John Li: Previous Research

I was one of the fortunate students who knew exactly what major to enroll in long before entering college: physics. While some students were unsure of what major to choose, I was unsure of which area of research within physics that am I most passionate about. In fact, I did not find the answer until recently. As a freshman, I thought I was passionate about String theory, which is the theory of everything. Then I thought maybe I wanted to develop Chaos theory, which can potentially help predict all the future. My entire journey of all my research experience was what eventually solved my puzzle. Now when an underclassman asks me how to discover their future research interest, I would simply advise him or her to start to do research: it will not reveal what your research interest is, but it will show you what it is not. At some point in time, the topic that truly interests you will just jump out, as it did for me.

It was an honor that I was able to conduct my first research project at the California Institute of Technology in the summer of 2011 right after my sophomore year of undergraduate education. My research at Caltech with Dr. K. Schwab was on *Back-action Evasion Measurement*, which verifies an experimental technique that measures more accurately beyond the quantum limit. My research split into two directions: the experimental setup of the device used, and theoretical derivation of the Kalman filter algorithm. For the experimental aspect, I worked on the most basic level of experimental setup under Postdoc Dr. Suh. Despite my lack of background, I learned many useful skills such as soldering, plumbing and screwing. Although I worked hard every day, my postdoc seemed to notice my interest was not in experiments, so he put me onto a theoretical aspect of the project where we needed a digital signal filter. Although I had minimal knowledge in digital signal processing, I was much more excited about working on Maple and Matlab to derive the algorithm; the complex analysis I had just learned played an important role for understanding Fourier-transform and Z-transform. Another postdoc in the lab on a different project noticed the excitement on my face, and asked me, "John, are you more theoretical than experimental? Because I see the excitement on your face while you're working on Maple." At that time, I never thought about this question; I just knew I loved physics. However, that question allowed me to understand for the first time that there is a difference between theoretical and experimental research. At the end of the summer, as I finished all my assigned experimental and theoretical work, I did my final report and presentation mainly on the theoretical half of the research. Since this was a large project, no concrete results were obtained at the end of the summer. However, my research in Caltech helped me realized my research interest is theoretical physics.

After the summer research, I returned to UC Merced to continue my studies. My previous for-interest discussion with Professor Umurhan officially turned into a research project in which we numerically investigated the chaotic dynamical behavior of Newton's method applied to a highly oscillatory function. We took a dynamical approach of this system and viewed it as a map, and we also analyzed it using fixed points. I also invented an efficient algorithm to invert this "irreversible map" backward, with the cost of having multiple "past". Where we found in this map, the future certain, but the past branches– and we further proved every iteration yields either three or one branch. I invented many techniques such as tree structure to organize the result and visualize the result. Recently I suggested the method of using information entropy to analyze each branch. Because of the non-linear nature of this problem, most of our research must be done on Matlab, which is doing "experiments" on computer. I realized that I am not against the idea of experimental work; I just do not like to set up the experiments. For example, when

I need intuition for my theoretical work, I often obtain insight through experiments or simulations. Because this research is between Professor Umurhan and me, this granted me a new research experience to work under direct mentorship of the professor instead of a postdoc. I prefer this style of research because I will have more frequent information exchange with the professor, and the professor is more experienced to give guidance to students. Another important lesson I learned from this research is that a research does not require a direct application. While formulating the theory, Riemann would have never expected Einstein to make use of his Riemann Geometry to generalize relativity. Although we still did not find any direct application of our research, the biggest value of this research is the experience I gained that made me a qualified researcher. I learned how to write a scientific paper using LaTeX and document math digitally. In addition to three semesters of *Numerical Analysis* class, my full year of actual research experience in Matlab has made me very proficient in numerical simulations.

While my research with Dr. Umurhan was still going on, I was selected as a McNair Scholar in my senior year and started theoretical physics research with Dr. Mitchell on his newly developed *Burning Invariant Manifold* theory on fluid flow. Initially, I worked under postdoc Dr. Mahoney on Matlab simulations; however, all my previous research experience paid off. I jumped right in to the research without a learning curve. I documented all my results nicely in LaTeX in an organized manner. Soon, within four weeks of starting the research, I had already produced 40 pages of results in my digital LaTeX notebook. While I used to doubt the purpose of my numerical research with Dr. Umurhan, I realized the previous research prepared me for my current work. In addition to working hard, I also took ownership of the research, asked my own questions, and started developing solutions on my own. Soon, I received direct mentorship under Dr. Mitchell and worked on the theory of *basins of attraction* of reaction convergence, where I needed to develop an elegant theory to organize the front behavior according to the initial conditions. It was not easy to formulate a theory. I started with intuition and made many hypotheses. In the weekly meeting with Dr. Mitchell, many ideas and approaches would be proven false. However, every time, some ideas would survive and even inspire other ideas. As these ideas added up, eventually I established a *Partial-order* on the fixed points and formulated a beautiful theory to organize the front behavior. I first used ϵ-δ definition to define reaction from one fixed point converging onto another fixed point. This definition has properties of *reflexivity* and *transitivity* made the system *Pre-ordered.* Then I group the *equivalence class* and made the system of *equivalence classes Anti-symmetric.* Together with previous *reflexivity* and *transitivity*, the system now becomes *Partial-ordered.* This result is not just grouping fixed points together, but this ordering has a clear physical interpretation to predict front behavior. I presented my research at the 2012 SACNAS conference, and I am going to present my newest result on Nov. 20, 2012, at the 65th Annual APS Division of Fluid Dynamics conference. Throughout the research with Dr. Mitchell, I eventually understood that my research interest does not fit in a traditional framework. Instead, I found out that my research interest is in new theories or even opening a new branch of physics.

In conclusion, my research strength is my intuition, independence and creativity, and my research interest is in what can fully reveal my strength: newly developed theories or developing a new theory. Before I graduate from UC Merced, it is expected I should have two papers published: one with Professor Umurhan on Chaotic behavior of Newton's method and one papers on BIM theory with Professor Mitchell. Therefore, my undergraduate education and research has prepared me to excel as a graduate student.