The Academic and Social Consequences of Multidisciplinary Laboratory Structure in the Context of Dr. Warren Warren's Laboratory at Duke University

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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

INTRODUCTION

Most labs are structured in a way that encourages a variety of research categorized under the same discipline. However, Dr. Warren Warren's lab at Duke University somewhat breaks this typical structure by consisting of two groups performing research into different phenomena. One subgroup of the lab does research into laser spectroscopy, and the other subgroup does research into NMR spectroscopy. The two groups are autonomous in many of their academic endeavors, but the lab space and associated activities facilitate potentially beneficial interdisciplinary interactions.

Research into Dr. Warren's history and the development of the lab structure yielded insight into the merits it provides, and investigation into the lab philosophy was performed to explore the motivations behind it. Surveys and interviews were performed with lab members of many different backgrounds to reveal member opinions on their experience with the lab. By performing this background research into the lab history and gathering information from individual lab member experiences, a clearer picture on the true effects of this lab structure were constructed. The general structure may not be rare on its own, but the official and unofficial activities associated with it reveal a philosophy of interdisciplinary education and development of scientific communication skills. In this investigation, the dynamics between the mostly autonomous groups and the benefits of this configuration were explored using Actor-Network Theory and Social Identity Theory as social frameworks.

LITERATURE REVIEW

Warren's Research History

To gain a better understanding of how the specific structure of the Warren Lab came to be, I got information from publication histories, interviews with current graduate students, and observations of meetings among alumni. The history of Dr. Warren's research incorporates magnetic resonance research and laser spectroscopy to different degrees at various points of his career. Dr. Warren completed his doctoral degree in the field of magnetic resonance at UC Berkley in 1980. His research involved using pulse sequences with up to 4096 individual pulses to selectively excite different nuclei.[1] He became disillusioned with the experimental applications of magnetic resonance because of the complexity of new pulse sequences. Nuclear Magnetic Resonance (NMR) is a field where theoretical models are simple and exceptionally accurate which makes experimental replication almost a moot point.

After graduating in 1980, he shifted focus to translating magnetic resonance concepts from the simple and easily reproducible magnetic resonance regime, to the more complex and difficult to interpret optical regime. In his work at Cal Tech with Dr. Zewail, he used his understanding of the radiofrequency electromagnetic pulses commonly used in NMR experiments to introduce phase coherent control of nanosecond laser pulses.[2,3] The laser community could now implement some well-known NMR experiments in a regime which previously had not had the experimental control to do so. In 1982, Dr. Warren was appointed as Junior Faculty at Princeton University where he started researching electromagnetic pulse shaping. Some of the more well-known pulse shapes for selective excitation (Dr. Warren's PhD research topic) were first derived in an optics textbook. However, because the technology to deploy such pulses already existed in NMR experiments, Warren returned to magnetic resonance to further understand the area.[4] Eventually, he translated the NMR regime to the optical limit once again when technological development caught up with theoretical advancements.[5,6]

It is around this time that Warren started to pursue research in both magnetic resonance and optics concurrently. His research into pulse shaping in NMR demonstrated some interesting interactions between the sample and detector called radiation damping.[7] However, the advent of pulse shaping in laser systems opened up various experimental applications in optics including multidimensional laser spectroscopy and pump-probe imaging (the technique that his laser lab currently has its focus).[8] He went on to discover some unexpected interactions between distant nuclei in magnetic resonance called intermolecular Multiple Quantum Coherences (iMQC) which would reshape the theoretical foundation of the field. At the same time, he was refining his pump-probe laser system for future experimental applications.[9] When Warren moved to Duke University in 2005, he was experimenting in both NMR and laser spectroscopy and was given lab space for various optical tables, NMR spectrometers, and MRIs.

He continued work in both areas with students vaguely grouped into the "laser side" and "magnet side". However, the students are not necessarily siloed into these categories. The recent study on a low cost method for testing the efficacy of various face masks in the COVID pandemic involved collaboration between the MD-PhD student and quantum theory student on the magnet side with the experimentalists on the laser side.[10] His notable research has included the introduction of various hyperpolarization techniques in NMR which can increase the SNR for low concentrated samples of a wide variety of nuclear targets.[11] His optical research has expanded to work in art conservation[12], characterization of pigments[13], and clinically relevant interrogation of the metastatic potential of malignant melanoma.[14] Recently, Jacob Lindale, one of Dr. Warren's senior graduate students in magnetic resonance has introduced a new theoretical model for rapidly exchanging systems in the NMR limit.[15] He is now working to translate this technique into the optical limit where Warren would once again use one energy regime to inform experimental progress in another energy regime.

Warren comments that having an understanding of NMR theory which is very well characterized and understood, is a fundamental need of any optical spectroscopist.[16] He teaches a class geared towards students working in the optical energy regime about NMR theory and believes that this is a crucial part of their education. Dr. Warren is also not alone in this belief. Many optical and NMR spectroscopists agree with this sentiment and it seems to have worked for Dr. Warren as much of his research has sprouted from the interplay between the two energy regimes.[17] It seems that the structure of Warren's two-part lab grew out of necessity for his interest in two traditionally different spectroscopic fields, but it was solidified by a large degree of success.

Graduate Student Development

Graduate level training has a high degree of variability between countries, institutions, and even academic departments. Numerous studies have been done to compare the design of various academic programs and determine the efficacy of the training in developing well-rounded graduates ready to join the scientific work-force. First, from a general perspective, it has been demonstrated that the participation of students, both graduate and undergraduate, in research groups is beneficial to their academic training. This benefit comes in the form of direct training in various forms of research from participation in the research activities of a group as well as introducing several mentors at various stages of training into the student's personal network.[18] Within these research groups, there are two pertinent categories which will be explored here. First, how does an interdisciplinary approach to research groups affect the academic training process? Second, what is the importance of learning appropriate scientific communication strategies during graduate training and how can this be efficiently taught?

A recent case study from Klaassen provides a nice definition of interdisciplinary research for the purposes of this thesis. He defines it as "a team or an individual expert (scientist or otherwise), who integrates methods, knowledge and skills, theories, perspectives and different disciplinary knowledge bodies, to realise innovative solutions and knowledge advancement in uncharted problem areas".[19] As the research performed by the Warren lab comes from two connected, but generally distinct fields of molecular spectroscopy, it is important to note here that "interdisciplinary" can have a broad interpretation depending on the scientific discipline. With that in mind, Klassen goes on to note that students involved in interdisciplinary research which occurs on the border of knowledge for two or more disciplines of science generates new regions of expertise for the trainees and trains them in integration of varied and often vastly different information bases.[19] One natural area of interdisciplinary research, clinical translation, is a pursuit of both sides of the Warren lab with one study on the characterization of the pigment characteristics of melanoma from the laser side of the lab and a continued pursuit of hyperpolarized clinical and preclinical MRI images on the magnet side of the lab. It is not a new phenomenon to observe improved scientific discourse in interdisciplinary settings. Research from Pelz back in 1959 suggested for many years that in research organizations, an increase in the diversity of research disciplines increases, individual performance and productivity improves and the reverse trend is seen with an increase in the homogeneity of research disciplines.[20]

One additional benefit to an interdisciplinary learning environment is an increased ability to communicate across disciplines.[19] In fact, Dr. Warren and his students both claim that improved scientific communication outside of one's specialty is one of the fundamental aims of the group and group meeting structure for the lab. The two aspects of scientific communication most emphasized by the lab according to student interviews is appropriate targeting of the scientific audience and reducing anxiety in public speaking forums for native and non-native English speakers.

Appropriate communication of scientific ideas with others in a specific scientific discipline is relatively trivial as a common language and baseline of knowledge is shared. However, when a researcher or student looks to communicate ideas with people outside of their specialty, or even outside of the scientific community, there is a major disconnect which must be bridged.[21] Climate change is just one example of a scientific principle which has not been well-received by the public. Emphasizing a decrease in the use of scientific jargon and terminology known only to individuals in one specific field is critical in increasing the transparency of the scientific community.[21] Additionally, having the ability to communicate complex ideas in simple terms is a powerful learning method which allows students to be more confident in their understanding of certain material.[22] More confidence is one critical part of decreasing anxiety in public speaking forums to better facilitate communication of scientific ideas. Desensitization and practice in speaking with a friendly and receptive audience which provides both constructive criticism and encouragement are also key factors in improving public speaking especially for students for whom English is a second language.[23] The full group meetings for the Warren lab act on many of these principles with the explicitly stated intention of improving communication skills and decreasing student anxiety around speaking in large public forums.

Social Frameworks

Actor-Network Theory (ANT) is a way to describe the world based on the associations of human or non-human actors. ANT does not heavily focus on agency of human actors, but rather tries to account for the contributions of all objects regardless of intelligence.[24] Since this investigation into the structure of the Warren Lab involves individuals, lab equipment, and locations of interest, the abstract definition of an agent provided by ANT will provide a useful framework to model complex networks of interactions.

In Social Identity Theory (SIT), a person's social identity is their belief that they belong to a certain category or group of people. SIT provides a set of relatively rigorous definitions for those that are in-group and those that are out-group, which is helpful when dealing with the usually nebulous idea of a social group.[25] The Warren Lab with its split lab structure lends itself well to analysis through SIT since there are multiple overlapping group definitions related to the lab. Being able to discuss group associations concretely is important for understanding the nesting structure of groups Warren's lab houses.

RESEARCH METHOD

The data collection for this study was three-fold. First, a thorough literature review was conducted to gather background information on the research history of the lab and look at prior research into graduate student development and social theory of group dynamics to best evaluate the lab group structure and impact. Next, direct observation of subgroup and full group meetings and alumni seminars were conducted to collect primary information about the structure of the group meetings, social interactions among the current and past students, and delivery of scientific ideas across group boundaries. Lastly, interviews were conducted with several volunteers at various points in their training from each subgroup in the lab regarding the group structure and the impact of the hierarchy, group/subgroup dynamics, and input from across group lines.

The primary means of direct data collection for this study was interviews. In total, there were five respondents to the initial survey: Jacob Lindale, Shannon Eriksson, Xiaoqing Li, Heidi Kastenholz, and

Dr. David Grass. Jacob, Shannon, and Xiaoqing are doctoral candidates working in the magnetic resonance subgroup. Heidi Kastenholz is a first-year graduate student interested in the laser side of the lab and Dr. Grass is a post-doc on the laser side of the lab. Other members of the lab declined to interview. This selection of interviewees represents a good cross section of the lab. Both the laser and magnet subgroups of the lab haver representatives and multiple levels of training are present. There is one junior graduate student having just affiliated with the lab, multiple senior doctoral candidates, one doctoral candidate in the thesis writing stage of his training, and a post-doctoral researcher. All of the various levels of training of the individuals populating the lab are accounted for in the interviews. I followed up with Jacob Lindale because of his overlapping research and attendance at both subgroup meetings. Full transcripts of all these interviews can be found in the appendix.

DATA ANALYSIS

Warren's Research History

From the detailed history of Dr. Warren's research path it is clear that there is a foundation of translational research between two different, but related scientific fields. In fact, a good portion of the early laser spectroscopy experiments performed by Dr. Warren and his lab were direct results of his previous NMR research. From a research productivity perspective, Dr. Warren was able to publish many high impact papers in both research areas. His graduate level training in magnetic resonance theory and practice have informed applications to the more theoretically complex regime of higher energy laser and optical spectroscopy. Dr. Warren and many other optical and NMR spectroscopists agree that the two fields can be used to inform each other and many breakthroughs come from the overlap of the simpler theoretical constructs of magnetic resonance with the more rigorous experimental regime of laser spectroscopy. Dr. Warren's research career to date demonstrates the merits of this frame of view.

In terms of the development of the current research lab model, the initial cross-over in Dr. Warren's research was not born out of a desire to apply magnetic resonance concepts to a laser focus, but rather a disillusionment with the potential of magnetic resonance research. He used his background from his graduate training to engage in research in a new energy regime. After the success of this cross-over, he made the dual research into both topics a part of his career. However, as a young investigator with fewer resources and graduate students, it seems that he had to focus more on one topic or another. Very quickly, he was able to extend additional applications from magnetic resonance to the optical limit and as his lab expanded, he and his students published on topics across both specialties. During his time at Princeton, there was a large physical distance between the two halves of his lab, as his access to MRI was through the hospital system in Philadelphia and his optical tables were at Princeton. This may have contributed to the separation of the two specialties in the early days of the development of his research group.

After moving to Duke University, Dr. Warren had combined lab space for both of his experimental topics in the same contiguous area as well as combined graduate student offices and a combined group conference room for use by both arms of the lab. It was at Duke that the current iteration of his bifurcated group style grew into the current form. The combined space makes for easier crosstalk between the groups and promotes interdisciplinary communication. Full group meetings incorporating both sides of the lab additionally promote scientific communication and are described by the graduate trainees as an opportunity to improve presentation skills and broader understanding of their field. Overall, Dr. Warren's group structure reflects both a pathway to increase research productivity through crosstalk between scientific concepts and a pathway to increase the strength of graduate student trainees as they enter the broader scientific community where they will encounter many interdisciplinary discussions and collaborations.

Graduate Student Development

An analysis of the graduate student development was completed using the interviews with the trainees in the lab as well as observations from the alumni seminar series. In the interviews the graduate students were asked to evaluate the group structure and efficacy of the interdisciplinary crosstalk in their self-perceived development as graduate students. Self-evaluation of current graduate trainees in the lab were supplemented with more objective measures of the career trajectories of Warren's previous graduate and undergraduate students, post-doctoral trainees, and assistant professors.

The first topic of interest was the view of the trainees on the different group meetings. All trainees identified the individual lab meetings as detail-oriented meetings with Warren where their research and progress on the week were presented and evaluated. Several students noted that this was an opportunity to collaborate with colleagues from their subgroup on problems and pitfalls they are encountering in their research. The Friday group meetings are identified as individual presentations by students, or post-doctoral researchers which are meant to educate the general group about a scientific topic, or practice research progress updates with a target audience of interdisciplinary scientists.

When asked how constructive input from individuals in the other research subgroup has been, the respondents responded favorably on a 5-point Likert scale with 1 corresponding to "very unhelpful" and a 5 corresponding to "very helpful". The mean response was 4.2/5 with a standard deviation of 0.8. From discussion with the interviewees, it seems that the Friday talks as well as the easy access to students with a different experimental and theoretical background from their own has been useful in the development of their presentation skills, scientific communication, and development of research questions. It does appear that the crosstalk is somewhat limited with very little desire to do research collaborations with the students in the other side of the lab. On average the students reported that the likelihood of collaboration with students in the other subgroup was 2.6/5 with a standard deviation of 1.5 where 1 corresponded to "highly unlikely" and 5 to "highly likely". On the same scale, all respondents reported that their likelihood of collaborating with individuals in their own subgroup was 5/5. This idea is somewhat supported by the response to the question regarding interest in engaging in research with the opposite subgroup. On the same Likert scale, students responded that their likelihood of engaging in research projects related to the research topic of the other subgroup was 2.8/5 on average with a standard deviation of 1.8. While the average response is not favorable in this case, it is interesting to note that there were two students who responded that they do have interest in engaging with the research topic of the other subgroup.

Observation at the alumni seminar series demonstrated the wide variety of careers and research topics that Dr. Warren's previous students participate in. Of note, Warren has had students graduate from his lab and go on to participate in a wide variety of traditional and nontraditional careers. Several alumni have gone on to have prolific careers in academia including the Nobel laureate Donna Strickland, among others. However, several of his students have gone on to work in industry, government, and military in research fields ranging from magnetic resonance imaging, fundamental spin physics, laser applications, optical spectroscopy theory, machine learning, network engineering, and materials sciences. One of his former students, Dr. Banash, noted in one of the alumni meetings that the wide dispersion of scientific inquiry and career trajectories coming out of the Warren lab speaks to the rigorous interdisciplinary and multi-level training received by all graduate students in the lab. Some of the graduate students agreed with this sentiment, stating that they had received training in electrical engineering, theoretical and experimental physics, grant writing, 3D printing, and plumbing among other disciplines in their time in the Warren Lab.

Social Frameworks Analysis

Actor-Network Theory in the context of Social Identity Theory was used to contextualize the interactions between the two disciplinary groups in the Warren Lab. The two most important actants identified for this purpose were the meeting room and the laboratory office/experimental space. Observation of individual group meetings and collaborative meetings along with support from survey responses highlights these two actants as the most prominent points of contact between the groups.

The role of the meeting room as an actant appears particularly important to derive benefits from the unique lab structure. Both the NMR and optics groups in the Warren Lab use the meeting room for either meetings with their own group or meetings with both groups. This makes it a contact point between the NMR and optics groups that acts like a forum for discussion of research from many viewpoints. Although Dr. Warren and Dr. Martin Fischer attempt to guide conversations in productive ways, these interdisciplinary meetings give everyone an opportunity to absorb unfamiliar knowledge and provide advice in a relatively unrestricted way. Using Social Identity Theory as a lens, the utility of the meeting room as an actant can be expanded upon. Interdisciplinary meetings allow for lab members to emotionally associate themselves with the lab as a whole rather than their individual discipline's group. This has potential to make members more receptive to critique coming from their colleagues with other backgrounds, as they feel like they are both parts of the same whole. Lab members from different sides reported that they participate in recreational activities with each other, giving further evidence to their identification of the lab as a cohesive unit rather than two parts.

Like the meeting room, the lab office and experimental space act as a point of contact between the two groups of the Warren Lab in an actor-network. However, unlike the meeting room, the lab space does not facilitate collaborative efforts. The two groups share the same overall lab space, but the lab is essentially split down the middle of both the office and experimental space. The spatial separation highlights the degree of autonomy both groups have despite the overall image of a lab unified in academic development. When viewed through the lens of Social Identity Theory, the spatial separation of the two groups in their primary work environments likely leads them to associate more strongly with members in their own disciplinary group. This is supported by observation and interview responses, which confirms that the lab members typically share space with their own group members for most of a workday, and that members still categorize other members into either "laser" or "magnet" sides of the lab. This also explains the survey results that imply members value the input of members outside their own group, but do not actively see themselves participating in collaborative research with them. Members of each group typically spend most of their time working in the lab space with their fellow group members, but since it is a shared space social interaction still occurs during breaks and the door is still open to collaboration.

DISCUSSION/CONCLUSION

Summary of Findings

The two fields that eventually characterized Dr. Warren's interdisciplinary lab environment stem from Dr. Warren's previous shifting research interests. Dr. Warren began his research career with many high-impact contributions to NMR but became disillusioned with the subject as applications of his research became increasingly convoluted. His research focus then began to shift into optics, a field where skills from NMR could be translated. As Warren continued further into his research career, he started to return to some NMR research. Because of commonalities between his work in NMR and optics, his research efforts were focused on both subjects. The modern-day split-lab structure found its roots early on as two spatially distant labs, each focused on one of the two focus subjects. After Dr. Warren found his way to Duke he kept this multi-focus lab structure, but performed the research for both subjects in the same lab space.

Graduate students in Dr. Warren's lab seemed to recognize certain effects of the split-lab structure as beneficial to their development as a researcher. The most universally agreed upon benefit was the access to cross-disciplinary critique. Students responded with a strong belief that input from those outside of their research group has been somewhat or very helpful. This response in conjunction with open ended interview questions indicates a student belief that input from those with different backgrounds provides improved learning. However, the desire to participate in research with members from outside of their group is quite low, especially when considering the strong drive each student had to collaborate inside their group. The same is true about the sentiment of participating in research topics from the other group. It seems although students in Dr. Warren's lab believe there are real benefits from having criticism from unique perspectives, the drive to collaborate with their counterparts is not a focus in the lab culture.

Analysis of actants in the context of Actor-Network Theory implies certain actants play an important role in facilitating useful cross-disciplinary critique and reveals potential explanations for the lack of collaborative drive. When compared to Dr. Warren's spatially distant lab setup earlier on in his career, the lab at Duke University has many more contact points between the two disciplines. The environment that facilitates the most exchange of ideas is the meeting room, where most of the activity believed to be highly beneficial by students occurs. The meeting room is a critical actant in the exchange of critiques. Other actant contact points are severely limited however, such as the shared space of the lab. Each group shares the same lab but are spatially separated into two sides, facilitating discussions inside each group but not as much between. This along with spatial separation of experimental setups is likely a strong factor in the lack of explicit interdisciplinary research, since social identity theory implies the lack of direct avenues of conversation makes group members identify much more strongly with members of their own lab sub-group.

Here, we gather that the interdisciplinary group-subgroup structure employed by the Warren lab at Duke University seems to benefit the scientific and professional development of the group members both from their perspective and from observation of alumni of the lab group. While there is little scientific collaboration between the groups at this stage, the major benefit of the communication between subgroups comes from the improved scientific communication across disciplines. The critical actant which facilitates this between group communication is the combined location for the group meetings. Alternatively, the scientific output is generated out of physically separated actants which are divided into "sides" of the lab. This may be a contributing factor in the lack of scientific collaboration between groups, but it leads to strong social identification among the students and post-doctoral researchers in each of the subgroups, resulting in ready intra-group collaboration and therefore cohesive and prolific scientific output.

Future Directions

Given the opportunity to continue this research, I would like to perform a more longitudinal study and follow-up with the members of the lab over the course of their time in the Warren Lab and afterwards. With this follow-up, I would specifically be interested in respondent research productivity, discipline or disciplines of interest, comfort with cross-discipline dialogue, and comfort with public presentations. I would be particularly interested in any lab alumni who might switch research interests or begin research in the discipline of the other subgroup. Learning how the research careers develop for the students graduating from the Warren lab would allow for a more quantitative and less biased understanding of student outcomes coming out of the lab. Recruiting more students into the study and expanding the study to similarly organized labs would also allow for more reliability and provide some insight into inter-group variability.

Lastly, doing a comparative study of a group which is solely focused on a single research topic would provide a control comparison for the dual-topic group-subgroup approach of the Warren lab. It is likely that the scientific focus of different groups would naturally work well with some structures, so it may be of benefit to examine many research labs across multiple institutions to look for correlations in scientific scope and research group structure. These expansions on the topic of this thesis would require many man-hours to complete but would provide some interesting further insights into the benefits of different group structures across a wide variety of scientific disciplines and could generate some recommendations which may improve overall graduate student training.

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