Engineering, as introduced in the core course and used in UC Berkeley's DevEng minor is illustrated in Figure 1.

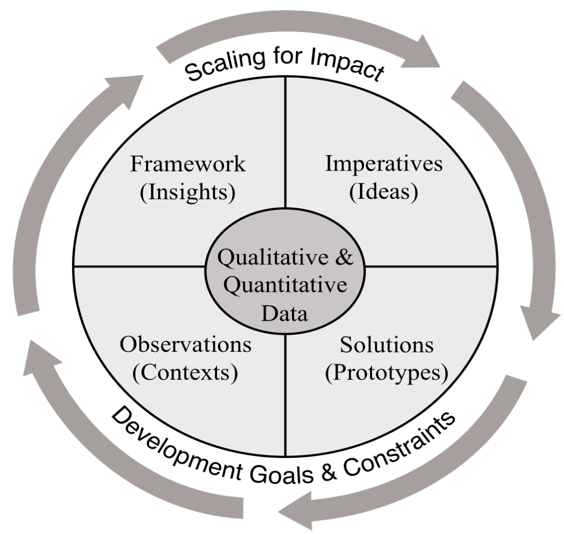

Fig. 1. Framework for human-centered design in development engineering

2.1. Human-centered design in development

We use human-centered design as the starting point for development engineering because it provides a rich toolkit for deep needs assessment, tools for creative ideation and prototyping potential solutions, and an emphasis on iterative phases of assessment and improvement [3-6].

A DevEng project would typically begin in the research phase in the lower left quadrant for Figure 1 and cycle clock-wise. Starting with an immersive user needs assessments (*e.g.*, interviews and observations), students need to analyze data to gain insights for framing the problem (upper left quadrant) and for developing imperatives and design principles (upper right quadrant) for concept development and prototyping (lower right quadrant). The cycle begins again testing concepts and prototypes with users and other stakeholders for rapid improvement (lower left quadrant again) and re-design. If a project already has a prototype (right half, as in [7], it would follow the model by testing and either validating or revising this solution.

2.2. Incorporating development goals, constraints and opportunities

The goal of development engineering – to improve poor people's lives at scale – affects all phases of the design process. DevEng researchers must confront the constraints facing the global poor and apply them to inform design of the solution and associated business models for scaling [8]. In addition to the obvious constraint of poverty, poorer regions typically suffer from "institutional voids"; that is, governments and markets that work ineffectively [9]. The markets for capital, labor, supplies and distribution lack high-quality information, methods to verify credibility, and trustworthy means to regulate and to settle legal or contractual disputes.

Additionally, the institutions and cultural norms that are present, such as gender inequality or ethnic discrimination, affect many domains of life [10]. Yet at the same time, developing regions yield many opportunities. For example, the social goals of development engineering make it attractive to donors and governments as potential funders or partners. Microfinance and community-level institutions such as women's groups often work well in poor settings, providing opportunities that transcend many sectors. Mobile phones are often prevalent and increasingly used for mobile banking, crowd sourcing and other functions.

The assessment of user needs must examine these constraints and opportunities. For example, a needs assessment for a cooking solution must not only examine users' perceived needs for cooking, but also examine how more efficient cook stoves affect broader goals such as reducing deforestation and improving health. Additionally it must examine the needs of each potential stakeholder, such as governments or donors. Often the needs assessments should also examine institutional voids; for example, if liquidity constraints are important, existing sources of credit, timing of income and so forth should be understood. Because gender inequality can be a challenge and mobile phones an opportunity in almost every sector, most needs assessments must examine both.

Geographic distance and cultural distance are barriers for many projects. There is no replacement for direct interaction with users in their own settings. At the same time, there are often low-cost substitutes that can help early-stage research: experts living near the designers, migrants who grew up in regions similar to those of the intended users, remote interviews with experts and users in poor regions, and so forth.

Development issues can also provide stimuli for creativity. For example, many products will have to overcome additional liquidity constraints, because the poor often have limited access to capital [10,11]. Design engineers will want to brainstorm combinations of sales offers (e.g., installment payments), partners (e.g., microfinance institutions), selling at harvest time, and other means to overcome liquidity constraints. Designers can also examine how, if their solution fills an institutional void (*e.g.*, by creating a cold chain for food), other problems the solution address [9]. "Frugal design" with appropriate technologies can provide another stimulus of innovation that might provide boomerang benefits for the developing world [12,13,14,15]. We can learn from innovators in poor communities, as they continue their long traditions of innovation [16].

Constraints and strengths of developing regions also influence the process of prototyping, testing and rapid improvement. For example, mobile phones can help in user surveys and business models can often build on mobile banking.

2.3. Scaling for impact

We posit that a research and teaching program in development engineering should focus as much on concerns about scaling for impact as on the product or service itself. In rich nations, considerations of how to scale are important, but a well-designed product that satisfies a niche in the market can often make an economic return. The problems in poor regions are massive, and it is important for design engineers to focus on solutions that can solve problems at scale. As noted above, poor regions often contain institutional voids that make it difficult for distributors to transport products, for consumers to trust distributors, for vendors to process payments, and so forth. The many constraints facing users in poor regions make it especially important for development designers to consider how to scale from the very start.

Scaling considerations show up in the needs assessment, framing, ideation, and improvement phases. During the needs assessment, designers must also examine all the issues of the business model, such as financing, supply chains, and distribution. We use the term "business model" to encompass public, NGO and hybrid models for taking solutions to scale. Thus, almost any project's needs assessment needs to consider demand-side issues such as how to deliver products, how customers learn about offerings, ways to build trust with customers, and so forth – and a similar set of questions on the supply side. During the ideation phase, development engineering must also apply creativity tools in designing the business model. Distribution channels and financing options will often require as much creativity as choosing feature sets and designing technology. During prototyping and testing for rapid improvement, development engineers must quickly prototype the business model as well as the product or service. For example, consider the challenge: Why will consumers trust or desire my product? Rapid prototyping can include showing consumers potential marketing messages; running pilots in a few shops and seeing what messages and presentations increase sales; lending out free trials and measuring consumer response; and so forth [17].

2.4. Integration of qualitative and quantitative data

Human-centered design builds on rich qualitative tools [3-6] as well as a range of quantitative tools for testing [18,19]. A new generation of sensors and quantitative tools offer novel opportunities for all phases of the design process: needs assessment and insights, design principles, creative design, and prototyping for rapid improvement. While these new tools can be helpful in all settings, the challenges of geographical and cultural distance in development engineering make them particularly important for development engineers.

Sensors, for example, can help us understand current practices. Examples range from monitoring electricity use [20] or water pressure over the day or week [21-23] to embedding usage sensors in medical equipment [24]. Sensors can complement interview data by comparing what people say versus what they do. For example, Wilson, *et al*. [25] found that efficient cookstoves with embedded sensors showed far lower usage than that reported by interviews with users. *Experiments* can help us understand barriers that a potential new solution must address. For example, to see if liquidity constraints are important, one can experiment and offer a product for sale with installment payments to some consumers and with a fixed price to others [26]. *Large datasets* (relative to a normal survey of users) are increasingly available in poor regions. Sources include the Internet, regular operations of enterprises (*e.g*., mobile phone call records), government operations (*e.g*., procurement and school test scores), crowdsourcing (*e.g.*, Yelp! product reviews), sensors and satellites. All of these data sources can help identify where a drought is worst or where an epidemic might spread [23]. The institutional voids of poor regions raise the value of existing large datasets relative to their importance in most prosperous settings.

These quantitative tools can also provide stimulus to creative design. Crowdsourcing can be used to expand the breadth and depth of creating solutions for the developing world and provide the ability for distant designers to work on global challenges [27]. Embedded sensors can improve functionality, speed improvement, and address challenges to scaling. Examples range widely, from using RFID tags on inventory to track stock-outs and corruption to putting sensors on appliances such as cookstoves [25] to monitor usage that informs carbon credits or results-based financing from a donor. Large data sets can also add value to the product and address challenges to the business. For example, Amazon and Netflix provide recommendations to users based on millions of other users' choices. Data from weather satellites and soil sensors can help target advice for farmers.

Quantitative tools can also help in prototyping for rapid improvement. Sensors can help measure how well early design products or services meet users' needs. Usage monitors are integral to some products, such as pay-as-you-go solar lights and water kiosks [22], and services such as mobile banking. In other cases, a usage monitor may be easy to include (e.g., D-Rev measures usage of its lights to combat infant jaundice [24]). Usage patterns help inform both designers and users what is working and why. For example, an efficient stove can only reduce deforestation and household air pollution if cooks largely stop using their traditional three-stone fires. Measuring usage of traditional stoves can help improve the design of the new stove (*e.g.*, answering: "Would multiple burners help?") as well as the business model (*e.g.*, "Should there be more training on the dangers of traditional stoves?"). Sensors beyond product usage can often be useful. For example, if a donor cares about health, then monitoring air quality in a kitchen with a new stove can be useful.

Experiments have a long history in speeding product improvement. In computer science, Google's experiments with its user interface are famous examples of A/B testing for continuous improvement [18]. In development engineering, consumer responses to variations in physical or on-paper prototypes can provide valuable information. Experimentation can also inform the business model. Installment payments greatly increase demand for both water filters and efficient cook stoves. In contrast, free trials increased cook stove usage in some studies, but were not needed with a nice-looking water filter in Dhaka [10,26]. Experiments can also provide rigorous evidence on the impacts of new products or services. Such evidence is required by some donors and governments, and can also be useful for attracting paying customers. As such, experiments can be integral to plans for scaling.

3. Lessons Learned

The DevEng core course was first offered in Fall 2014 at UC Berkeley. We had 34 graduate students representing a wide range of disciplines. Student feedback on the core course strengths fell into four themes: putting theories into practice, applying human-centered design, focusing on social impact, and connecting with the multidisciplinary development engineering community.

Putting theories into practice: Students valued experiential learning through hands-on activities that used concepts learned in class. For example, to practice needs assessment and the rich qualitative methods of observation and interviews, an early course exercise focused on hand washing with soap. Lack of hand hygiene contributes to disease both in the U.S. and in the developing world. Students observed local hand washing practices. They noticed changes in behavior once the observer was recognized, documented the associated facilities and interviewed users. Students practiced how to collect qualitative and quantitative data, how to understand the users' most important challenges and needs, and how to communicate these insights. They also gained insights from the contradictions between what people say (e.g., they say they wash their hands for 20 seconds with soap) and what they do (e.g., they are observed to wash hands with no soap for only 10 seconds).

Students also benefitted from the cookstove case study, in which teams tested several stove designs by cooking a large pot of rice. Cookstoves make a good case study for development technology design and deployment as half of the world's population cooks on dirty and inefficient stoves [25]. Each team broke into (1) *participant observers* (that is, cooks), focusing on the user experience; (2) *design researchers*, gathering observational data; and (3) *data analysts*, collecting temperature information using thermocouple sensors.

> *"What seemed like a very simple task (lighting a fire and boiling rice) turned out to be much more challenging than anticipated. Our success could be attributed to resources which the typical user would not have."*

Incorporating human-centered design: In-class exercises of concept generation, journey mapping (of a user experience), persona definition (to help understand a sample user) and user assessment were useful, especially when students applied them to their capstone projects. Practice of low-fidelity prototyping, using basic art supplies such as modeling clay and popsicle sticks, provided fun and effective learning lessons. Students experienced the iterative process and saw the value of failing quickly, getting rich feedback and improving the design.

One major course challenge was connecting students with users and stakeholders in target communities. Because all capstone projects except one (which worked with a local Native American tribe) were international, students and users were far apart. Students recognized that human-centered design requires access to the customers and users. Although the challenges of cultural and geographic distances face most development engineering projects, our approach is to connect teams with current development engineering projects (either from students in the class, elsewhere on campus [28 29,30] or presented by guest speakers). Such projects should have both primary field contacts and secondary researchers who have worked with the target population. Through case studies of successful and not-so-successful projects, students recognized the importance of human-centered design in development engineering.

> *"While working on the project, I realized that the concept of living on $1 a day is very difficult to grasp, especially for those who have never traveled to third world nations or those without experience in the development sector. Because of this, and as you both taught us, trying to design for this target population becomes twice as difficult."*

Focusing on social impact: Students benefitted from the introduction of a social business model and social impact evaluations as important considerations in designing, evaluating and scaling technologies. Even for the business students, the social business canvas [8] was a new way to present a business model with an emphasis on both social goals and stakeholders (donors, governments, etc.). Students found it useful to apply this framework to their capstone group projects. For example, one student had worked on new technology for training Ghana midwives in a low-cost method of screening for cervical cancer. She initially hoped her group would design a financially sustainable business model. By prototyping their business model with a few calculations, they determined that screening for cervical cancer might have a financially sustainable private business model, but that *training* the screeners would require donor funding. After the class ended, the project team used their capstone work to submit a successful proposal that received further recognition and pilot funding [31]. Another group worked on a student's technology for turning urine from public toilets into fertilizer. They started with a business model in which they would both produce and distribute. During the semester they determined that NGOs already existed that distributed fertilizer to smallholder farmers (their target group). Thus, they created a model that included a strategic partnership to distribute the fertilizer [32].

Connecting with the development engineering community: Many students mentioned the value of interacting with members of the development engineering community. Guest speakers from academic, public and private sectors gave interactive presentations on their projects and lessons learned from the field. Several students asked for more feedback and after-class interaction with the instructors and guest speakers. Furthermore, students requested increased discussion of development engineering opportunities for students and future career paths.

> *"Overall, the course was awesome, and potentially life-changing for me. Using engineering for development is something I never really considered until now."*

4. Conclusions

This editorial provides a framework for embedding human-centered design into the teaching, research and practice of "Development Engineering," a new interdisciplinary Ph.D. minor at UC Berkeley. The DevEng program is intended to stimulate research in, and equip graduate students with the skills to improve human development at scale in low-resource settings. In designing our core class, we augment human-centered design with: 1) Incorporating development goals, constraints and opportunities; 2) Scaling for impact; and 3) Integrating novel sensors, experiments, and large datasets (*e.g.*, from the Internet, satellites, mobile phones, etc.). Although targeted to low-resource settings in emerging economies, these approaches can also help students develop 21st century skills needed for tackling almost any challenge.

Acknowledgements – The Development Engineering minor was partially funded by the Development Impact Lab, with support from the USAID Global Development Lab and Higher Education Solutions Network (Cooperative Agreement AID-OAA-A-13-00002). We would also like to thank the UC Berkeley School of Civil and Environmental Engineering, Blum Center for Developing Economies, and the Center for Effective Global Action, Technology and Infrastructure for Emerging Regions for their support of our Development Engineering program.

References

1. UC Berkeley, Requirements for the Designated Emphasis in Development Engineering, http://deveng.berkeley.edu/, accessed 9-2015.
2. USAID Development Innovation Ventures (DIV) program, 2015, http://www.usaid.gov/div, accessed 9-2015.
3. IDEO.org (2015). The Field Guide to Human-Centered Design, http://www.designkit.org/resources/1, accessed 9-2015.
4. M. Fuge, A.M. Agogino, Pattern analysis of IDEO's HCD (Human-Centered Design) methods in developing regions, 2015, ASME *J. of Mechanical Design,* 137 (7), 2015.
5. T. Brown, J. Wyatt, Design thinking for social innovation, *Development Outreach,* **12**(1), 2010, pp. 29–43.
6. Levine, D.I., M.A. Lesniewski, A.M. Agogino, Design thinking in development engineering, to appear in the *International J. of Engineering Education*, 2016.
7. S. Blank, Why the lean start-up changes everything, *Harvard Business Review*, May 2013, Reprint: R1305C.
8. J. Calderon, The Social Blueprint Toolkit: Social blueprint business design framework, version 3, September 2014, http://impactstrategyadvisors.com/wp-content/uploads/2013/07/ISA_The-Social-Blueprint_-Business-Design-Framework_v3.01.pdf, last accessed 9-2015.

9. T. Khanna, K.G. Palepu, R. Bullock, *Winning in Emerging Markets: A Road Map for Strategy and Execution*, Harvard Business Review Press, Cambridge, April 28 2010.
10. R. Guiteras, T. Polley, D. I. Levine, B. Quistorff , Credit Constraints, Discounting and Investment in Health: Evidence from Micropayments for Clean Water in Dhaka, 2014, https://www.econ.umd.edu/research/papers/648/download/379, accessed 5-2014.
11. T. Beltramo, D. I. Levine, G. Blalock, The effect of marketing messages, liquidity constraints, and household bargaining on willingness to pay for a nontraditional cookstove, *J. of Economic Behavior and Organization*, 2014, UC Berkeley: CEG. http://www.escholarship.org/uc/item/4cq705v3, accessed 5-2015.
12. A.G. Winter, Stakeholder and constraint-driven innovation of a novel, lever-propelled, all-terrain wheelchair, *Proc. International Conference on Design Theory and Methods*, ASME IDET/ CIE, 2013.
13. I. Oosterlaken, Design for development: A capability approach, *Design Issues,* **25**(4), 2009, pp. 91–102.
14. V. Papanek, *Design For The Real World: Human Ecology and Social Change*, 2 revised ed. Academy Chicago Publishers, Aug 2005.
15. D. Nieusma, Alternate design workshop: Working toward appropriate design, *Design Issues*, **20** (3), 2004, pp. 13-24.
16. N. Radjou, Creative problem-solving in the face of extreme limits, TED talk, https://www.ted.com/talks/navi_radjou_creative_problem_solving_in_the_face_of_extreme_limits?language=en, accessed 9-2015.
17. A. Osterwalder, Y. Pigneur, *Business Model Generation: A Handbook for Visionaries, Game Changers, and Challengers,* 2nd Edition, John Wiley & Sons, 2010.
18. Google, Benefits of Experiments, https://support.google.com/analytics/answer/1745147?hl=en, accessed Jan., 26, 2015.
19. C. Roschuni, J. Kramer, A.M. Agogino, Design talking: How design practitioners talk About design research methods, *Proc. International Conference on Design Theory and Methods*, ASME IDET/ CIE, 2015.
20. Development Impact Lab, Rural Electric Power Project, http://dil.berkeley.edu/technology-portfolio/current-projects/repp/, accessed 9- 2015.
21. General Electric Co*,* Big data for big water, Economist, Look ahead blog, Sept. 6, 2013, http://gelookahead.economist.com/big-data-for-big-water/, accessed Jan. 26, 2015.
22. Water.org, My life as a kiosk operator, http://water.org/post/my-new-life-kiosk-operator/], accessed 9- 2015.
23. M. Wohlesn, Big data helps farmers weather drought's damage, *Wired*, Sept. 6, 2012. http://www.wired.com/2012/09/big-data-drought/, accessed 9- 2015.
24. D-Rev, Newborn health, 2015, http://d-rev.org/projects/newborn-health/, accessed 9-2015.
25. D. Wilson, M.I. Adam, O. Abbas, J. Coyle, A. Kirk, J. Rosa, A. Gadgil, Comparing cookstove usage measured with sensors versus cell phone-based surveys in Darfur, Sudan, *Proceedings of the Technologies for Development (Tech4Dev),* 2014, UNESCO.
26. D.I. Levine, T. Beltramo, G. Blalock, C. Cotterman, What impedes efficient adoption of products? Evidence from randomized variation in sales offers for improved cookstoves in Uganda, 2013, CEGA working paper, http://www.escholarship.org/uc/item/86v4x8nn, accessed 9-2015.
27. M. Fuge, A.M. Agogino, N. Maton, How online design communities evolve over time: the birth and growth of Open IDEO, *Proceedings of the International Design Engineering Technical Conference* (IDETC), August 2014.
28. Development Impact Lab (2015). UC Berkeley, http://dil.berkeley.edu/, accessed 9-2015.
29. CellScope, 2015, http://cellscope.berkeley.edu/, accessed 9-2015.
30. WE CARE Solar, 2015, http://wecaresolar.org/, accessed 9-2015.
31. C. David, Big Ideas@Berkeley winners visualize an end to cervical cancer, Blum Center, University of California, Berkeley, http://bigideas.berkeley.edu/2015/09/03/big-ideasberkeley-winners-visualize-an-end-to-cervical-cancer/, accessed 9-2015.
32. bigIdeas@berkeley, ElectroSan: Recovering nitrogen from urine in Nairobi, Kenya, University of California, Berkeley, http://bigideas.berkeley.edu/winners/electrosan-recovering-nitrogen-from-urine-in-nairobi-kenya/, accessed 9- 2015.

Author Biographies

David I. Levine is the Eugene E. and Catherine M. Trefethen Professor of Business Administration at the Haas School of Business at the University of California, Berkeley. He is past chair of the University's Center for Health Research, on the Advisory Board for Center for Effective Global Action (CEGA), and the Haas School's Economic Analysis and Policy Group.

Address: Haas School of Business; University of California, Berkeley; Berkeley, California 94720

Email: levine@berkeley.edu

Alice M. Agogino is the Roscoe and Elizabeth Hughes Professor of Mechanical Engineering and is affiliated faculty at the Haas School of Business at the University of California at Berkeley. She currently serves as Chair of the Graduate Group in Development Engineering housed in the Blum Center for Developing Economies. She directs research in the BEST (Berkeley [Energy and Sustainability/ Expert Systems/ Emergent Space] Technologies) Lab and co-directs the Berkeley Institute of Design, the Human-Centered Design course threads for undergraduates and the Engineering and Business for Sustainability graduate certificate program. She works with approximately 50 San Francisco Bay Area companies and nonprofits on research and educational projects in product design and sustainability. Agogino received a B.S. degree from the University of New Mexico (1975), M.S. degree from UC Berkeley (1978) and Ph.D. from Stanford University (1984).

Address: Department of Mechanical Engineering; University of California, Berkeley; Berkeley, California 94720.
Email: agogino@berkeley.edu

Martha A. Lesniewski is a graduate student in the UC Berkeley – UC San Francisco Graduate Group in Bioengineering and works in the Herr Laboratory at the University of California at Berkeley. Her research is on the development of a rapid microfluidic electrophoretic assays for nucleic acid detection of trachoma. Her background includes biomaterials design, material characterization and tissue engineering and her interests include development engineering, global health innovation and outdoor education. Lesniewski received a B.S. in Materials Science and Engineering from the Georgia Institute of Technology (2010).

Address: UC Berkeley - UC San Francisco Graduate Group in Bioengineering, University of California, Berkeley, Berkeley, CA 94720 and University of California, San Francisco, San Francisco, CA 94143

Email: marthal@berkeley.edu