METAL – ORGANIC FRAMEWORK (MOF) FABRIC FOR THE FILTRATION OF PARTICULATE MATTER
(Technical Paper)

IS MORE ALWAYS BETTER? EXAMINING NANOTECHNOLOGY R&D IN CHINA AND THE US
(STS Paper)

A **Thesis Prospectus Submitted to the**

Faculty of the School of Engineering and Applied Science
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In Partial Fulfillment of the Requirements of the Degree
Bachelor of Science, School of Engineering

Rachel L. Ho
July 26, 2019

On my honor as a University Student, I have neither given nor received unauthorized aid on this assignment as defined by the Honor Guidelines for Thesis-Related Assignments

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From carbon nanotubes to cancer fighting nanorobots, nanotechnology offers promise for a better future. According to the US National Nanotechnology Initiative (NNI) (2018), "nanotechnology is the understanding and control of matter at the nanoscale, at dimensions between approximately 1 and 100 nanometers" (para. 1). It represents a wealth of untapped potential for humans across multiple areas, and is generally perceived in a positive manner by the public. Taken from a report by the Rennsselaer Polytechnic Institute Nanotechnology Center, this quotation summarizes the buzz of excitement behind nanotechnology near the turn of the century:

> Nanotechnology can make it all better – literally – by re-engineering the fundamental building blocks of matter. It is one of the most exciting research areas on the planet, and it may lead to the greatest advances of this century. (Lightman et al., 2003, p. 67)

On the other side, there are considerable dangers associated with nanotech, involving environmental concerns, privacy issues, and the potential to create deadly weapons (Gupta et al., 2015). Despite this present risk, the global nanotechnology market is expected to grow to $90.5 billion by 2021 (BCC Research, 2016). Nanotechnology will only continue to become more relevant in our lives, so it is important to understand how, and in what direction, this field is developing towards. The technical and STS project I propose will attempt to address this by providing insight into the research and development (R&D) of nanotechnology, the first step toward widespread manufacturing and consumer use. On the technical side, under the supervision of Professor Guarav Giri, chemical engineering, I will investigate the feasibility of creating nanomaterial-based filters using novel methods. The loosely coupled STS project will research how societal views and values affect the education and research systems for nanotechnology, particularly in China compared to the US, two countries which are major contributors to nanotechnology R&D. Both will be reported in the form of a scholarly article.

POLLUTION AND THE PLIGHT OF THE POOR

One problem the use of nanomaterials is being applied to is air pollution, which is a threat to human health across the globe. Chen and Kan (2008) report that particulate matter is one of the three traditional air pollutants, and exposure to it, specifically those smaller than 2.5 μm ($PM_{2.5}$), is linked to a variety of health issues including adverse effects on cardiovascular and respiratory mortality (p. 94). But while this is a global problem, air pollution is specifically an epidemic in developing countries where it has increased dramatically in the past two decades. As Dr. P. M. Mannuccio and M. Franchini (2017), both prominent researchers in the field of health and medicine, report, “pollution explosions along with widespread industrialization … have resulted in dense urban centers with poor air quality” (p. 2). Besides attempts to address this issue through public policy and improved air quality standards, the dominant protective measure has been the use of facemasks. However, these masks can either be expensive or ineffective at preventing the inhalation of pathogens due to leakage (Cherrie et al., 2018). Because of this, the people in developing countries who cannot afford masks and are untouched by these new air policy standards are left vulnerable to pollution, and even those with access to masks are susceptible and may also suffer the consequential health effects.

MOF NANOFILTERS

With this increasing pressure to find solutions, scientists are researching new technologies for effective pollution control. This includes the study of metal-organic frameworks (MOF), which are a class of crystalline nanomaterials (Kumar et al., 2015). Because of their incredibly high surface area and tunable pore size, they are ideal materials to use in pollution capturing devices. Their specific pore size can house particulate matter, and the charged metal ions that make up the nodes of the nanomaterial can induce electrostatic interactions that attract and bind to the pollutants (Zhang et al., 2016). Current research, however, uses expensive procedures, such as electrospinning, so this technology is not readily implementable or available in developing countries where pollution is the most rampant (Lu et al., 2017).

Thus, the objective of the technical project is to create an efficient and widely available pollution-capturing device by attaching MOFs to inexpensive fabrics with simplified methods. This project, titled MOF Filters for the Filtration of Particulate Matter, will be a semester long project that seeks to probe this objective through a methodological approach. Over the course of this project, several methods of attaching MOFs to fabrics will be tested and developed, such as the Layer-by-Layer (LbL) solution dipping approach shown below in Figure 1. Afterwards, MOF loading will be measured using several analytical techniques such as Brunaeur-Emmett-Teller (BET) isotherm measurements and thermal gravimetric analysis (TGA), and filtering capabilities will be measured and optimized through a filter tester equipped with a particle counter.

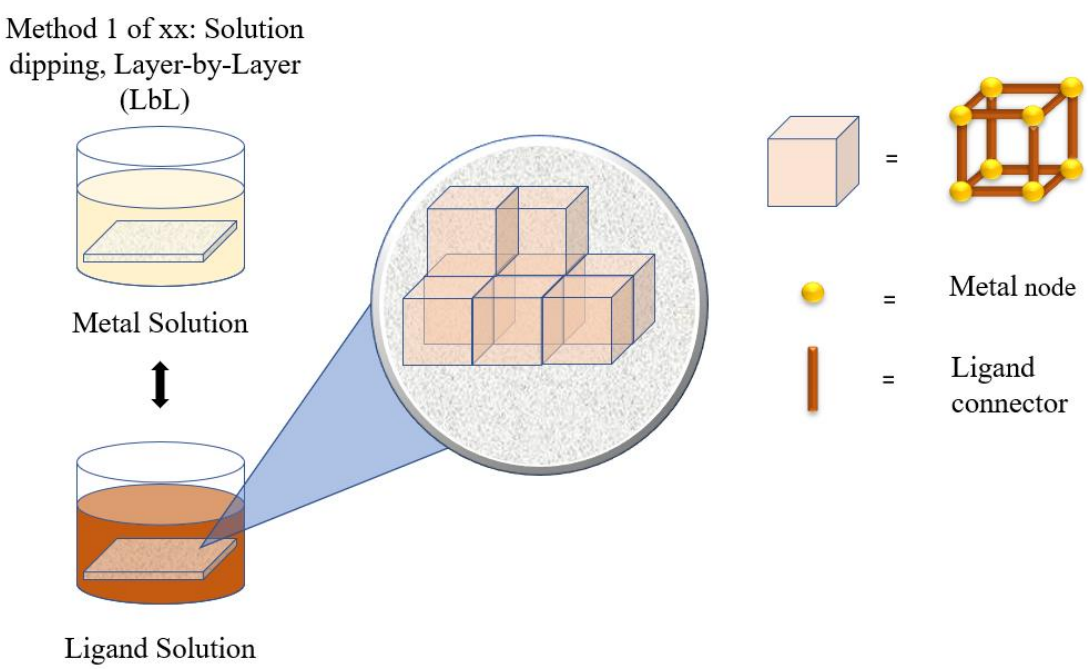

Figure 1: LbL Approach for MOF Growth: This shows basic structure of MOFs and overall methodology for LbL approach, one of the several methods that will be used (Ho, 2019).

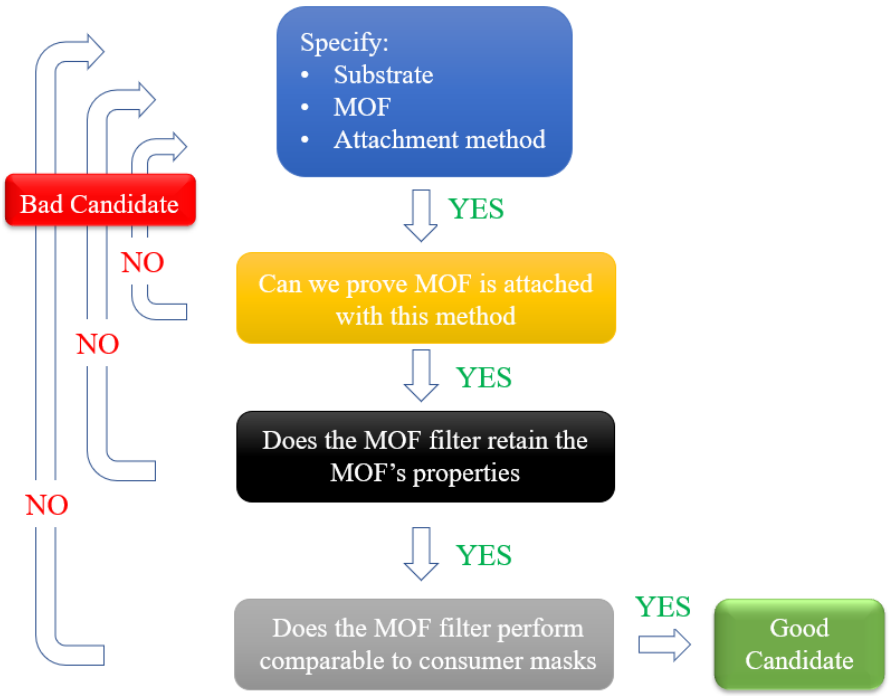

Figure 2: Research Methodology for Optimizing MOF Filters: A simplified optimization flow chart that focusses on filters' performance and characteristics (Ho, 2019).

In this project, there are many parameters of control, including fabric type, MOF material, and attachment method. Because of this, a systematic approach will be used to optimize and remove as many unsuitable candidates as possible. A simplified diagram of this approach can be seen in Figure 2. After iterating through this process multiple times, we should increasingly gain knowledge on the parameters that produce the best performing MOF filter. Measurements of performance may include not only filtration ability, but also filter durability and safety evaluations for human use.

After investigating a sufficient range of materials and methodologies, I will report my findings in the style of a scholarly article following American Chemical Society (ACS) guidelines. I hope that this research will not only reveal important information on the feasibility of this technology, but also give insight in how to control a major class of nanomaterials.

THE NANOTECHNOLOGY RACE

Despite the dreams of what nanotechnology can be, nanotechnology is still only a developing technology, early in its stages of research and widespread adoption. Nanotech nonetheless is developing rapidly, and the question of how to commercialize and control this area of research is becoming more and more relevant. Dr. Andrew Maynard (2007), a former physicist and current director of the Rest Innovation lab in the School of Future Innovation in Society at Arizona State University, offers his opinions on the matter in a *New York Times* article, stating that "it is clear that the successful commercialization of nanotechnology means maximizing its benefits and minimizing its risks. This will require strategically focused research, backed up by adequate funding" (para. 12). From this quotation, we see that there are two key drivers that successful nanotechnology development must have: research initiatives and funding; and for the most part, many nations have followed this, pouring out resources and money in order to have a spot in the nanotechnology race.

The US and China are examples of leading countries in the nanotechnology race, both of whom have comparable nation-wide programs and support. According to Y. Gao et al. (2015), the US government started the first nanotechnology program, the National Nanotechnology Initiative, and former President Obama proposed a $1.5 billion investment in it in 2015 (p. 13). The Chinese government similarly houses program initiatives like the Nanoscience Basic Research Program, and invested $1.6 billion for research in the field of nanotechnology in 2009 (Gao et al., 2015, p. 13). So, comparatively the US and China are both engaging in funding and focused research as Dr. Maynard suggested; but overall, how are they performing in the area of R&D?

CHINESE STEM EDUCATION: THE COMRPOMISE IN QUANTITY AND QUALITY

Examining the research side of R&D, the Chinese are reportedly publishing more scientific papers on nanotechnology than the US. StatNano (2019), a comprehensive statistical database of nano-relate information, reports that in 2018, China held 39.47% of total nanotechnology publications while the US only held 14.75%. Interestingly, nanotechnology research in China also appears to be a topic of higher interest for top-tier universities compared to the US where interest is spread out across various academic institutions (Kostoff et al., 2007, p. 705). But while China may have published more, Chinese publications are noted to primarily be in journals of lower impact factor compared to the US. The impact factor is the yearly average number of citations of publications in a given journal; the higher it is, the higher its quality is generally regarded as. In a 2016 research report, between 2003 and 2013, the US published 1,068 nanotech paper in journals with an impact factor >20, while China only produced 76 papers in journals with an impact factor >20 (Dong et al., p. 9). This discrepancy between the quantity and quality of China's research in nanotechnology may be the result of several factors, but the most prominent reason is most likely the educational systems of China, which feed into R&D and are impacted by societal and governmental factors.

The Chinese education system, while once held in high esteem, is now noted to be influenced by academic fraud, discredited research, and a culture of performance evaluations that emphasizes and rewards quantity above all else (Han & Appelbaum, 2018). The prospect of success has become the main motivation in China, and this has become so engrained into its education system that fraudulent writing to gain more prestige is normal among academic professionals. Cheating and fraud is so normal, in fact, that there is minimal academic discipline even after being caught. As Professor Zhang Lei, a professor of applied physics at Xi'an Jiaotong University, states when discussing the outbreak of academic fraud, "In America, if you purposely falsify data, then your career in academia is over … But in China, the cost of cheating is very low. They won't fire you" (as cited in Qin, 2017, para. 18). Ironically, China is striving to achieve higher quality work than its competitors, but it is demoralizing and degrading the structure of its academic institutions in the process.

Government intervention in research also exacerbates issues in nanotechnology R&D. In a speech at the opening ceremony of The Belt and Road Forum for International Cooperation in 2017, Chinese President Xi Jinping rallied Chinese citizens toward its new technologically driven future with innovations in several areas, including nanotechnology development:

> We should pursue innovation-driven development and intensify cooperation in frontier areas such as digital economy, artificial intelligence, nanotechnology and quantum computing, and advance the development of big data, cloud computing and smart cities so as to turn them into a digital silk road of the 21st century. We should spur the full integration of science and technology into industries and finance, improve the environment for innovation and pool resources for innovation. We should create space and build workshops for young people of various countries to cultivate entrepreneurship in this age of the Internet and help realize their dreams. (as cited in Xinhua, para. 29)

Science and technology, especially among young people who are the future of China, is the focus of President Jinping's dream of the digital silk road, a complexly-knitted IT communication network. This motivation is one of the many that is pushing the Chinese government to pour out money to fund various research projects. But while government intervention helps enable researchers financially, it also decreases academic freedom and restricts research from following individual or market influences (Han & Applebaum, 2018, p. 15). Researchers are then left under the scrutiny of the government, producing only work that benefits the state.

Considering all of these issues feeding into the hindrance of high-quality nanotechnology R&D in China, we can develop a System in Context Model of the situation, as developed by Professor Bernard Carlson. This can be seen in Figure 3 on the next page.

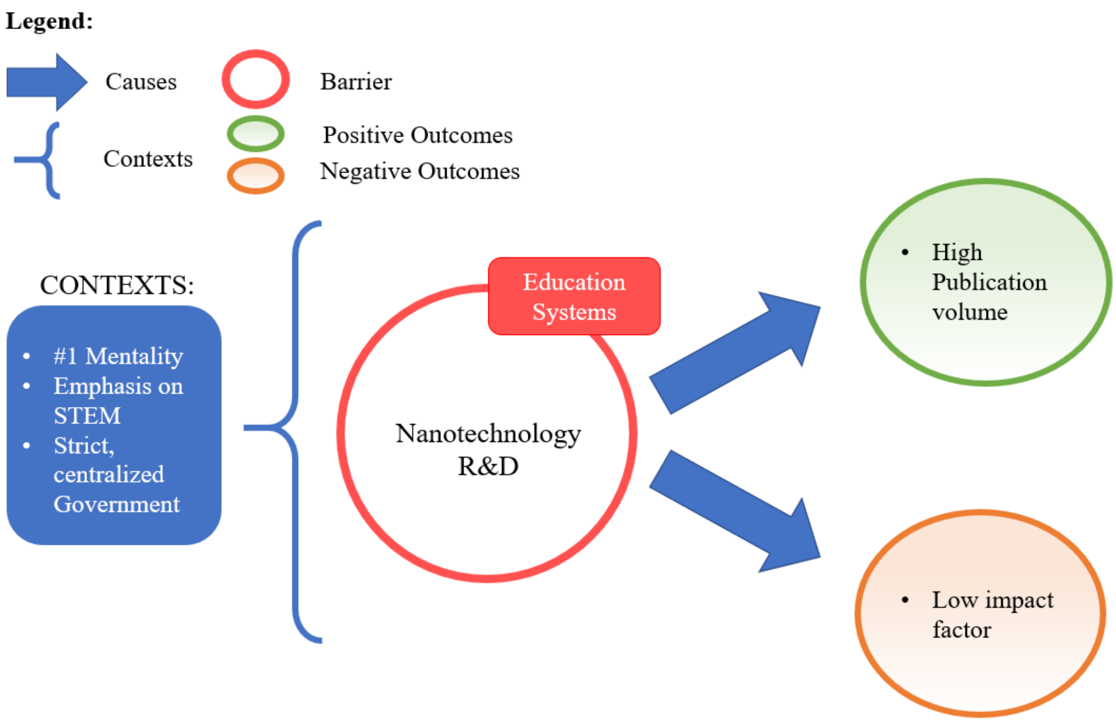

Figure 3: System in Context Model of Nanotechnology R&D in China: Education systems in China serve as a barrier to nanotechnology R&D. This barrier results in both positive and negative outcomes (Ho, 2019).

With this model, a clear barrier to nanotechnology R&D is shown to be the education systems of China, reinforced by the contexts of the nation's culture and political structure. This barrier leads to high publication numbers, but generally low-quality research, which will most likely harm China in the long run if they hope to keep up with their US counterparts. With this model in mind, we can gain visual powers in seeing the main issues that persist for nanotechnology R&D. It is important to note, however, that this model does not present any clear solutions to this growing problem. For ways in which to overcome this barrier, we will need to apply the Social Construction of Technology model (SCOT) in addition to our current analysis.

THE ENGINEER AS THE CENTER OF RESEARCH

In order to fully evaluate how nanotechnology R&D may be improved given this situation, the SCOT model should be applied. As seen in Figure 4, the researcher/designer is at the center of the model, surrounded by several key relationships.

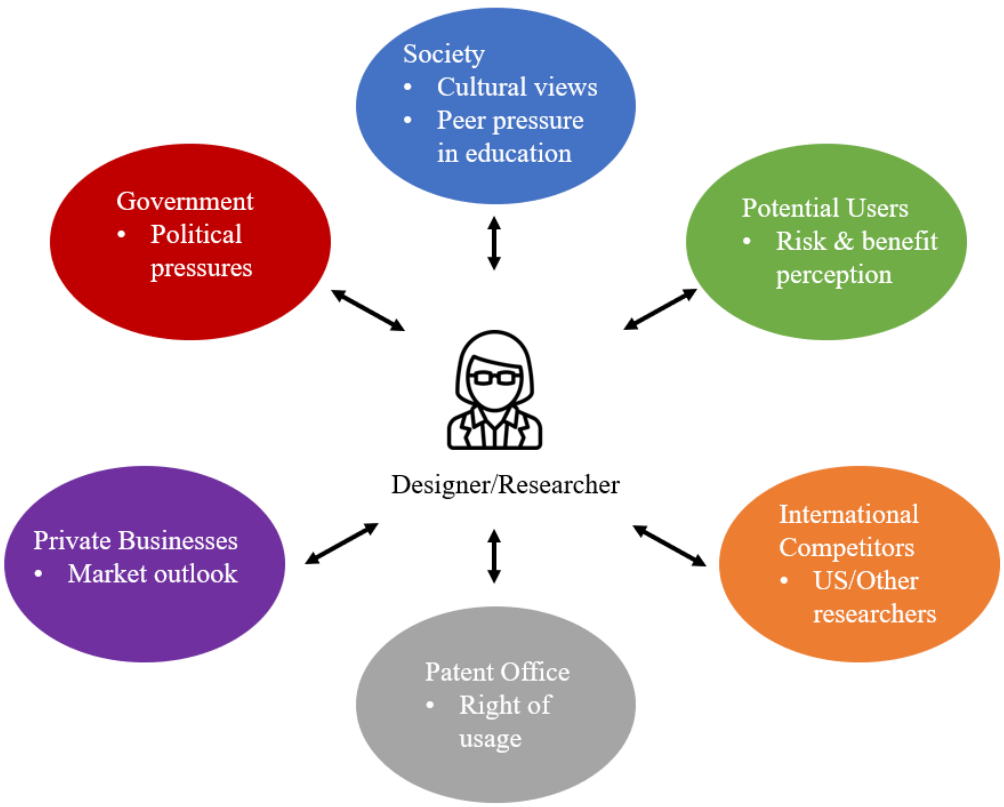

Figure 4: Social Construction (SCOT) Model of Nanotechnology R&D in China: A SCOT model in which key relations are drawn between the researcher and private businesses, the patent office, international competitors, potential users, society, and the government (Ho, 2019).

Despite what China's government may or may not think, the heart of nanotechnology research is the researchers themselves, who have the greatest ability to steer R&D. They are affected by several key relationships, which include private businesses, the patent office, international competitors, potential users, society, and the government. Using this model, we can see that education systems are no longer a barrier, but have become part of the larger influence of society. We also see that government and society still play an important role in influencing the researcher, but are not the *only* influencers as there are now several other key relationships.

There are also many shortcomings to over-bearing government influence. For example, governments often look to expert opinions when considering technology regulation because the policy makers themselves are unfamiliar with many different kinds of technology, especially nanotechnology which remains relatively new and mysterious to the general public. But as Nye (2006) points out in *Technology Matters*, "when approving new products, governments that listen to experts may fail to consider cultural and political effects" (p. 145). But conversely, if private businesses take control instead of the government, Nye (2006) also notes that "leaving 'the market' in control permits corporations with little hindrance or discussion to disseminate thousands of products that foster lasing changes in everyday life" (p. 146). Clearly, we need a balance between forces on the researcher between all the key players, and outlining them and their current role in the R&D process using the SCOT model will be the first step in our analysis of this issue.

My STS paper, in the form of a scholarly article, will seek to examine Chinese nanotechnology R&D contrasted to the US by first applying the system in context model on nanotechnology. After identifying the main issues that exist with the R&D structures in place, the SCOT model will be applied in order to reveal other possible key relationships that should be considered for the researcher beyond the social/cultural forces of its environment and government intervention. By doing this, important aspects of nanotechnology, an exponentially increasing industry, may be better understood that future researchers can use to create safer, ethical, and more efficient systems to develop nanotechnology.

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