ASEE's 123rd Annual • Conference & Exposition • New Orleans, LA • June 26-29, 2016

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Paper ID #15580

HYPOTHEkids Maker Lab: A Summer Program in Engineering Design for High School Students

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INTRODUCTION

The current deficit in the quality and quantity of K-12 STEM education in the U.S. [2, 3, 6-10] is particularly detrimental to minority students, who often do not have access to, or do not choose to take, STEM-related courses [5]. This non-participation at the K-12 level is attributable to a variety of factors, including: i) under-trained teachers, as many science teachers for underrepresented populations are not adequately prepared to teach students modern trends in engineering and science; ii) curricula not tailored to emphasize STEM fields; and iii) disconnect between STEM education and practical utility that would motivate students to pursue these fields. Even though underrepresented minorities account for 33.2% of the U.S. college-age population, these groups receive only 17.7% of all undergraduate degrees in engineering and other STEM fields and comprise only 5.4% of all doctoral students in STEM. Significantly, even when minority students enter a four-year STEM major, only 42% of African Americans and 49% of Hispanics complete their STEM degree [4]. This lack of STEM education manifests in minorities not attaining STEM-related occupations: African Americans make up less than 5% of scientists and engineers, and Hispanics 6% [1].

We are particularly interested in the lack of pre-college engineering and design emphasis in STEM education. Currently, there is an engineering renaissance across the country that is capturing the imagination of young innovators. This interest includes coding, hardware and software hackathons, and the bourgeoning “Maker” movement. The Next Generation Science Standards (NGSS), which are increasingly becoming part of K-12 curricula, emphasizes engineering and design principles. The NAE and NRC Center for Education established the Committee on K-12 Engineering Education. This committee stresses that STEM education should include engineering design training; however, there remains a lack of cohesive engineering thrusts in primary and secondary school curricula [7]. This gap misses a huge opportunity, as engineering design encourages students to critically think about important societal challenges and link their work immediately to tangible outcomes which would promote continued interest in STEM. Hence, there is an emergent demand for (a) students who have had significant, hands-on engineering and design experiences and (b) trained K-12 teachers who can impart engineering and design principles to their students.

To address the pressing need for high school engineering design training, particularly for young people from underserved minority populations**,** we have created the HYPOTHEkids (Hk) Maker Lab, a six week summer program in which high school students from underserved communities are introduced to biomedical engineering (BME) and biodesign. They are then challenged to apply the biodesign principles by devising engineered solutions to biomedical problems. BME and biodesign are particularly fertile areas for young students in STEM because these fields challenge students with tangible, real-world problems. Biodesign efforts can lead to solutions that can improve people’s well-being. The Hk Maker Lab provides a hands-on introduction to biomedical engineering and biodesign, empowering the students by showing that they can devise solutions to real-world problems. The Hk Maker Lab is meant to be a formative educational experience, encouraging these students to continue pursuing opportunities in STEM fields , including undergraduate degrees, and careers. The goal of this paper is to outline the programmatic activities of the Hk Maker Lab summer program, describe initial assessments and outcomes; and provide a vision for how this program can enhance engineering education for high school students.

HK MAKER LAB CURRICULUM

The Hk Maker Lab takes place over a six-week span each summer. Rising high school Juniors and Seniors are recruited from schools across New York City with populations that are primarily made up of underserved minority populations. A rigorous application process, including procuring letters of recommendation from teachers, principals, and mentors, ensures a candidate pool of high-achieving students. The selected participants, typically 24 - 26 students, meet four (4) days per week (Monday – Thursday, 20 hours/week) at Columbia University. The course consists of a combination of in-class workshops and laboratory activities, progressively introducing the biodesign process. The students, working in teams of four, then embark on the creation and verification of a prototype biomedical device that will be designed and built to satisfy a biomedical need of their identification (see Table 1.)

Table 1 Hk Maker Lab Program Schedule (2015)

DATE	DAY	TOPIC	TYPE
Week 1	MON.	Course Intro	Workshop
	TUES.	Basic Physiology - Body Temperature, Body Temperature Monitor	Lab
	WED.	Problem Identification and Needs Statement, Basic Physiology - Breathing Rate	Workshop/Lab
	THUR.	Guest Speaker, Breathing Monitor	Workshop/Lab
Week 2	MON.	Call with Customer (Uganda) Research & Design Inputs	Workshop
	TUES.	Basic Physiology - Cardiac System, Heart Rate Monitor	Lab
	WED.	Idea Generation & Brainstorming	Workshop/Lab
	THUR.	Guest Speaker, Microcontroller - Arduino	Workshop/Lab
Week 3	MON.	Brainstorming & Solution Selection, Solution Mockups	Workshop/Lab
	TUES.	Basics of Prototyping and Testing, Solution Selection	Workshop/Lab
	WED.	Proof of Concept Testing	Lab
	THUR.	Guest Speaker, Proof of Concept Testing	Workshop/Lab
Week 4	MON.	Call with Customer (Uganda), Business Planning in Design, Prototyping	Workshop/Lab
	TUES.	Prototyping	Lab
	WED.	Prototyping	Lab
	THUR.	Guest Speaker, Prototyping	Workshop/Lab
Week 5	MON.	Professional Presentations & Pitches	Workshop/Lab
	TUES.	Prototyping	Lab
	WED.	Guest Speaker, Prototyping	Workshop/Lab
	THUR.	Prototyping	Lab
Week 6	MON.	Prototyping	Lab
	TUES.	Prototyping & Testing, Final Pitch Preparation	Lab
	WED.	Final Preparations	Lab
	THUR.	FINAL PITCH EVENT	

Workshops

During the first three weeks of the program, students are introduced to a formal biodesign process, the same process taught to Columbia University BME undergraduates. The design-focused workshops take place in the morning (10 a.m. – noon) on Mondays and Wednesdays. Each session covers a critical aspect of the process with specific focus on biomedical technology development (Figure 1.) The lectures are highly interactive and engaging for the students, emphasizing how biodesign principles are employed to shape the real-world devices and medical breakthroughs that are used to improve lives. This approach ties the STEM training that students have previously received to the creation of tangible solutions.

Students are first introduced to Needs Finding and Problem Identification. This process involves determining where there are biomedical problems that warrant engineering solutions. In coordination with the needs identification, students are introduced to research tools and charged with developing a knowledge base about the problem from which the need arises. The goal of this process is to get the students thinking about how they can apply their knowledge to relevant problems, emphasizing the importance of STEM education and providing the opportunity for application. More importantly, students are challenged with identifying problems on their own so that they can be self-starters in the design process, priming them for innovation beyond the Hk Maker Lab.

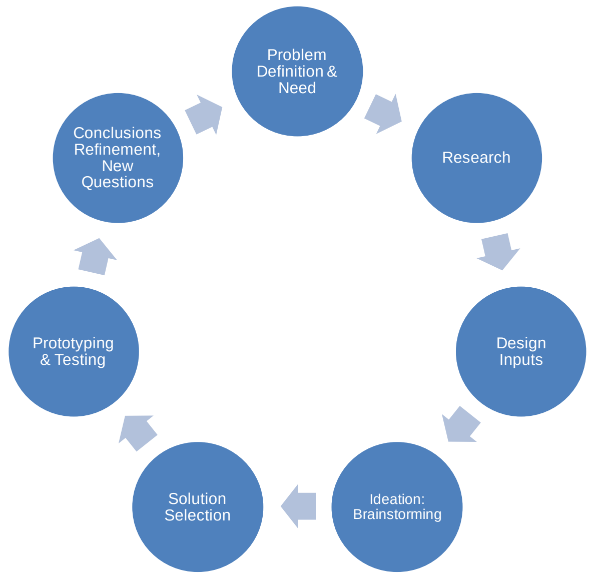


Figure 1 Cyclical biodesign process employed at Columbia University

The next phase focuses on the definition and evaluation of Design Inputs, the criteria that governs the solution(s). Students have to identify for whom their solution is being developed as well as who will utilize the solution (patients, governments, physicians, etc.). It is these customer needs that the students strive to satisfy with their inventions, thus spurring them to use STEM knowledge to devise solutions for explicit users. Students are also introduced to the concept of constraints, that is, the real-world limitations, such as cost, aesthetic considerations, native language of users, etc., that will govern their prospective solutions.

Next, prospective solutions are developed through Ideation and Brainstorming. The teams perform extensive brainstorming exercises to devise creative solutions for their identified design problem, calling upon both their STEM knowledge and their imaginations to solve the problems. The prospective solutions are then evaluated with respect to the customer needs and real-world constraints to determine which solutions are most appropriate to pursue further. The product of this ideation phase is a solution set that is then explored through prototyping and testing.

In the final biodesign workshop sessions, students are introduced to the basics of business planning with an emphasis on market analysis and business model formation. Students create the basic components of a business plan showing how their venture may be profitable or sustainable. This entrepreneurial focus helps demonstrate that both economic interests and technological innovation work together to solve biomedical problems, further connecting their growing engineering design knowledge to real-world considerations. Furthermore, we want to expose the students to the business aspects to demonstrate that viable careers can arise from innovation. That is, their STEM skills and imaginations can be used to make money!

Guest Speakers

In coordination with biodesign education, the Hk Maker Lab is meant to introduce students to STEM careers. To show students the different STEM-related career paths, we had weekly guest speakers visit the program. These speakers, who usually visited on Thursday mornings, were from academia, medicine and industry. The guests spoke to the class about their backgrounds, professional activities, and provided general guidance on what the Hk Maker Lab participants should do to attain STEM-related goals. Guest speakers from the 2015 class included:

- Dr. Sam Silverstein, John C. Dalton Professor of Physiology & Cellular Biophysics, and Professor of Medicine, Columbia University
- Dr. Rakesh Sahni, Associate Professor of Pediatrics Columbia University College of Physicians and Surgeons
- Profs. Clark Hung, Henry Hess, Paul Sajda, Sam Sia, and Qi Wang, Professors of Biomedical Engineering, Columbia University
- Profs. Christine Hendon and David Vallancourt, Professors of Electrical Engineering, Columbia University
- Matthew Wilkins, inventor and entrepreneur, Founder, Pedal Forward.

Additionally, we had graduate students from the Department of Biomedical Engineering visit the students for weekly lunchtime chats about undergraduate and graduate school. The graduate student visits provided an excellent set of near-peer role models for the Hk Maker Lab students; showing them some of the short term outcomes that come from pursuing STEM undergraduate degrees.

The guests were a particularly exciting aspect of the program for the students. They greatly enjoyed learning more about the actual applications of engineering and biodesign. We regularly overheard students discussing their desire to go to medical school, their interest in conducting biomedical research, or their desire to work in biotechnology. This component of the program further bolsters the idea that a foundation in a STEM field can open the doors to a variety of exciting career options.

Laboratory Procedures

The biodesign instruction is complemented by hands-on, laboratory activities, which are critical in getting the students excited about STEM and biomedical engineering. The lab sessions give students opportunities to design, build, test and refine their project efforts. The students typically begin our program with very little experience building biomedical devices. To get the students started and to establish their confidence in the lab, the first set of sessions involve a series of well-defined laboratory activities to enhance the students' understanding of their biomedical problems of interest.

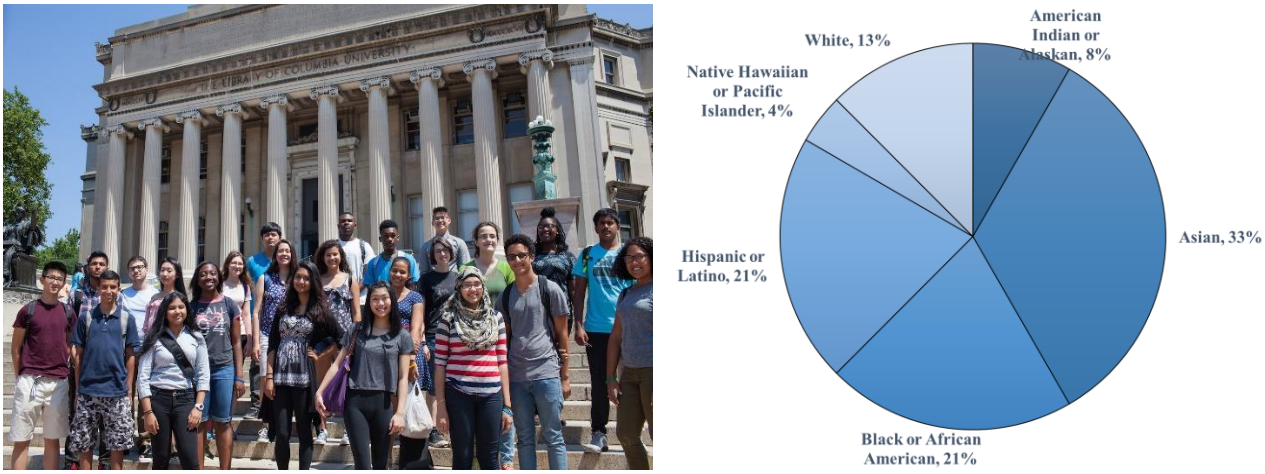
The lab sessions take place in the afternoons on Mondays and Wednesdays and throughout the day on Tuesdays and Thursdays during the first three weeks of the program (~ 16 hours/week of hands-on lab time). For these structured laboratory activities, student teams are charged with building and testing various vital sign monitors; simple devices to measure body temperature, respiratory rate, and heart rate. The sessions are fairly open-ended, allowing the students freedom to explore various techniques and the equipment necessary to create a solution to their identified problems. Upon completion of each of the vital sign monitors, the student teams give short presentations detailing the problems of interest and their methods to measure the vital signs.

Prototyping
During the workshops and the initial lab sessions, the student teams identify problems that mandates a biomedical solution and a prospective device solution. The second half (3 – 3.5 weeks) of the program is devoted to creating prototypes of their solutions. Students are introduced to Proof of Concept testing, that is, prototyping for the purpose of answering the critical questions related to the device solution. In addition, students are introduced to how prototypes are iteratively re-designed until the customer needs are addressed within the design constraints.

The students subsequently embark on creating the solutions to their problems. The initial prototyping sessions are heavily guided by the instructors, ensuring direction as students embark on an unfamiliar process. Instructors identify what tools and techniques will allow them to develop their solutions. As they gain knowledge, confidence, and momentum, the guidance is reduced and the students dictate the necessary steps to progress with consultation input from instructors. By the conclusion of the program, students have designed, built, and refined a viable prototype, demonstrating to themselves that they can create innovative solutions to real-world problems.

Final Pitches
Throughout the program, the students are provided instruction on crafting formal presentations and practice discussing their project progress. The course culminates in the students giving final "pitch-style" project presentations in which they describe their biomedical problem and the associated elements that have been discovered throughout the program. They extensively discuss their prototyping efforts and the outcomes of prototype testing. The presentations are structured as though the students are attempting to "sell" their solutions to potential investors. A group of invited guests from academia, industry, and entrepreneurial sectors are impaneled to evaluate the presentations based on the program objectives and criteria. The final pitches are also open to the public; giving the students the opportunity to demonstrate their newfound engineering skills to family, friends and teachers. We hope that, through these presentations, the students will be able to effectively communicate their design efforts as well as other technical projects they might encounter in the future.

OUTCOMES – 2015 HK MAKER LAB
The Hk Maker has been offered annually since 2014, with the most recent cycle being held in the Summer 2015. High school students from throughout NYC, 18 rising Seniors and 6 rising Juniors (14 female, 10 male) were recruited from schools where >50% of students, or the participants themselves, were eligible for free or reduced priced lunch or from schools where >50% of the student population are from minority groups. We targeted these schools to create an ethnically and socioeconomically diverse student body, a goal that was reasonably accomplished with the program participants (see Figure 2(b)).



(a) (b)

Figure 2 (a) Photo of 2015 Hk Maker Lab participants at Columbia University, NY and (b) self-reported ethnicities of inaugural Hk Maker Lab participants (24 students total)

Surveys were administered at the start and end of the program to (indirectly) assess the students' interests and perceived skills gained through participation in the Hk Maker Lab. Many of the students expressed pre-existing desire to pursue engineering and design; however, through the surveys and initial discussions, it was clear that most were not knowledgeable of engineering. Often we found that they equivocated experiences with technical tools, e.g., computer programming, 3-D printing, basic circuit work, with engineering. While the students had good technical knowledge, they did not have a foundational understanding of engineering as a field. This provided a unique opportunity to give the students a formative pre-college engineering experience. This initial experience provides a preview of the challenges that arise while pursuing an undergraduate engineering degree and engender confidence that these students will be able to take on and learn from these challenges. With regards to specific outcomes, participation in the Hk Maker Lab resulted in a significant student-perceived increase in engineering design knowledge. There was not a significant increase in the students' interest in applying engineering design or in their desire to pursue STEM undergraduate majors (Figure 3). This is not necessarily a negative outcome: the students' strong interest in engineering and science coming into the program persisted despite the highly rigorous nature of the program: These young students were able to successfully complete a biodesign program whose core

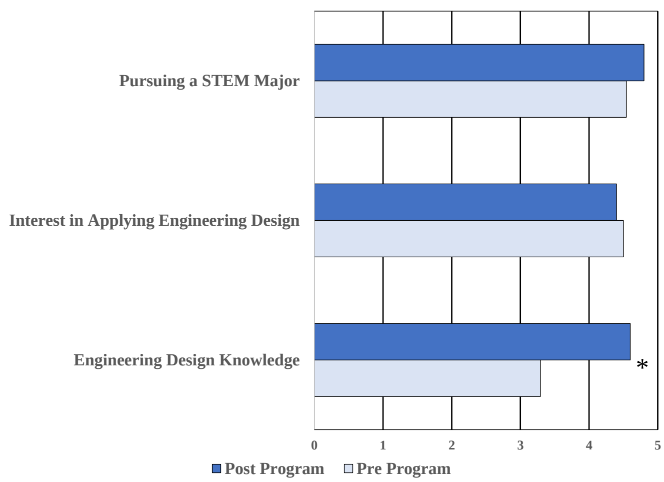


Figure 3 Student pre- and post-course survey responses with respect to the objective-related course outcomes (1~Strongly Disagree, 2~Disagree, 3~Neutral, 4~Agree, 5~Strongly Agree.) *~ significant difference between pre- and post-course scores (Wilcoxon Rank Sum Test, $p < 0.05$.)

content is comparable to the concepts taught in the undergraduate Biomedical Engineering Design class at Columbia.

2015 Hk Maker Lab Designs and Prototypes

Utilizing their burgeoning design skills, the student teams uncovered biomedical needs that mandated biomedical solutions. To avoid being overwhelmed as they uncovered problems, students were allowed to select either global health technology projects or from a pool of pre-screened needs. The global health technology projects were particularly attractive to our students; four of the six groups choosing these projects. We believe that they are excited by these projects because they: (1) allow students to free explore and identify a problem of their interest; (2) clearly demonstrate how engineering acumen can be used to improve the human condition; and (3) afford students opportunities to directly interact with prospective users as we regularly had the student teams speak to medical professional colleagues in Uganda to learn about their specific medical technology needs.

The six 2015 Hk Maker Lab teams successfully created engineered prototypes for their biomedical needs. The devices created during the 2015 cycle included (*global health technology project):

- A needle sterilization system to prevent infections from secondary needle sticks*
- A fall detection and alarm system for elderly persons
- An air filtering system for eliminating airborne pathogens in low resource medical facilities*
- A device for obtaining uncontaminated cervical tissue samples from women who were subjected to genital mutilation*
- An O_2 generation system to provide respiratory therapy in low resource settings*
- A temperature monitor to detect the onset of hyperthermia in athletes.

(a) **(b)**

Figure 4 2015 Hk Maker Lab participants (a) creating vital signs monitors during lab sessions and (b) developing a prototype solution for their biomedical problem.

PRELIMINARY CONCLUSIONS AND FUTURE WORK

We have created the Hk Maker Lab, a pre-college program that provides an engineering experience for New York City high schools students. By targeting students from economically disadvantaged schools and underrepresented minority groups, we provide an opportunity for young people that would not normally engage in such a rigorous engineering program. Although still in its infancy, the Hk Maker Lab is off to a promising start. Forty-nine students have participated in the program. Eight of these students have gone on to attain internships in biotechnology or biomedical engineering labs. One of our 2014 students, an African American from Democracy Prep Harlem Charter High School (66% African American, 32% Hispanic,) interned with a NYC-based startup companies ExVivo throughout his final year of high school. This student has stated that participation in the Hk Maker Lab directly impacted his education and career aspirations; he is currently a student in the joint BA/BS program in bioengineering at Emory University and the Georgia Institute of Technology. The 2015 cohort yielded our first student admitted to Columbia University (early decision). Feedback from 2015 student participants included (culled from the aforementioned post-course survey): "*This was definitely an intense program but I learned so much. It really exposed me to… a whole new world, and I'm glad I did this program. It made me more interested in engineering.*" "*Although the HK maker lab program is 6 weeks, it feels like 1 whole year of learning*." "*The course made me realize that I was in love with engineering and lab work.*"

The next phase of the Hk Maker Lab will involve examining the trajectories of students following participation in the program. We recognize that participants came into the program with a pre-existing interest in engineering. Our goal is to introduce them to design aspects of engineering and stoke continued desire to pursue STEM. Accordingly, in upcoming Hk Maker Lab classes, we will track student participants beyond their experiences in the program. This assessment will include but is not limited to tracking Hk Maker Lab alumni:

- Pursuing STEM undergraduate majors
- Completing undergraduate degrees
- Post-collegiate plans, i.e., grad or medical school, graduate school, jobs in biotechnology.

This type of longitudinal assessment will be primarily performed via regular communications (e-mails, online surveys, etc.) with program alumni. We will examine the proportion of our students who pursue STEM compared to national averages. We are particularly interested in having an increased number of minority students completing four-year STEM programs. Ongoing evaluation will be provided with support from the Education Development Center's Center for Children and Technology (EDC/CCT), an education research organization that focuses on how technology can impact teaching and learning. EDC/CCT will form the evaluation strategy for the Hk Maker Lab and associated activities related to the summer program.

The advent of the NGSS and increased emphasis on K-12 engineering education demands engineering-centric curricular elements in high schools. The Hk Maker Lab is a good initial experience, but the relatively small number of annual participants limits its impact. To promote early engineering across a large population of students, especially for those in economically disadvantaged, minority-serving high schools, the Hk Maker Lab will also be used as an engineering design education training platform for high school teachers. The Hk Maker Lab summer program will be a co-learning environment in which the high school teachers learn biodesign instruction. This unique approach will allow the teachers to learn the design process while observing how it is imparted to students and creating their own instructional content. They will subsequently utilize these lessons to form their own design class(es) and/or to integrate design concepts into existing courses. This innovative approach will provide a professional development opportunity for teachers that will ultimately result in their creation of courses that will enhance students' STEM education. This approach will also facilitate the creation of a scalable engineering design curriculum that can be readily applied to other high school students with whom we might not have direct contact, expanding our impact beyond the 24 students who participate in the summer program. We have started testing this approach with two local high school teachers participating in the 2015Hk Maker Lab to observe the engineering design instruction. We are currently working with these teachers to translate their observations and experiences into their classrooms. The goal of these efforts is to create an innovative professional development platform that will enhance the quality of engineering instruction throughout New York City.

REFERENCES

1. *Women, Minorities, and Persons with Diabilities in Science and Engineering*. National Science Foundation, National Center for Science and Engineering Statistics: Arlington, VA.
2. *National Action Plan for Addressing the Critical Needs of the U.S. Science, Technology, Education, and Mathematics Education System*, N.S. Board, Editor. 2007: Washington D.C.
3. *Mathematics and science partnerships*, O.o.E.a.S.E. U.S. Department of Education, Editor. 2008.
4. *Expanding Underrepresented Minority Participation: America's Science and Technology Talent at the Crossroads*. 2010, National Academies Press: Washing, D.C. p. 286.
5. Griffith, A., *Persistence of women and minorities in STEM field majors: Is it the school that matters?* 2010, Wake Forest, NC: Winston-Salem, NC. p. 37.
6. Jeffers, A., A. Safferman, and S. Safferman, *Understanding K-12 Engineering Outreach Programs.* Journal of Professional Issues in Engineering Education, 2004. **130**: p. 95-108.
7. Katehi, L., G. Pearson, and M. Feder, *Engineering in K-12 Education: Understanding the Status and Improving the Prospects.* . The Bridge: Linking Engineering and Society, 2009. **39**(3).
8. Kimmel, H., J. Carpinelli, and R. Rockland. *Bringing Engienering into K-12 Schools: A Problem Looking for Solutions*. in *International Conference on Engineering Education*. 2007. Coimbra, Portugal.
9. Project 2061 (American Association for the Advancement of Science), *Benchmarks for science literacy*. 1993, New York: Oxford University Press. xv, 418 p.
10. Silverstein, S., et al., *Teachers' Participation in Research Programs Improves Their Students' Achievement in Science.* Science, 2009. **326**(5951): p. 440-442.