ABSTRACT

Formation in Science: A Cultural Exegesis of Scientific Research Practices

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While many influential philosophers, sociologists, and anthropologists of science have theorized how science works to discover or construct truth, less work has been done examining how scientific practice forms scientists. As an alternative to the purely rational formulation of humans in the Western philosophical tradition, theologian James K. A. Smith argues that humans are fundamentally desiring beings whose loves are shaped and directed by cultural practices. Drawing from these conceptual frameworks and my firsthand experience in an inorganic chemistry lab, this thesis explores how the daily routines in a scientific research lab shape scientists' images of the good life. From washing glassware to writing in a lab notebook, the various practices comprising scientific research activity instill in scientists a complex constellation of values, including truth, purity, objectivity, order, and utility.

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FORMATION IN SCIENCE: A CULTURAL EXEGESIS OF SCIENTIFIC RESEARCH PRACTICES

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PREFACE

During my freshman year at Baylor University, I first began my career in scientific research by joining the Martin Lab, an inorganic synthesis research group led by Dr. Caleb Martin. In the lab, chemistry came alive in a way to which textbooks, class lectures, and even teaching labs could not compare. I could truly see, hear, touch, and breathe in science for myself for the first time. I spent countless hours in the lab, eager to watch my labmates carry out the most mundane tasks, burning with questions and utterly captivated by this whole new world. Scientific research did not mean a mad scientist working alone in a lab, as I had once imagined, but joining a team, asking focused questions and solving problems in a fast-paced, dynamic work environment. As my hands slowly gained the necessary dexterity and learned the motions, the rest of me was also being shaped by the work I was doing, although I was unaware exactly how.

I was simultaneously taking my first Great Texts class, reading foundational works in the Western tradition, exploring broader questions about what we know, how we should live, and who we aspire to be. I joined the Crane Scholars Program, a three-year program in which we gather regularly with faculty mentors and peers to discuss our assigned readings, particularly focused on themes of faith, formation, and vocation. In the communities of my church and the Honors Residential College, we try to live out many of the same values, embracing models of servant leadership and pursuing the loves of God, neighbor, and learning. Pulled in two different directions, I felt these indescribable tensions between the images of the good life offered by scientific research those I was glimpsing through my Great Texts classes, church, and life in the Honors Residential College. This was even manifested in my hurried, mile-long treks between the Baylor Sciences Building and other parts of campus. However, I did not know why; I was not troubled by the information I was learning, but something deeper.

When I read the first few chapters of James K. A. Smith's book, *Desiring the Kingdom: Worship, Worldview, and Cultural Formation* (for a Cranes meeting), I knew. Smith's core argument is that "liturgies—whether 'sacred' or 'secular'—shape and constitute our identities by forming our most fundamental desires and our most basic attunement to the world. In short, liturgies make us certain kinds of people, and what defines us is what we love."[1] Reading these words, I immediately thought of a set of thick, embodied practices that I knew intimately: those in the scientific research lab. The tension I felt was not in an incongruence of abstract ideas, but a clashing of two cultures, embedded in their formative practices, which try to shape who I am and how I imagine the good life. In many ways, this thesis is simply that: a wrestling and an articulation of the ways I have been formed through my time in the chemistry lab.

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1. James K. A. Smith, *Desiring the Kingdom: Worship, Worldview, and Cultural Formation* (Grand Rapids: Baker Academic, 2009), 25.

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I would like to express my appreciation to my thesis defense committee, Dr. Darin Davis and Dr. Tom McGrath, for taking the time to read my thesis and participate in my defense. You both represent the very best kinds of professors, remarkable for your scholarships in your fields and your love for your students. Because of the roles you have played during my time at Baylor, I am honored that you are a part of my thesis and blessed to have known you.

I would like to thank those who have been a part of my journey in chemistry, especially Dr. Caleb Martin and the members of the Martin Lab at Baylor University (past and present), Dr. Jeffrey Urbauer, Ramona Urbauer, and Cynthia Tope at the University of Georgia, and all my professors. You have contributed to this thesis without even knowing it by supporting me as a scientist.

Lastly, I want to thank my family (especially my parents and brother) and friends for all your encouragement, grace, and support throughout the thesis process. A special thanks goes to Rachel Brown, Elise Baldwin, and Anna Wickenhiser for your feedback throughout the whole writing process (but especially in the end). You all have tolerated my muddled musings, rambling reflections, and thesis thought trains, with such patience and careful thought, and I am grateful to have friends to whom I can entrust my words. Another thanks goes to my communities, including the Honors Residential College (especially Team SLither), Dayspring Baptist Church, and the Crane Scholars Program. You all have shown me a beautiful vision of the good life and encouraged me to pursue the love of God, love of neighbor, and love of learning through everything.

INTRODUCTION

Biologist and historian of science Stephen Jay Gould describes science as "a social phenomenon, a gutsy human enterprise, not the work of robots programmed to collect pure information."[1] He characterizes science as a dynamic, creative, social activity, inseparable from the humans who conduct it. By extension, scientists are not disembodied, purely objective beings through which scientific facts are discovered. Instead, scientists are social and moral creatures embedded in a larger cultural context, and by extension, are members of a subculture of scientific research. In light of my own experiences in scientific research, my analysis builds on this insight by examining how some specific scientific research practices form scientists as people, who are deeply influenced by cultural forces.

In Chapter 1, I will briefly discuss several influential accounts of science, all of which articulate various aspects of this culture underlying scientific research. Beginning with C. P. Snow's lecture "The Two Cultures," Snow dramatically remarks on the drastic divide between the scientists and the literary intellectuals. Thomas Kuhn describes his theory of for scientific change in terms of the paradigm, an all-encompassing, foundational framework of assumptions, questions, and theories, in which science operates. As a sociologist, Robert Merton writes about the ethos of science, identifying

1. Stephen Jay Gould, *The Mismeasure of Man*, 2nd ed. (New York: W. W. Norton & Company, Inc., 1981; 1996), 53. Citations refer to the Revised and Expanded edition.

four institutional imperatives: universalism, communism, disinterestedness, and organized skepticism. Taking a classic anthropological approach, Bruno Latour and Steve Woolgar observe scientists as if they were an indigenous tribe, noticing even the most minute of details of scientific practice. Drawing from the tradition of virtue ethics, some philosophers have applied virtue theory to scientific practices, trying to link the formation of various virtues to scientific research. However, this scholarship tends to either neglect the moral dimension of scientific practice or the day-to-day reality of life inside a scientific laboratory.

Noticing this gap, I then apply the framework of theologian James K. A. Smith in his book, *Desiring the Kingdom: Worship, Worldview, and Cultural Formation*, which is presented in the second chapter. Beginning with an alternate anthropology of humans as fundamentally desiring creatures, Smith links the practices of our bodies with the desires of our hearts. He argues that our loves are directional, pulling us to particular images of the good life, which capture our hearts and imaginations through the power of stories. Remarking on their formative nature, he likens our cultural practices to a form of secular liturgy. Because of this deep relationship between our desires, practices, and visions of the good life, Smith proposes a method of cultural exegesis, in which features of the images of the good life can be discerned from the formative practices they are embedded within. He gives an example of a shopping mall, and he analyzes how various elements of the mall—from the mannequins in the store windows to the act of purchasing at the cash register—all try to teach us that to shop is to be happy, advocating for a consumerist vision of the good life. Inspired by Smith's approach, I then apply his framework to the scientific laboratory, beginning with a description of the Baylor Sciences Building.

In Chapter 3, I begin conducting this kind of cultural exegesis on three important, highly sensory and deeply embodied practices of a typical chemistry laboratory in inorganic synthesis: washing glassware, preparing NMR samples, and growing crystals. The rituals of base bath and acid bath, long procedures for cleaning glassware, are simply one specific example of a cultural purification ritual, which reflect scientists' association of purity with truth and contamination with error. The repetitive routine of preparing samples for instrumental analysis, such as NMR (Nuclear Magnetic Resonance), reveals scientists' obsession with data and inscriptions, relating objectivity with truth and fearing subjective bias. The last set of practices examined involve growing crystals for x-ray diffraction studies, a process of literally creating order from disorder, that also instills a deep sense of care in researchers for their data. Together, all these research practices demand extraordinary amounts of effort and time from scientists, a reality also manifested in the long working hours and work-life imbalance that is a reality for so many scientists. When considering all three of these scientific research practices, a vision for the good life begins to emerge, one dominated by truth, which is connected to notions of purity, objectivity, and order.

In the fourth and final chapter, I step outside of the bench laboratory into the lab office to analyze another set of scientific research practices: writing in a lab notebook, attending group meetings, and preparing manuscripts for publication. Although not quite as embodied as the bench laboratory practices, these practices are powerful because they are all story-telling activities. The lab notebook is often the first place for scientists to tell their story, and in doing so, they already begin to remove themselves from the story, favoring depersonalization and data over their own role. Regular group meetings are a standard part of the flow of scientific research, and here the story is told for an audience, fostering transparency, accountability, and a sense of community. The last scientific research practice I analyze is one of the most iconic: the scientific journal article. However, despite science's affinity for accuracy and precision, the scientific publication does not prioritize historical accuracy and the crucial role scientists play. Instead, the scientific journal article tries to tell a story that is deeply connected to the stories of others in the scientific community and focused on the communication of data. Unifying these three forms of story-telling is a reliance on figures and the need to communicate with the rest of the scientific research community.

In this thesis, I hope to tell a slightly different story of how science works, one from the perspective of how the practice of science shapes its scientists, not just the other way around. This story of science is deeply informed by the messy reality of daily laboratory practices, but with an eye to the visions of the good life embedded within these practices.

CHAPTER ONE

Approaching Research Labs as Loci of Scientific Cultures

In this chapter, I will survey influential accounts of scientific work, including C. P. Snow's lecture "The Two Cultures," Thomas Kuhn's philosophy of science in *The Structure of Scientific Revolutions*, Robert Merton's sociological ethos of science, Bruno Latour and Steve Woolgar's anthropological approach, and Daniel Hicks and Thomas Stapleford's application of Alasdair MacIntyre's virtue ethics to science. These analyses robustly describe various aspects of the scientific life, from its broad contrast to the humanities to theories about how science makes progress to a minutely detailed examination of the inner workings of a research lab. Underlying all of this scholarship is an understanding that a culture of scientific research exists and that scientists both influence and are influenced by this culture. Although these analyses explicitly or implicitly describe a shared culture amongst scientists, they often neglect the moral dimension of this culture, such as in Kuhn, Latour, and Woolgar, in favor of discussions of how science works, both theoretically and practically. Alternatively, others, including Snow, Merton, Hicks, and Stapleford, do explore some of the scientific research culture's influences on scientists' morality, but in a broad, theoretical sense, not deeply embedded in the specific, at times mundane, activities composing scientific labwork.

A Culture of Science: C. P. Snow

In the highly influential 1959 Rede Lecture titled "The Two Cultures," C. P. Snow dramatically characterized "the intellectual life of the whole of western society…into two polar groups," the literary intellectuals and the scientists.[1] Although he acknowledges the specialization within these groups, he argues that "There are common attitudes, common standards and patterns of behaviour, common approaches and assumptions. This goes surprisingly wide and deep…without thinking about it, they respond alike. That is what a culture means."[2] What unites scientists is "the pole of total incomprehension of science" in traditional culture, even though the physicist and biologist may also not understand one another completely.[3] For Snow, this idea of a scientific culture transcends the traditional disciplinary divisions to encompass deeper, more fundamental shared ideas and values.

Culture not only provides shared abstract beliefs and common practices, but also the very purpose of a community, providing an implicit moral dimension to Snow's analysis. In contrast to the literary intellectuals' tendency to bemoan the human condition, Snow describes scientists as optimistic, having "the future in their bones."[4] This optimism among scientists impels them to be "inclined to be impatient to see if something can be done: and inclined to think that it can be done, until it's proved otherwise."[5] This shared drive to actively work toward solutions to current problems reveals a deep cultural connection between one's moral duties and one's scientific work

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1. C. P. Snow, *The Two Cultures,* (Cambridge: Cambridge University Press, 1998), 3.

2. Snow, *The Two Cultures*, 9-10.

3. Snow, *The Two Cultures*, 11.

4. Snow, *The Two Cultures*, 10.

5. Snow, *The Two Cultures*, 7.

within the scientific culture. "There is a moral component right in the grain of science itself," Snow argues, and science is inseparable from this sense of ethical responsibility to do something rather than nothing.[6] However, Snow does not elaborate much further on the development of this scientific ethic or on the means that the scientific culture uses to instill this moral responsibility.

Also missing from Snow is any sort of description of scientific activity since he primarily intends this lecture as a call to educational reform, warning against the dangers of increasing specialization and polarization. Because his analysis focuses on scientists' contrast to the literary intellectuals, he characterizes the scientists as people belonging to a distinct culture, rather than by their shared practices. He tries to articulate what uniquely unites scientists in the face of traditional culture despite the differences between disciplines, and his observations are foundational in reformulating the definition of culture and applying it to scientists as a group. Because science is more than a common profession, Snow's characterization demonstrates the existence of a shared culture with intellectual, moral, and behavioral trends of scientists shaping their identity beyond their work. However, due to the limited scope and purpose of this lecture, Snow does not explore how this culture is instilled amongst scientists, nor the role of practices in these cultural trends he identifies.

Beyond Culture: Paradigms and Thomas Kuhn

While Snow describes his observations in terms of culture, Thomas Kuhn uses the term "paradigm" to refer to this combination of law, theory, application, and

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6. Snow, *The Two Cultures*, 13. Snow sees the aim of science is to improve human life, so the rest of his lecture is about poverty and severe social inequality.

instrumentation that "provide models from which spring particular coherent traditions of scientific research" in his 1962 book, *The Structure of Scientific Revolutions*.[7] As these all-encompassing frameworks in which science operates, paradigms supply not only the current working theories and standard methodologies within a field, but also the unquestionable first principles, the range of acceptable puzzles to solve, and a fundamental understanding of how the world works. The paradigm is so foundational that "the paradigm is prerequisite to perception itself" because it provides a certain, inseparable lens to view all other reality.[8] Kuhn compares paradigms to lenses, and as a result, paradigms inevitably "restrict the phenomenological field accessible for scientific investigation" and the kinds of questions that can be asked.[9] The goal of a scientific education is to initiate students into the paradigm, which is why students learn theory simultaneously with its applications and solve practice problems based on previous work that shaped the paradigm.[10] In this sense, Kuhn's paradigms are much more rigid than Snow's description of culture, providing the very fabric of reality in which scientists operate.

Due to the shared "commitment and apparent consensus it produces," the paradigm is the prerequisite for what Kuhn calls "normal science," which is the everyday

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7. Thomas S. Kuhn, *The Structure of Scientific Revolutions*, 3rd ed. (1962; repr., Chicago: University of Chicago Press, 1996), 10.

8. Kuhn, *The Structure of Scientific Revolutions*, 113.

9. Kuhn, *The Structure of Scientific Revolutions*, 60.

10. Kuhn, *The Structure of Scientific Revolutions*, 46-47.

activities that compose scientific research.[11] Kuhn argues that the goal of scientific work is "to display a new application of the paradigm or to increase the precision of an application that has already been made," to fill in the gaps rather than make novel discoveries.[12] He describes normal science as "puzzle-solving," drawing parallels between "the existence of this strong network of commitments—conceptual, theoretical, instrumental, and methodological—[as] a principle source of the metaphor."[13] Because both the normal scientific and puzzle-solving communities already agree upon the limits placed on both acceptable problems and valid solutions, their work primarily becomes tests of their practitioners' skill and ingenuity. Kuhn then argues that viewing scientific research as puzzles, the motivation behind scientists' passion and dedication to their work include "the desire to be useful, the excitement of exploring new territory, the hope of finding order, and the drive to test established knowledge."[14] Kuhn's idea of normal science, which results from the paradigm, provides many helpful insights regarding how scientists view and approach their own work.

According to Kuhn, this process of initiation into the paradigm begins with textbooks, which are the principal pedagogical instruments of the current paradigm. He describes how textbooks provide a linear, cumulative view of science, fitting "the work of past scientists…as contributions to the statement of the texts' paradigm problems," and

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11. Kuhn, *The Structure of Scientific Revolutions*, 11.

12. Kuhn, *The Structure of Scientific Revolutions*, 30.

13. Kuhn, *The Structure of Scientific Revolutions*, 42.

14. Kuhn, *The Structure of Scientific Revolutions*, 37.

presenting no alternatives except the currently accepted paradigm.[15] In fact, according to Kuhn, "until the very last stages in the education of a scientist [third or fourth year of graduate work], textbooks are systematically substituted for the creative scientific literature that made them possible."[16] In addition to reading textbooks, a scientific education involves learning by doing, often by working practice problems and completing laboratory exercises, which Kuhn argues happens all the way from introductory freshman courses through doctoral work. Even in graduate work, "the problems assigned to him become more complex and less completely precedented…they continue to be closely modeled on previous achievements as are the problems…during his subsequent independent scientific career."[17] While his assessment of the use of textbooks in graduate education is likely less accurate today due to the increased access to scientific journal articles and other changes in graduate education, Kuhn still emphasizes that in scientific education, its primary goal is to instill the current paradigm in its students.

By replacing the idea of linear, cumulative progress with revolutionary shifts in paradigms after crises, Kuhn's work radically challenged fundamental views of how science works. These paradigms are all-encompassing and held practically universally by the scientific community. In contrast to Snow, Kuhn does offer ideas about scientific education and how students are initiated into the paradigm. However, Kuhn's philosophy

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15. Kuhn, *The Structure of Scientific Revolutions*, 138.

16. Kuhn, *The Structure of Scientific Revolutions*, 165.

17. Kuhn, *The Structure of Scientific Revolutions*, 47.

neglects the actual activities and laboratory practices that comprise normal science in favor of a more abstract conception of how scientific paradigms change and undergo revolutions. He also avoids discussion of a moral aspect of these paradigms. While Kuhn primarily restricts his description of paradigms to explain how scientific knowledge progresses, his theory is still predicated on the existence of underlying shared assumptions and commitments, which guide the scientific community's work.

An Ethos of Science: Robert Merton

On the other hand, as a sociologist of science, Robert Merton is interested in questions about the moral dimension of scientific culture. Writing during the mid-twentieth century, when social, political, and economic forces have launched a "frontal assault on the autonomy of science, this crisis and "revolutionary conflict of cultures" have necessitated scientists' "clarification and reaffirmation of the ethos of modern science."[18] He describes an ethos of science, which is "an affectively toned complex of values and norms…expressed in the form of prescriptions, proscriptions, preferences, and permissions."[19] Based in his approach to science as an institution, these norms are "transmitted by precept and example and reenforced by sanctions," and as a result, they are "internalized by the scientist, thus fashioning his scientific conscience."[20] For

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18. Robert K. Merton, "The Normative Structure of Science," in *The Sociology of Science*, ed. Norman W. Storer (Chicago: The University of Chicago Press, 1973), 268. This chapter was originally published as a separate article; see: Robert K. Merton, "Science and Technology in a Democratic Order," *Journal of Legal and Political Sociology* 1 (1942): 115-126.

19. Merton, "The Normative Structure of Science," 268-269

20. Merton, "The Normative Structure of Science," 269.

Merton, this collection of mores, or institutional imperatives of science, are derived from the institutional goal of science, which he defines as "the extension of certified knowledge."[21] He argues that these mores of science are powerful, "binding, not only because they are procedurally efficient, but because they are believed right and good," ascribing both a technical and moral dimension to these norms, and by extension, the ethos of science.[22]

Merton identifies four institutional imperatives that comprise the ethos of modern science: universalism, communism, disinterestedness, and organized skepticism. The first, universalism, demands that "truth-claims, whatever their source, are to be subjected to *preestablished impersonal criteria*: consonant with observation and with previously confirmed knowledge."[23] He writes that "the imperative of universalism is rooted deep in the impersonal character of science."[24] What matters when evaluating someone's research—indeed the only thing that matters, according to universalism—is its scientific validity. In addition to the scientific truths, universalism requires that those wishing to become scientists must also be subject to the same standard, being judged only on competence, not any other demographic factors. In universalism, "expediency and morality coincide," for they both serve to achieve the goal of science, the advancement of knowledge.[25] Merton also acknowledges that both aspects of universalism often find

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21. Merton, "The Normative Structure of Science," 269.

22. Merton, "The Normative Structure of Science," 269.

23. Merton, "The Normative Structure of Science," 270. Italics in original quote.

24. Merton, "The Normative Structure of Science," 270.

25. Merton, "The Normative Structure of Science," 272.

themselves at odds with the ethnocentric particularism and prejudices of the larger social structure. However, despite this conflict, the rejection of and deviation from the norm reaffirms its very existence. A key tenant in the scientific ethos is the egalitarian sense of universalism.

The second imperative, "communism," refers to "the nontechnical and extended sense of common ownership of goods" as it relates to scientific knowledge and the communal character of science.[26] Scientific research is "a product of social collaboration and are assigned to the community," not the work of any one individual.[27] Because scientific progress is the result of a community, communism also embodies "a sense of indebtedness to the common heritage and a recognition of the essentially cooperative and selectively cumulative quality of scientific achievement."[28] As a result, this institutional imperative of communism leads to the need to communicate findings, and secrecy is condemned. When considering the relationship between science and the larger social structure, communism is incompatible with the patent system and the capitalist view of technology as private property. Instead, "the scientist's claim to 'his' intellectual 'property' is limited to that of recognition and esteem," perhaps culminating in an eponym if sufficiently deemed worthy by the scientific community.[29] This practice

26. Merton, "The Normative Structure of Science," 273.

27. Merton, "The Normative Structure of Science," 273.

28. Merton, "The Normative Structure of Science," 275.

29. Merton, "The Normative Structure of Science," 273.

maximizes the efficiency of the extension of knowledge, balancing recognition of priority and the status of scientific knowledge as communal.

The last two elements of the scientific ethos that Merton identifies are disinterestedness and organized skepticism. Like many other professions, science is disinterested, which he defines as having "a distinctive pattern of institutional control of a wide range of motives which characterize the behavior of scientists."[30] When considering the virtual lack of fraud within science, Merton rejects the claim that scientists have greater moral integrity than non-scientists on the basis of lack of evidence. Instead, he attributes this phenomenon to the ethos of science, specifically disinterestedness, which involves the unusually rigorous verification of results, "the exacting scrutiny of fellow experts," known as peer review.[31] The result of the norm of disinterestedness is an accountability system within science, which leads to greater institutional stability in knowledge production. Related is the imperative of organized skepticism, which is "the temporary suspension of judgement and the detached scrutiny of beliefs in terms of empirical and logical criteria."[32] Often in conflict with religion and politics, science "asks questions of fact, including potentialities, concerning every aspect of nature and society," unafraid to traverse the social boundaries of the sacred and profane for the purpose of the expansion of knowledge.[33] The disinterestedness of

30. Merton, "The Normative Structure of Science," 276.

31. Merton, "The Normative Structure of Science," 276.

32. Merton, "The Normative Structure of Science," 277.

33. Merton, "The Normative Structure of Science," 277.

science keeps the organized skepticism of science in check, both still serving the ultimate goal of science.

Merton's ethos of modern science with its four imperatives—universalism, communism, disinterestedness, and organized skepticism—is a remarkably influential articulation and characterization of the institutional culture of science. As a sociologist, he understands and appreciates the moral dimension of cultural imperatives as well as their technical aspects, commenting on the mores' methodological and moral significance. With its considerable autonomy, science, "has evolved an institutional complex which engages the allegiance of scientists," even when in conflict with the larger social structure.[34] The formation of scientists' allegiance is related to their training, which is also how they internalize and adopt these imperatives for themselves. Despite his rich commentary and insights on the cultural influences of scientists' morality, Merton does not relate his analysis to the day-to-day life in a scientific research lab, preferring to discuss his ethos in broad terms that he takes to be distilled from practices.

Scientists as a Tribe: Bruno Latour and Steve Woolgar's Anthropological Study

The idea of the existence of a distinct culture of scientific research is nothing new, and research labs have been the object of sociological and anthropological studies, such as Bruno Latour and Steve Woolgar's field work in the Salk Institute between 1975 and 1977. Similar to how an anthropologist might observe an indigenous tribe, they

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34. Robert K. Merton, "Science and the Social Order," in *The Sociology of Science*, ed. Norman W. Storer (Chicago: The University of Chicago Press, 1973), 259. This chapter was originally published as a separate article; see: Robert K. Merton, "Science the Social Order," *Philosophy of Science* 5, no. 3 (1938): 321-337.

meticulously scrutinize and analyze even the most seemingly mundane details about the inner workings of a laboratory and the behavior of its scientists in this distinctly anthropological approach to science. Latour, a sociologist of science, and Woolgar, a philosopher of science, define culture as "the set of arguments and beliefs to which there is a constant appeal in daily life and which is the object of all passions, fears, and respects," which includes the scientific community and its own mythology of noncontroversial and readily assumed beliefs.[35] This description of the "complex mixture of beliefs, habits, systematized knowledge, exemplary achievements, experimental practices, oral traditions, and craft skills" echoes similar sentiments to Snow and Kuhn's discussions of science.[36] In contrast to more abstract philosophizing, their account is a richly detailed "preliminary presentation of accumulated empirical material," rooted in the particulars of their specific cultural context, as well as guided by a broad understanding of the social nature of science (beyond just norms).[37] With their anthropological study, Latour and Woolgar are less concerned with a general descriptions of structure and function typical of a sociological analysis.

As observers, Latour and Woolgar endeavor to remain between the two extremes of a "total newcomer (unattainable ideal) and that of a complete participant (who in going native is unable usefully to communicate to his community of fellow observers)" in

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35. Bruno Latour and Steve Woolgar, *Laboratory Life: The Construction of Scientific Facts*, 2nd ed. (London: Sage Publications, Inc., 1979; Princeton: Princeton University Press, 1986), 55. Citations refer to the Princeton edition.

36. Latour and Woolgar, *Laboratory Life*, 54.

37. Latour and Woolgar, *Laboratory Life*, 28-32.

order to most effectively study and share their findings to those outside the tribe.[38] As they seek to understand how scientists arrive at truth, constructing order from chaos, Latour and Woolgar also do the same, using specific notions to organize their copious observations about scientists. Some of the first observations and their resulting conclusions that Latour and Woolgar describe all revolve around the principle of literary inscription. For example, they note the distinct division between the bench and the office, the stacks of literature printed outside the laboratory and those documents produced within, and the notebook on each bench.[39] They are struck by how all "members are compulsive and almost manic writers," resulting in the proliferation of such documentation and notes.[40] In addition to their own notes, inscriptions can be produced by measurements made with advanced instrumentation, which hold even more weight in scientists' attempts to construct ordered facts out of disorder. From this collection of observations, it is clear that documentation is important to scientists, both in the setup of the office and laboratory as well as scientists' behaviors.[41]

Latour and Woolgar continue their analysis a step farther. They explain that scientists tend to understand the inscription as more than just mere documents or diagrams, but rather as "evidence for or against particular ideas, concepts, or theories," transforming "the simple end product of inscription into the terms of the mythology

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38. Latour and Woolgar, *Laboratory Life*, 44.

39. Latour and Woolgar, *The Laboratory Life*, 45-48.

40. Latour and Woolgar, *The Laboratory Life*, 48.

41. I will further analyze scientists' relationship with instrumentation in Chapter 3. For my description and analysis of the scientific research practices related to lab notebooks and preparation of manuscripts for publication, see Chapter 4.

which informs the participants' activities."[42] In this way, Latour and Woolgar take concrete observations about the structural aspects of the laboratory, the activities of its members, their interactions with others, and the use of laboratory resources, among others, in order to make broader statements characterizing the underlying motives, values, and beliefs of scientists and their larger culture. Their attention to detail and anthropological lens are quite relevant for this thesis, but their analysis of the scientific research practices they study is only used as evidence for these trends in scientific research culture. Latour and Woolgar do not understand these practices as formative parts of the culture, but instead laboratory activities are merely the byproduct of a culture and part of the process of the construction of knowledge. However, in this thesis, I will instead analyze these practices in their formation and construction of people.

Virtues and Scientific Practice

Various philosophers have also explored various questions relating virtue formation and the scientific life. To consider the moral implications of these shared practices amongst scientists, Daniel Hicks, philosopher of science, and Thomas Stapleford, historian of science, apply philosopher Alasdair MacIntyre's work in *After Virtue* to the historiography of science. They describe how the practice-based lens has pervasively characterized contemporary studies of science, in terms of both theorizing and experimentation.[43] These "complex, collaborative, socially organized, goal-oriented,

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42. Latour and Woolgar, *The Laboratory Life*, 63.

43. Daniel J. Hicks and Thomas A. Stapleford, "The Virtues of Scientific Practice: MacIntyre, Virtue Ethics, and the Historiography of Science," *Isis* 107, no. 3 (2016): 1-3.

sustained activities," or communal practices, are a normative subset of general social practices directed to internal goods.[44] Related to these goods of excellence are virtues, defined as "valorized dispositions…embodied values formed through pedagogy…[which] serve three functions: to enable individuals to achieve excellence, to protect the practice from threats of corruption by goods of efficiency, and to be constitutive components of the good human life."[45] These virtues are learned "in and through our relationships with others, in our communal practices," from watching and imitating mentors, just like scientific techniques are taught in the lab setting.[46] Hicks and Stapleford argue that "every aspect of science is necessarily normative…because communal practices have *teloi* to which they are accountable," providing a holistic normativity and a sense of what good science, scientists, methods, and more *ought to* look like, even if it is not done explicitly or homogenously.[47] By considering scientific practices from a perspective of virtue ethics, Hicks and Stapleford draw on a rich tradition to provide a novel approach to explore the moral dimensions of science.

Another scholarly venture interested in concepts of virtue in science was the three-year, multidisciplinary "Developing Virtues and the Practice of Science" project led by Celia Deane-Drummond, Stapleford, and Darcia Narvaez at the University of Notre Dame. With topics ranging from an empirical basis for virtue ethics, the importance of

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44. Hicks and Stapleford, "The Virtues of Scientific Practice," 6.

45. Hicks and Stapleford, "The Virtues of Scientific Practice," 21.

46. Hicks and Stapleford, "The Virtues of Scientific Practice," 13.

47. Hicks and Stapleford, "The Virtues of Scientific Practice," 19.

virtue in machine learning, and intellectual virtues such as wonder, *Virtue and the Practice of Science: Multidisciplinary Perspectives* lives up to its title. The project focuses on "how what scientists actually do both reflects and shapes their cognitive and behavioral dispositions."[48] Their perspective on practice is theoretical, interested in the philosophical conceptions, psychological basis, and educational methods related to virtue in a scientific context. For example, Nathaniel Warne tries to bring these ideas of scientific practices and virtues "into the teleological frame of thinkers like Aristotle and Thomas Aquinas, who thought of happiness not as an activity but as contemplation."[49] However, he neglects to consider that most scientists do not explicitly seek virtues through their work, and this article is primarily a discussion of a classical philosophical understanding of happiness with vague notions of scientific practices. As a result, the project remains fairly distanced from the richly formative laboratory life described by Kuhn, Latour, and Woolgar.

Conclusion

These descriptions of the inner workings of a scientific laboratory from Snow, Kuhn, Merton, Latour, and Woolgar, all paint a robust picture of the scientific life. As members of a distinct community, scientists participate in a shared culture that guides

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48. Celia Deane-Drummond, Thomas Stapleford, and Darcia Narvaez, *Virtue and the Practice of Science: Multidisciplinary Perspectives* (Notre Dame: Center for Theology, Science, and Human Flourishing, 2019), "Editorial Introduction," Pressbooks.

49. Nathaniel A. Warne, "Have We Forgotten About Happiness?: Scientific Practice and the Contemplative and Active Life," in *Virtue and the Practice of Science: Multidisciplinary Perspectives*, ed. Celia Deane-Drummond, Thomas Stapleford, and Darcia Narvaez (Notre Dame: Center for Theology, Science, and Human Flourishing, 2019), Pressbooks.

their ideas, dispositions, and actions in ways deeper than standard instrument operation and safety protocols. Although some work has been done to consider the moral dimension of scientific research practices, such as Hicks and Stapleford's use of MacIntyre, most descriptions of the scientific research culture neglect this aspect of scientific culture. These accounts acknowledge the existence of shared research practices and may possibly even see them as indicators of a broader scientific culture, but their analyses end there. Practices are viewed as a mere byproduct or sign of scientific culture. Instead, I propose that these practices are inherently richly formative and serve as the very means by which scientists become integrated within the scientific research culture, practically as well as morally. In the chapters that follow, I will first explain the framework of philosopher James K. A. Smith and his method of analyzing various cultural habits and institutions before applying his work to explore various common practices in scientific research labs in order to address the moral dimension of scientific research practices that has been somewhat neglected.

CHAPTER TWO

Applying James K. A. Smith's Model of Cultural Formation to the Lab

In Chapter 1, I surveyed influential perspectives on scientific research culture, all which study science from various perspectives: philosophical, sociological, and anthropological. However, there is a gap in scholarship between analyses that address the moral and ethical aspects of scientific culture and those which are based in the daily routines of an actual scientific research lab. When considering questions surrounding moral formation, practices, and habits, a study of scientific virtues seems appropriate, such as Hicks and Stapleford's application of MacIntyre's *After Virtue*. Going back to Aristotle, "moral virtue…is formed by habit," and since then, many have tried to articulate various sets of scientific virtues or find virtues embedded in scientific practice.[1] Although helpful, an analysis of scientific virtues is also limited in its scope. Virtue ethics begins with these philosophical and theological categories of virtue, each with long pedigrees in Western thought. However, this top-down approach would impose a philosophical framework on science, looking for examples of scientific research practice that already fit into these preestablished conceptions of virtue or vice. By focusing on the

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1. Aristotle, *Nichomachean Ethics*, trans. Martin Ostwald (Upper Saddle River, Prentice Hall, 1999), 34. For studies of scientific virtues, see: Robert T. Pennock and Michael O'Rourke, "Developing a Scientific Virtue-Based Approach to Science Ethics Training," *Science and Engineering Ethics* 23, no. 1 (2017): 243-262; Celia Deane-Drummond, Thomas Stapleford, and Darcia Narvaez, *Virtue and the Practice of Science: Multidisciplinary Perspectives* (Notre Dame: Center for Theology, Science, and Human Flourishing, 2019).

ideal and limiting the analysis to what we consider to be good, this approach tends to neglect the messy reality of scientific practice.

Therefore, in this chapter, I will take an alternative approach to studying the moral formation of scientists by drawing upon the work of theologian James K. A. Smith in his 2009 book, *Desiring the Kingdom: Worship, Worldview, and Cultural Formation*. First, Smith proposes that humans are fundamentally lovers and that our desires are shaped by our habitual practices. These formative practices serve as a type of liturgy, inscribing on our hearts particular images of the good life. Due to this deep relationship between practices, desires, and imagination, we can analyze scientific practices to explore scientists' images of the good life, in Smith's method of cultural exegesis. Modeled after his analysis of a typical suburban shopping mall, I will apply Smith's framework to the scientific laboratory and the Baylor Sciences Building. This chapter will also contextualize the upcoming exegesis of seemingly mundane scientific research practices as powerful, formative liturgies in the rest of the thesis.

Humans as Lovers

Smith begins his argument by claiming that humans are fundamentally desiring creatures, rather than primarily thinking animals, per the traditional rationalist view. The idea of humans as rational animals has dominated western philosophical thought since Plato through Descartes and into modernity with Kant, Hegel, and countless others. Summarized in Descartes' famous maxim, "I think, therefore I am," underlying the rationalist view is a picture of humans as "a cognitive machine defined, above all, by thought or rational operations."[2] By focusing on the "essentially immaterial mind or consciousness," our worldview is formed by "a steady diet of ideas, fed somewhat intravenously into the mind through the lines of propositions and information."[3] Smith does not deny that humans have reason or that our minds are impacted by ideas and information, but he does pushes back on the concept that humans first and foremost are rational beings. He argues that the rationalist view is too narrow, reducing human identity to a matter of one's thoughts and neglecting "our noncognitive ways of being-in-the-world that are more closely tethered to our embodiment or animality."[4] Although our capacity to reason is certainly important to our humanity, Smith rejects the rationalist anthropology as reductionist.

As a response to the rationalist view, another picture of the human person emerged, especially within the Reformed Christian tradition, of humans as fundamentally believing animals. According to this view, "what defines us is not what we think—not the set of ideas we assent to—but rather what we *believe*, the commitments and trusts that orient our being-in-the-world."[5] Critiquing the neutral, objective thinking implied by rationalism, the believing model tries to recognize how much of our thought depends on "a whole constellation of beliefs—a *worldview*—that governs and conditions our

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2. James K. A. Smith, *Desiring the Kingdom: Worship, Worldview, and Cultural Formation* (Grand Rapids: Baker Academic, 2009), 42.

3. Smith, *Desiring the Kingdom*, 42.

4. Smith, *Desiring the Kingdom*, 46.

5. Smith, *Desiring the Kingdom*, 43.

perceptions of the world."[6] Appreciating how this faith-based anthropology has pushed back on the dominant rationalist view, Smith affirms that the Reformed approach is a step in the right direction, agreeing that "our knowing is governed and conditioned by constellations of belief that are more primordial than our ideas."[7] However, he still thinks the person-as-a-believer model is too disconnected from the body, simply moving the center of humanity from our ideas down to our beliefs. Calling it "quasi-rationalist," the prerationalist view also neglects our embodiment.

Instead, Smith moves the center of our humanity from our heads to our hearts and guts. Drawing on the Augustinian tradition, Smith proposes that "the most fundamental way that we intend the world is love," defining humans as fundamentally desiring animals.[8] In *Confessions*, Augustine presents humans as driven first and foremost by their desires, observing an infant's jealousy of his brother being fed, even before he is able to communicate his thoughts or direct his body's motion.[9] Near the end of his book, he writes that "A body by its weight tends to move towards its proper place…my weight is my love. Wherever I am carried, my love is carrying me."[10] For Smith and Augustine, everything is defined in terms of our loves. Smith argues that "we are what we love, and our love is shaped, primed, and aimed by liturgical practices that take hold of our gut and

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6. Smith, *Desiring the Kingdom*, 43.

7. Smith, *Desiring the Kingdom*, 46.

8. Smith, *Desiring the Kingdom*, 50.

9. Augustine, *Confessions*, trans. Henry Chadwick (Oxford, Oxford University Press, 1992), 9.

10. Augustine, *Confessions*, 278.

aim our heart to certain ends."[11] Through these practices, our embodiment is central to this anthropology because "the senses are portals to the heart, and thus the body is a channel to our core dispositions and identity."[12] Augustine also emphasizes the power of our embodiment in directing our desires, and Smith contrasts this dynamic view of desire with the static and reductionistic rationalist and quasi-rationalist views of humans. This model of humans as lovers articulates "a more dynamic sense of human identity as both unfolding and developing over time (a process of formation)" in a way that acknowledges our temporality.[13] For Smith, this alternative model of humans as fundamentally desiring animals most effectively captures the essence of our humanity, especially our embodiment and temporality, in contrast to other traditional views.

Practices as Formative Liturgies

In Smith's framework, if humans are "embodied agents of desire or love," then everything else is also defined in terms of love: our telos, habits, and practices.[14] Due to the directional nature of love, the end to which we are striving, or a telos, is implicit. Smith emphasizes that our teloi are images, attracting our hearts and capturing our imaginations, not abstract values and disembodied ideals in our minds. Instead, these pictures of the good life are "aesthetic articulations of human flourishing," transmitted to

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11. Smith, *Desiring the Kingdom*, 40.

12. Smith, *Desiring the Kingdom*, 58-59.

13. Smith, *Desiring the Kingdom*, 47.

14. Smith, *Desiring the Kingdom*, 47.

us through images and stories, art and music.[15] More than philosophical treatises, religious doctrines, and academic textbooks, stories and images "seep into us—and stay there and haunt us," resonating deeper into the core of our being and eventually shaping our very desires toward them.[16] These visions pull us towards our teloi as we "emulate, mimic, and mirror the particular vision that we desire," becoming certain kinds of people in the process.[17] Related to being fundamentally lovers, not thinkers, our desires are also mapped out in affective images, pulling us towards certain visions of the good life.

How then are the desires of our hearts directed to these particular visions of the good life? Smith points to our habits, which are "our precognitive tendencies to act in certain ways and toward certain ends," turning and orienting our hearts in these directions.[18] As identified by Aristotle, Aquinas, MacIntyre, and other philosophers, habits represent "our default tendencies and quasi-automatic dispositions," which is why both virtues and vices are habits.[19] The power of habits lies in their precognitive state, how they function apart from our conscious reflection. However, philosophers emphasize how "this precognitive engine is the product of long development and formation," and even though our habits are powerful in steering us unconsciously, we too have control in choosing and changing our habits.[20] Because they are precognitive, our

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15. Smith, *Desiring the Kingdom*, 58.

16. Smith, *Desiring the Kingdom*, 58.

17. Smith, *Desiring the Kingdom*, 54.

18. Smith, *Desiring the Kingdom*, 55.

19. Smith, *Desiring the Kingdom*, 56.

20. Smith, *Desiring the Kingdom*, 56.

habits are corporal, "inscribed in our heart through bodily practices and rituals that train the heart…to desire certain ends."[21] Over time, habits, "often in tandem with aesthetic phenomena like pictures and stories—mold and shape our precognitive disposition to the world by training our desires."[22] Through habits, Smith reiterates our embodied status because the way to our hearts, and by extension, our desires, is through the body.

In this way, our physical actions, desires, and images of the good life are deeply connected. According to Smith, "no habit or practice is neutral," for all are somehow directing us to certain ends.[23] Practices carry an understanding of the world that cannot truly be separated from the rituals themselves. Smith calls these practices, "thick," for their rich meaning and habit-forming power. We choose some of our thick practices wholly intentionally, such as consistently participating in a religious service. However, we have other thick practices that are there practically by default or preference, such as checking our email when we wake up. Regardless, "thick habits often both signal and shape our core values of our most significant desires."[24] Smith goes as far to use the term "liturgies" for the thickest type of practice, calling them "*rituals of ultimate concern*, rituals that are formative for identity…[and] function as pedagogies of ultimate desire."[25] He expands the concept of worship to include "secular liturgies" that are not religious in

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21. Smith, *Desiring the Kingdom*, 58.

22. Smith, *Desiring the Kingdom*, 59.

23. Smith, *Desiring the Kingdom*, 83.

24. Smith, *Desiring the Kingdom*, 82.

25. Smith, *Desiring the Kingdom*, 86-87.

the traditional sense, but likewise competing for our hearts to orient our lives toward an ultimate telos. While not all are overtly religious, "all thick habits are meaningful and identity-significant," which is why he compares them to liturgies.[26] Linking Smith's whole framework of cultural formation is the role of our practices or liturgies, which shape and teach us what we desire, and by extension, show and form us into who we are.

The Shopping Mall as a Formative Institution

Having established the significantly formative nature of practices, Smith turns his attention to his method of cultural exegesis of these "secular liturgies." Because practices are necessarily directed towards a certain end, an analysis of the ritual itself can reveal aspects of the visions of the good life held by a particular cultural institution. The goal of cultural exegesis is apocalyptic, or "to make strange what is so familiar to us precisely in order to help us see what is at stake in formative practices."[27] In the Bible, apocalyptic literature, such as the last chapters of Daniel and the Book of Revelation, are not intended to foretell the end of times, but instead to render alternative visions of the world, in place of the dominant worldviews of the Babylonian and Roman empires. Similarly, Smith describes this kind of reading of culture as "apocalyptic," which is "not prediction but *unmasking*—unveiling the realities around us for what they really are."[28]

26. Smith, *Desiring the Kingdom*, 83.

27. Smith, *Desiring the Kingdom*, 23.

28. Smith, *Desiring the Kingdom*, 92.

Smith begins his book with a case study of "one of the most important religious sites in our metropolitan area," which ends up being a typical suburban mall.[29] How might one describe a shopping mall apocalyptically? Beginning with the parking lot, the asphalt lots and concrete decks full of cars are transformed into a "glistening sea of black and color…a haven for our vehicle, still quite a distance from the sanctuary."[30] He peppers his description with religiously loaded vocabulary. First, he calls shoppers, "pilgrims," characterizing them based on their quest. The atrium becomes a narthex, welcoming both new seekers and the regular faithful alike, and the individual stores are smaller chapels in a labyrinth-like cathedral. He compares the stained-glass depictions of saints to the three-dimensional mannequins in store windows because both are examples of iconography, which "inspires us to be imitators of these exemplars…embody for us concrete images of 'the good life.'"[31] Within a few short pages, Smith takes us on a tour of the seemingly mundane shopping mall, leading us to completely reimagine this familiar location in apocalyptic terms, in light of the ways it tries to shape us.

His analysis goes beyond the physical space itself to also include conceptions of time, key activities, and the fundamental message. Governing the mall is a different liturgical calendar. Instead of the church's seasons of Advent, Christmas, Lent, Easter, and Ordinary Time, there are sales, sales, and more sales, fit for every occasion. After browsing the racks, "we proceed to the altar, which is the consummation of worship,"

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29. Smith, *Desiring the Kingdom*, 19.

30. Smith, *Desiring the Kingdom*, 20.

31. Smith, *Desiring the Kingdom*, 21.

understood to be referring to the sales desk.[32] Here, in the mall, “this is a gospel whose power is beauty,” preaching that salvation comes from consumption.[33] With his example of the mall, Smith effectively captures how the seemingly harmless aspects of everyday places and activities “offer a rich, embodied visual mode of evangelism that attracts us…which speak to our deepest desires and compel us to come not with dire moralisms but rather with a winsome invitation to share in this envisioned good life.”[34] Advertisers have capitalized on this rich relationship between the seemingly harmless actions we practice, spaces we inhabit, and images we consume with the habituation of our desires, even before we can realize it.

Smith’s description of the mall and its vision for the good life is incredibly powerful and deeply provocative, which invites consideration of other spaces as formative institutions. By first choosing to see the mall as a place of worship, other aspects of the mall can also be analyzed in terms of their participation in our formation. He unpacks the organization of the physical space and its ornamentation from the parking lot all the way to the altar (cash register) in various subchapels (stores). He recasts shoppers, employees, and managers in liturgical roles as pilgrims, acolytes, and priests. All together, these forces coalesce to give us liturgies to follow and images of the good life to seek, affecting us not as purely cognitive beings, but primarily imaginative, desiring ones.

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32. Smith, *Desiring the Kingdom*, 22.

33. Smith, *Desiring the Kingdom*, 21.

34. Smith, *Desiring the Kingdom*, 21.

The Baylor Sciences Building as a Formative Institution

If the shopping mall, representing a complex network of consumer culture, is a formative institution for those who shop, even occasionally, how much more powerful might the scientific laboratory be? First, very few of us shop as much as we work, and scientists spend dozens of hours every week working in their research labs. He also speaks of the importance of our embodiment, and scientific research engages all the senses with its mysterious materials, procedures, and equipment. According to Smith, the stories of a culture are important in capturing people's imaginations, and part of scientific research is telling and writing the story of one's research in several different ways. Clearly, the scientific laboratory is a formative institution, worthy of a closer look.

Although both the shopper and the scientist are likely oblivious to the formative nature of their locales, one key difference between the mall and the lab is in the intentionality of their design with regards to the cultural visions for the good life. On one hand, advertisers are aware of our nature and our attraction towards these affective images, so they intentionally design the mall and shopping experience to encourage us to shop and to ascribe to their gospel of beauty. Instead of the crafty manipulation by corporations which plague the shoppers, the danger for scientists lies in their lack of consideration for the formative nature of their spaces and practices. However, within Smith's framework, cultural formation occurs through thick practices regardless of one's conscious awareness and participation, due to our noncognitive habits shaping our desires. Therefore, after considering various accounts of the distinctive character of scientific research culture in Chapter 1, the mundane, daily scientific research practices are a rich and underutilized lens through which to examine the scientific life. In a similar revelatory, apocalyptic sense, I will re-engage the scientific laboratory as part of a formative institution, not just the hub of scientific research culture, using Smith's method of cultural exegesis.

In the summer, although thousands of the seasonal seekers are gone, the Baylor Science Building (BSB) remains the site of daily pilgrimages for the true believers. No matter the time of day or night, there are always some paying homage to an experiment, checking on an alarm, or working oblivious to the hour. Its pilgrims trudge in alone, heavy laden with backpacks and computer bags. Armed with thermoses of coffee and lunchboxes, they are prepared to stay. Despite the heat of the summer, they are clad similarly in long pants and closed toed shoes with long hair pulled back. After ascending the sunlight-soaked stairs in the atrium, they turn their back and penetrate the building's inner hallways. They are more than mere catechumens regulated to learning in the classrooms, but full members who have already performed the sacraments of initiation of safety training and been entrusted with keys and ID card access. The walls are adorned with research posters, a different kind of icon, but are still held up as examples worthy of emulation and praise.

They enter smaller chapels dedicated to specific saints. In the narthex, they lay down their bag and prepare to enter the inner chambers, buttoning on their vestments and putting on their goggles and gloves. What lies inside cannot be touched with bare hands or seen with naked eyes. Each sect has its own styles of worship, sounds, and smells. For example, the music of a chemistry lab may be guided by the rhythmic clanking of the vacuum pump, the spinning of the centrifuge, and the whooshing of air in and out of the gloveboxes. Instead of incense, they know the distinct smells of harsh chemicals, oil, and rubber. Purification rituals are particularly important, and the protocol for washing glassware and other instruments becomes comfortingly routine as hands mindlessly yet delicately clean, rinse, and dry. They spend hours preparing delicate samples to be offered up into complex machines, awaiting inscriptions containing truths they cannot know for themselves. They care for their data, protecting it against all the evil forces of contamination and subjectivity, which might produce error.

They have their own collections of sacred writings that they study often, which like the Bible, consists of varied genres, including descriptive histories and prescriptive procedures to follow. They gather regularly in group meetings to hear about their fellows' work and address group business as well as individually. Here they may confess their misdeeds, ask for guidance, and petition for additional resources, not from a pastor or a priest, but a PI (Principal Investigator). They even write their own stories, in lab notebooks, epistles, and accounts of the work they have done in order to proliferate the discoveries they have made to the wider community. Although by no means a religion, science is powerfully formative, requiring scientists to participate in various liturgical practices and offering a particular vision of the good life.

Conclusion

By describing the scientific laboratory apocalyptically, the liturgical dimension of scientific practices comes into sharper focus. By "looking at the mall through the eyes of worship and liturgy, with attention to the concrete material practices…we can at once appreciate that the mall is a religious institution because it is a *liturgical* institution, and that it is a pedagogical institution because it is a *formative* institution," and the same is true for the lab.[35] The mall and the laboratory are not only the physical loci for their respective cultures of consumerism and scientific research, but the very institutions that form the culture's images of the good life. Work in the scientific laboratory does not only train the mind to think in terms of the scientific method and the hands to perform the techniques. Rather, like religious worship or a shopping expedition, scientific research is a rich sensory experience, which captures the imagination and teaches the heart what to love through the body. Acknowledging the deeply formative nature of the laboratory environment is crucial to then understanding what scientists are being taught to love, how they imagine the good life, and how this formation is occurring. Because scientists learn how and what to love by participating in scientific research practices, the laboratory serves not only as a workplace, but a fundamentally formative institution.

35. Smith, *Desiring the Kingdom*, 23.

CHAPTER THREE

Inside the Lab: Washing Glassware, Preparing NMR Samples, and Growing Crystals

In the first chapter, I surveyed influential accounts on scientific culture, and in Chapter 2, I discussed Smith's apocalyptic readings of culture through its formative practices. He describes these formative practices as secular liturgies, orienting the desires of our hearts and instilling particular visions of the good life. In this chapter, I will draw upon my firsthand experience in an inorganic chemistry research lab to continue my cultural exegesis of scientific research practices. My analysis will be rooted in highly detailed descriptions of a few scientific research practices—washing glassware, preparing NMR samples, and growing x-ray crystals—which all are examples of the kind of thick, identity-significant practices that Smith calls liturgies.

Despite the vast heterogeneity in scientific practices due to the diversity of labs, disciplines, and methodologies in science, all scientists participate in these kinds of formative practices. There are countless to choose from, and I chose three prominent practices from my experience that are deeply embodied and captured my imagination. These three rituals—washing glassware, preparing NMR samples, and growing x-ray crystals—are also representative of broader kinds of scientific practice across various fields: purification, generation of inscriptions, and care for data. My focus is less on the specifics of the practices, but instead, on the aspects of the vision for the good life embedded within these practices, which involve truth, purity, objectivity, and order.

The Practice of Washing Glassware: Purity and Contamination

Practices related to cleaning and purification are clearly central to scientific research culture and worth analyzing as a formative liturgy. In addition to being critical work, the practice of cleaning glassware is deeply embodied, a true ritual in the synthetic chemistry lab. Although such strict and thorough cleaning procedures have the explicit purpose of cleaning the glassware for future use, the practice also orients chemists towards certain ends and forming their desires, even unintentionally and unconsciously, as the process becomes semi-automated. To the rhythm of the clinking glassware and sloshing liquid and with the sharp smell in the air, we carry out the ritual we have done countless times. The practice of base bath and acid bath is exactly the kind of routine that Smith considers a formative practice, a cultural liturgy, as it is multisensory, repetitive, and central to scientific research activities, and by extension, our identities as scientists. Dish soap, a sponge, hot water, and some good old-fashioned elbow grease is insufficient to clean the vessels for chemical reactions. This rigorous procedure for cleaning glassware contributes to the sense of the other-worldliness of the scientific lab and how the practices of scientific research are completely distinct from everyday life. As a practice shared only among certain scientists, the routine of base bath and acid bath is transformed into a powerful identity-forming liturgy, directing our deep loves and shaping our images of the good life.

When I have base bath duty for the week, every day, first thing in the morning, I immediately enter the quiet lab, put on my disposable gloves, followed by the big thick rubber ones on top. I open the base bath, a plastic bin containing 20 liters of a bright orange potassium hydroxide isopropanol solution, and I wrinkle my nose at its sharp, distinctive smell. Safety glasses firmly in place, I peer into the murky liquid, which is filled with dirty glassware of all shapes and sizes that has soaked overnight. I turn on the deionized (DI) water in the sink and start filling up our plastic rinsing bins. With the sound of running water in the background, I carefully remove each individual piece of glassware with the metal tongs, draining the excess liquid back into the bin, before submerging each piece into the running clean water. The tongs and the glassware clink together pleasantly, and my mind wanders as my hands carry out this deeply embodied ritual.

When the base bath has been fully unloaded, I drain the water out and bring the bins of glassware over to the fume hood containing the acid bath, an aqueous solution of nitric acid. I take each freshly rinsed piece and carefully use the green Teflon-coated tongs to carefully place it in the acid bath where they soak for several hours. Later in the afternoon, I repeat the process of removing and rinsing the glassware, handling each flask, vial, stopcock, condenser, and beaker, one by one. To dry everything, I grab the squeeze bottle of acetone, spraying every crevice and surface of each piece of glassware before hanging it on the drying rack or loading the bins for the ovens. The acetone runs cold on my skin through the nitrile gloves, jolting me awake from the afternoon wave of drowsiness. Tonight during lab shutdown, someone will load the 40°C and 135°C ovens with the freshly cleaned glassware to continue drying overnight, and then tomorrow night, the glassware will be loaded into the ports and put under vacuum for another night, attempting to remove every last molecule of water before use. However, my work is done—at least for the day.

Although these systematic practices for cleaning glassware with base bath and acid bath are more particular to inorganic and organic chemistry labs, almost all bench research labs have purification rituals. From autoclaving media before cell growth to isolated, controlled clean rooms, countless technologies and procedures have been developed with the sole purpose of removing contamination. In his article, Cyrus C.M. Mody applies aspects of Mary Douglas' anthropological explication of dirt in religion and culture from her 1966 book, *Purity and Danger*, to scientific research. Because "virtually all social groups have ideas about dirt and defilement, the meanings attributed to contamination can only be understood in relation to local contexts, meanings, and practices," quipping that "'dirt' is always relative."[1] Absolute cleanliness is an impossible standard, so impurities must be defined in relation to the research goals, especially those which interfere with the integrity of the results. In our lab, the days-long washing and drying of glassware may seem excessive, but water levels above 5 ppm (parts per million) can ruin months of hard work in the inert environment by decomposing water sensitive samples. As pollution can cause errors in measurements, undesirable side products in reactions, or even completely disrupt the system under study, purity is inherently linked with precision, accuracy, and truth. Through these rigorous, time-consuming, careful purification procedures, scientists are formed to value purity, because the validity and truth of their work may depend on this lack of contamination.

In addition, Mody anticipates two potential objections to his argument that are similar to potential critiques of the rest of this thesis. The first challenges the

1. Cyrus C.M. Mody, "A Little Dirt Never Hurt Anyone: Knowledge-Making and Contamination in Materials Science," *Social Studies of Science* 31, no. 1 (February 2001): 9, 17.

terminology of the analysis because material scientists do not refer to their actions in these terms, such as dirt and purification rituals. To this objection, Mody responds, "all material scientists with whom I have spoken readily acknowledge the considerations of purity and cleanliness in their works."[2] Despite the wide variation in purification rituals amongst different fields, "discerning contaminants and ways of getting rid of them is a recurrent theme in understanding dirt and cleanliness in laboratories."[3] The other objection argues that scientists only care about purity because contamination interferes with the quality of their results. However, although "all pollution rules *can* be rationalized as a product of 'proper' hygiene, no such rule can be completely abstracted from its symbolic elements."[4] In other words, these purification practices, such as base bath, have both a technical goal within science and a deeper symbolism. As Smith argues, "no habit or practice is neutral."[5] Despite their heterogeneity and their lack of explicit nontechnical purposes, these scientific research practices have a formative dimension, subconsciously capturing scientists' imagination and orienting their desires towards certain ends, which in the example of base bath and acid bath, is an image of purity and by extension, truth.

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2. Mody, "A Little Dirt Never Hurt Anyone," 20.

3. Mody, "A Little Dirt Never Hurt Anyone," 8.

4. Mody, "A Little Dirt Never Hurt Anyone," 19.

5. James K. A. Smith, *Desiring the Kingdom: Worship, Worldview, and Cultural Formation* (Grand Rapids: Baker Academic, 2009), 83.

The Practices of NMR Spectroscopy: Inscriptions and Objectivity

Although washing glassware may be a very formative practice in scientific research, almost no one would claim that purification rituals embody the heart of scientists' work. The practices are necessary to maintaining a lab, but not constitutive of performing research and "doing science." Instead, scientists run experiments, observing, measuring, and collecting evidence to support their hypotheses. During my time in the Martin Lab, much of my work involved running small-scale (<0.1 g) chemical reactions in the glovebox, a large container filled with inert gas where air- and water-sensitive chemistry can be conducted more easily. As a synthetic research group, our goal is to synthesize novel compounds by running new reactions and then trying to determine their structures with various spectroscopic techniques. Particularly relevant to our lab's work are multinuclear Nuclear Magnetic Resonance (NMR) spectroscopy and x-ray diffraction crystallography. Similar to base bath, the procedures for preparing samples for these instruments are "meaning-laden, identity-forming practices that subtly shape us…automating our desire and action without conscious recognition."[6] Through constant repetition, these seemingly minor practices participate in forming larger pictures of the good life and good science, which with regards to the practices related to NMR spectroscopy and x-ray crystallography, instill a constellation of values including objectivity, order, and care.

In the midst of setting up my reaction—weighing out the solids, dissolving the reactants, calculating the stoichiometry in my lab notebook—before actually staring the reaction, I pop into the office, grab my computer, and log onto FOM, Baylor's Facility

6. Smith, *Desiring the Kingdom*, 83.

Online Manager, to reserve time on an NMR spectrometer. Shared between all the labs, I scroll through the day' schedule, mentally juggling the available times with the reaction start time and my long list of other to-dos for the day. I need to hurry, or I will not be able to run my experiment. Click, click, I reserve my time, and my name pops up for all to see. I scribble my reaction number and spectrum number on my hand, triple-check the time, and head back into the lab.

When it is time for the first *in situ* NMR experiment, I re-enter the glovebox and find one of my quartz NMR tubes, labelled with my initials on its pink cap, and stand it upright in a beaker. I open my stirring reaction vial and carefully transfer less than 1 mL of the reaction mixture into the waiting NMR tube. With a fresh pipette, I add a few drops of precious deuterated solvent, discard my used pipette into my waste tray, and cap my NMR tube. The air whooshes as the box repressurizes as my arms leave. I move quickly yet with care; my movements are second-nature after countless repetitions. I open and close the doors of the small port, slide out the metal tray, and grab my sample. The pattern of sounds are the same: tap, whoosh, slide, tap, and whoosh as I evacuate the small port. I hustle over to the NMR lab in a different wing of the building, gripping the thin quartz tube with my thumb firmly on that soft plastic cap and praying the seal can hold out the outside air long enough for me to run a sample.

I swipe my ID card for access; the door beeps as it unlocks, and I am already at the instrument before it slams shut behind me. I grab the sample measurer and a numbered spinner from the carousel, slide in my tube until it hits the bottom, and drop my precious sample into the spectrometer. At the computer, I set the experimental parameters, double-checking the time, before clicking Start. The machine instantly responds. I hear the sample carousel turn and watch my tube get lifted up from among the rest and loaded into the belly of the magnet. The spectrometer hums as it tunes, locks, and shims, and I wait impatiently for the checks to appear on the screen for each step. Once successfully running, I leave, mentally noting the time I need to return to collect my sample. I have 16 minutes…maybe I should update my lab notebook or look for that other reagent I need or refill the liquid nitrogen dewar.

My phone buzzes with the PDF of my spectrum. As I walk quickly back to the NMR room, I am already opening it, even though I know I will have to look on my computer anyways. Is there another peak? Is there any change at all? Back into the port the NMR tube goes. Whoosh, slide, tap, whoosh…I refill, load, and evacuate the antechamber. I write down the time, NMR sample, 10 minutes, and my initials on the notebook next to the glovebox we use to keep track of the ports. My mental timer starts again as I download the spectrum on my computer and open it on Mstrenova, the software we use to examine our spectra. I sigh if there is no change or puzzle over any different or new peaks. Digital peaks on my computer screen correspond to real compounds swirling around my reaction vial. With no noticeable change in the peaks, I conclude that the reaction is not occurring. With the appearance any new peaks, I perk up, trying to guess what product might be forming, based on its location, or I crumple at any signs of decomposition. Either way, I keep moving. Now that I have the spectrum, I know what I need to do.

Similar to how the procedure of base bath and acid bath that I know as an inorganic chemist is only one example of a pollution ritual, this description of running an NMR experiment, although more particular to chemistry, is representative of many other rituals of sample preparation within other fields of scientific research. The generation of a spectrum, or *inscription* as Latour and Woolgar would say, from material substances in the laboratory is of chief importance. In their research of the Salk Institute, they observe how "particular significance can be attached to the operation of apparatus which provides some kind of written output," such as an NMR spectrometer.[7] Extraordinary amounts of time, money, and effort are spent for "the end product…no more than a curve, a diagram, or a table of figures written on a frail sheet of paper," which bewilders the casual, non-scientific observer.[8] In fact, "once the end product, an inscription, is available, all the intermediary steps which made its production possible are forgotten," in favor of the inscription, suggesting the significance of NMR spectra and other measurements.[9] Due to the importance of their end results, seemingly mundane, technical procedures for sample preparation then qualify as *rituals of utmost concern* for Smith, or liturgies that form our desires and images of the good life.

Although each step in the preparation of an NMR sample has an explicit purpose (such as the addition of deuterated solvent for locking, port operation procedures to maintain the inert glovebox environment, experimental parameters for instrument operation, etc.), the fully embodied practices also shape scientists' implicit ideas of what truth is. Latour and Woolgar argue that for scientists, reality does not only depend on

7. Bruno Latour and Steve Woolgar, *Laboratory Life: The Construction of Scientific Facts*, 2nd ed. (London: Sage Publications, Inc., 1979; Princeton: Princeton University Press, 1986), 51. Citations refer to the Princeton edition.

8. Latour and Woolgar, *The Laboratory Life*, 50.

9. Latour and Woolgar, *The Laboratory Life*, 63.

these inscription devices, but is "*thoroughly constituted by* the material setting of the laboratory."[10] Interestingly, this view implies that truth, at least the more important truths, can be known through intermediaries, such as NMR spectrometers and other forms of instrumentation. Although I can see for myself what color my reaction mixture is, the appearance, disappearance, or change in peaks in the NMR spectrum is ultimately more relevant in assessing the progress of a reaction. The NMR spectrum on my computer represents the chemical activity of the reaction occurring in the vial in the glovebox, but the digital inscription, not the physical chemicals, are seen as the source of this information.

Perhaps scientists trust the light they cannot see more than the light they can see. Atomic nuclei are spinning charged particles, which means they have a magnetic moment that can be aligned with or against an externally applied magnetic field. NMR uses radio waves, which is a form of light, to promote atomic nuclei from the lower to the higher state (from with the field to against the field), and this energy absorption is measured. Peaks are generated at distinct frequencies along the spectrum due to their differing chemical environments caused by shielding or deshielding effects from their surrounding electrons.[11] Radio waves, like most forms of electromagnetic radiation, are outside the visible region of light, and yet, these invisible forms of light are responsible for the

10. Latour and Woolgar, *The Laboratory Life*, 64.

11. This is a very basic description of how NMR works that can be found in a standard undergraduate level organic chemistry textbook. See: David Klein, *Organic Chemistry* (Hoboken: Wiley, 2015), 732-734. Citations refer to the second edition.

majority of spectroscopic characterization techniques in a chemist's toolbox.[12] The very narrow region of visible light (380-740 nm) encompasses all the light the human eye can detect or everything we see, from the color of the reaction mixture to the shape of the spectrum on a computer screen. Similar to the invisibility of the radio waves and magnetic fields involved in NMR spectroscopy, the molecules themselves that produce these signals are also impossible to see with the human eye. Embedded in the preparation of the NMR sample is a quest to see the invisible, to translate the atomic to the macroscopic, by using light that is also invisible.

This trust and dependence on these intermediary technologies and methodologies such as NMR spectroscopy reveal a preference for what can be known indirectly through instrumentation over what can be known directly with the five senses. While questions about the extent measurements can be truly objective are far beyond the scope of this thesis, within the scientific research community, certain kinds of evidence are viewed as far more substantial than others, and by extension, the truth of the theories they support. Claims based solely on observations without inscriptions are distrusted, insufficient, or irrelevant, such as the color of the reaction mixture, in favor of claims supported by inscriptions, generated by complex instruments, such as NMR spectra. Inscriptions are authoritative because scientists believe in their objectivity and inability to be swayed by

12. Other common forms of spectroscopy include (but are not limited to): IR (infrared), UV-Vis (ultraviolet), and circular dichroism (circularly polarized light). There are many variations and applications of these spectroscopic techniques that can be used to elucidate various aspects of molecular structure and bonding, but these few mentioned are so common that they are widely taught, even at the undergraduate level. See: Caroline Cooper, *Organic Chemist's Desk Reference* (Boca Raton: CRC Press, 2011). Citations refer to the second edition.

human biases, so they have faith in the truths they represent.[13] As a result, fearing their own subjectivity and bias, scientists-in-training quickly learn to seek the necessary inscriptions as inherently part of the quest for truth. The importance of inscriptions reveals how the ideal of objectivity has captured scientists' imagination, a vision for the good life which is further instilled through the rigorous rituals of sample preparation.

The Practices of X-Ray Crystallography: Order from Chaos

In their truth-seeking quests for molecular structure, chemists have many other characterization techniques in their analytical toolboxes. While NMR uses radio waves to excite spin flips in various atomic nuclei in sample solutions, on the other end of the electromagnetic spectrum, x-ray diffraction crystallography bombards single crystals with x-rays.[14] The x-ray diffractometer detects the diffraction pattern of these x-rays after passing through the molecule arranged in a crystalline lattice, and these scans can be solved to determine the structure of the compound composing the crystal.[15] In the Martin Lab, we use NMR for almost all reactions in order to try to determine molecular

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13. For an interesting discussion about what Gould called one of the twin myths of science, namely objectivity, see: Stephen Jay Gould, *The Mismeasure of Man*, 2nd ed. (New York: W. W. Norton & Company, Inc., 1981; 1996). All data requires interpretation, so Gould argues that nothing is truly objective, and even good, ethical scientists can unknowingly and unintentionally influence the data to match their preconceived notions.

14. Although solid-state NMR does exist, it is much less commonly used.

15. Cooper, *Organic Chemist's Desk Reference*, 225. For a more detailed introduction to the theory behind x-ray crystallography, crystal structure, and diffraction, see: Christopher Hammond, *The Basics of Crystallography and Diffraction*, International Union of Crystallography Texts on Crystallography (Oxford: Oxford University Press, 2001).

structure, identify present compounds, and check purity. On the other hand, we use x-ray crystallography in order to elucidate the definitive structure of a novel compound in a single crystal. If the structure has a sufficiently high resolution to be published, then a solved crystal structure (even with disorder modeling) is considered unambiguous proof of the synthesis of the compound with that particular arrangement of atoms.[16] In the characterization of our novel compounds, our routines about preparing, running, and solving crystals are central practices in our day-to-day life in our lab.

Although crude NMR samples can be easily taken and run in the instrument, the process of growing crystals of sufficient quality for diffraction is unpredictable. With the first few attempts of a new reaction, nothing goes to waste. Even when the NMR spectra show a messy mixture of products after any purification attempts, I use those solutions to try to grow crystals. Time is up, and the ten minutes of vacuum has passed. Whoosh, slide, tap, whoosh…I refill, load, and evacuate the antechamber, bringing my precious NMR sample into the glovebox. Is the big vacuum pump already running? If not, I slide my arms out of the glovebox and grab the trap from the fume hood. Twist and snap, I attach the greased glass joints of the trap with red Keck clamps to the adapters connected to the pump and the glovebox. I plug the pump in and listen as it suddenly kicks into gear. Once it chugs along steadily, I slowly twist the first valve, and the pump's clanking sharply increases until the trap is evacuated. Still listening to the rhythms of the pump, I slowly open the valves on the other side. Now it is time for the liquid nitrogen. I carefully find the big dewar and carefully pour the liquid nitrogen into the smaller dewar

16. The International Union of Crystallography (IUCr) offers a free service called checkCIF that checks the integrity and quality of x-ray crystal structures using a multi-tiered alert-based system on various parameters and restrains used during solving.

to pour into the dewar around the trap. The liquid hisses as it comes into contact with the room temperature dewars, and white clouds billow around me. Once it stops boiling off and has cooled the vacuum trap to -196°C (-320 °F), I am ready to pump down on my reaction vial.

Back into the glovebox, I open my reaction vial and attach it to another vacuum adapter. A few more twists of valves, and I hear the pump respond instantly, loudly chugging as the solvent is evaporated from my vial. Once all the volatiles have been pumped down, I carefully prep my crystallization vials, dropping the tiny 4 mL vials into our standard 20 mL vials and checking all the Teflon-lined caps for tight seals. I hem and haw as I consider the countless factors affecting crystallization, such as temperature, solvent combinations, inward and outward diffusion. More like guided guesswork than a rigorous methodology, I decide on the conditions I will try this time. I carefully redissolve my reaction mixture in a few drops of a solvent of choice and carefully transfer the solution with a pipette to one of the small, inner vials. I cautiously add the outer solution, careful not to let a drop fall into the precious inner vial. After screwing the cap on and labelling the vial, I place this round of crystallization attempts on the designated crystallization part of the shelf and wait.

Every day I check my crystallization vials, peering into them for any hint of crystal growth. I handle crystallization vials with care because too much movement can disturb the crystallization process and crack any crystals trying to form. If I see powder, I start over. Darn, that was too fast. Maybe, this is something! I ask the designated group crystallographer about the queue on the instrument, shared by the whole department. Aha, look at these little guys! These are crystals! I immediately inform the group crystallographer, and if the x-ray diffractometer is available, we immediately walk over to the x-ray lab and start preparing the instrument for use. This takes precedence.

Once the instrument is ready, I carefully take the vial out of the glovebox, and we return to the x-ray lab. We examine my vial under the microscope. Are those crystals? I shiver in the cold room as we try to find anything that might be runnable—a single, diffracting, uncracked, crystal of proper size. We open the vial and scoop out my sample, pushing them around on a microscope slide. This is the point of no return. Now this reaction mixture can be salvaged no more. We mount the most crystalline thing we can find on the goniometer loop, and with a few clicks on the computer, the instrument whirs into motion, and I spin in my chair. Is there diffraction? Are those spots real? I wait with nervous anticipation yet without high hopes for the fast scan. Too many times have we reached this point, thinking something is a crystal, only to be disappointed and need to start over. "Dang, this is a weak little guy," John says to me as we watch the reflections come in. If I am lucky, maybe we will have one that diffracts strongly. Click, click, this is the unit cell—the smallest possible volume that is representative of the entire crystal. We check the unit cell dimensions to see if it corresponds to a known compound or common contaminant. Can I dare to hope yet? If we decide to run the crystal, we finish setting up the experimental parameters. Most would run overnight, but we check the time anyway. When is the earliest we can come by for a rough autosolved structure? We are impatient once the experiment is running. This may be the compound I have been trying to make! Or not. We mentally mark the time we can return and go back into the lab. There is other work to do.

The process of growing crystals, as finnicky as it is, requires great care. For example, in the language we use, we say "grow crystals," instead of make or synthesize. Some intuition, a dose of good luck, and a great deal of persistence is needed in this process, due to the unpredictability of crystal growth. The crystals (and non-crystals) are handled with such delicate respect, sometimes even personified for their stubbornness, deception, and irregularity. Instead of a stereotypical detachment from their data, scientists' investment in their work is emotional. One lab ethnography discusses "the personal relationships human tie with data as they invest time, knowledge, and affects in the process of producing it," in terms of care.[17] For example, one epigeneticist in the lab "through the process of making and building the database…became personally invested in 'his' data and came to care about its future."[18] They discuss how "this relationship becomes inscribed in the data and in their researchers and contributes to the value of the dataset," because as researchers come to *know* their data, they gain contextual and practical knowledge about their data that would not be possible without this kind of caring.[19] This care-based view of scientists' relationship with their research echoes Smith's characterization of human beings as fundamentally lovers, not thinkers or believers. The painstaking process of growing crystals is merely one example of how scientists orient themselves with their work in terms of care, not just pure rationality.

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17. Clémence Pinel, Barbara Prainsack, and Christopher McKevitt, "Caring for Data: Value Creation in a Data-Intensive Research Laboratory," *Social Studies of Science* 50, no. 2 (February 2020): 179.

18. Pinel, Prainsack, and McKevitt, "Caring for Data," 187.

19. Pinel, Prainsack, and McKevitt, "Caring for Data," 189.

Embedded within the methods of growing crystals for x-ray crystallography is the attempt to create order out of chaos. Crystals are the most highly ordered arrangement of molecules, even in the solid state, and they are grown from solutions, in which molecules move and mix much more freely. This particular process of growing pure crystals from crude reaction mixtures reflects the broader desire of scientists to produce order from a messy collection of observations and inscriptions. When trying to assign peaks in an NMR spectrum, there may be some ambiguity in assigning each peak in the spectrum to each atom. Without the x-ray crystal structure, these proposed structures are only hypotheses informed by the data in each NMR spectrum, one probable way of interpreting the data.[20] Because "the elimination of alternative interpretations of scientific data…is a central characteristic of scientific activity," Latour and Woolgar try to characterize all activities in a scientific research lab in terms of "the confrontation and negotiation of utter confusion."[21] Once solved, these prized x-ray crystal structures represent the paragon of order, both literally and chemically but also symbolically and practically because they provide almost unambiguous proof of the solid-state molecular structure of a compound while rejecting other plausible interpretations. Cleary from all the time, energy, and resources dedicated to the techniques of x-ray crystallography, the desire for creating order out of chaos is deeply formed within scientists.

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20. For example, in our lab, we rely most on ^{1}H, ^{13}C, ^{11}B, and ^{31}P NMR spectroscopy with each type providing information on the different atomic nuclei present in the sample.

21. Latour and Woolgar, *Laboratory Life*, 36.

Conclusion

Implicit within the execution of all these scientific research practices is the demand on scientists' time. From the multiple-day lag of a vial being dropped in base bath until ready for use in the glovebox to the NMR spectrometers being booked for use long past normal working hours, the procedures of washing glassware and preparing samples for NMR spectroscopy and x-ray crystallography are labor-intensive and time-consuming. These questions about the long hours of the scientific research are widespread across all fields with the general consensus pointing to overtime being somewhat expected in order to be successful.[22] This pressure to log long hours is another example of the power of unsaid, implied cultural norms in forming one's images of the good life. In a literal sense, base bath works by removing a layer of the glass, and the result of such a corrosive manner of cleaning glassware is the inevitability of the need for the glassware's replacement.[23] Implicit in this practice is another reflection on the kind of unsustainability in the demands of the scientific life. These long hours spent in the laboratory demonstrate how powerfully formative scientific research practices can be, simply by how much time they dominate in scientists' lives.

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22. Questions about scientists' work-life balance (or lack thereof, in some case) and studies related to their long working hours routinely arise in editorials in leading scientific journals. See: Kendall Powell, "Young, Talented, and Fed-Up," *Nature* 538 (October 2016): 446-449; Chris Woolston, "Full-time Is Full Enough," *Nature* 546 (June 2017): 175-177. For an interesting approach looking at the hours of literature downloads by scientists, see: Xianwen Wang et al., "Exploring Scientists' Working Timetable: Do Scientists Often Work Overtime?" *Journal of Informetrics* 6 (2019): 655-660.

23. See most Standard Operating Procedures (SOPs) about base baths made by lab safety regulatory bodies. For example, see: "Laboratory Safety Guideline: Base Baths," Harvard Environmental Health and Safety, last modified April 22, 2019. https://www.ehs.harvard.edu/sites/default/files/lab_safety_guideline_base_bath.pdf

All three scientific research practices analyzed in this chapter—washing glassware, preparing NMR samples, and growing crystals for x-ray crystallography—are material, deeply embodied rituals. Although these are perhaps more particular to my subfield of chemistry, all scientists have these sorts of purification, preparation, and technical rituals in their own work. Smith would argue that these kinds of practices are even more than thick, formative practices. They are secular liturgies. Due to their repetitive, semi-automatic, multisensory, and material nature, these practices constitute liturgies because they "are formative for identity, that inculcate particular visions of the good life…function as pedagogies of ultimate desire."[24] Liturgies are directional, orienting their practitioners to certain images of the good life by shaping their desires. Embedded in these three scientific research practices are aspects of a vision for a good life, which is a constellation of values related to truth: purity, objectivity, and order, and away from pollution, subjectivity, and chaos.

24. Smith, *Desiring the Kingdom*, 86-87.

CHAPTER FOUR

Story-Telling Within Science: Lab Notebooks, Group Meetings, and Journal Articles

While many scientific research practices happen inside the bench laboratory, a significant part of scientific work also occurs in the adjoining office—in lab notebooks and at computers, while actively working and in the spontaneous coffee breaks turned brainstorming sessions. The activities in the office are integrated with the actual experiments characteristic of scientific research, whether that is ordering chemicals, reading previous literature, or analyzing spectroscopic data. Also, because good scientific research does not occur in isolation, many of the research practices performed in the office center around communication with the rest of the scientific community. In many ways, the office serves as the narthex, the antechamber, and the buffer between the bench laboratory and the outside world. As the "in-between" place, the office is a fundamental part of the lab, offering a space for preparation and reflection while still immersed in scientific research culture.

Although not as multisensory and embodied as the lab-based practices in Chapter 3, these office-based scientific research practices are equally powerful in the formation of scientists because they all are activities of story-telling. As described in Chapter 2, stories are instrumental in shaping our images of the good life. For Smith, the desires that shape us are not typically conscious parts of our own wills, but instead "a vision of the good life that has been painted for us in stories and myths, images and icons" that has captured our imaginations.[1] However, many scientists are not consistently exposed to this kind of identity-formative stories, for example from humanities educations or independent reading habits. Quoting a colleague in the natural sciences, Snow quips, "Books? I prefer to use my books as tools."[2] More recently, biologist David Smith regularly asks his fellow scientists at conferences if they have read any good books lately, to which they usually reply, "Books! I wish. I'm so busy that I don't have enough time to watch a movie, let alone read a novel."[3] Snow calls scientists self-impoverished as "their imaginative understanding is less than it could be" due to their lack of interest in literature.[4] Although lab notebooks, research group meeting presentations, and scientific journal articles are hardly the kind of rich stories that Smith refers to, these are the kinds of stories that inundate scientists and capture their imaginations. In this chapter, I will continue my cultural exegesis of scientific research practices by examining the aspects of the good life embedded in these three story-telling activities characteristic of science.

Lab Notebooks: Documentation of All the Details

Perhaps the most representative symbol of a scientist's story is the laboratory notebook. Ours have a brownish-red cover with a black binding, thick yellow graph paper pages, and light blue grid lines, and I can instantly recall its smell, the weight of the

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1. James K. A. Smith, *Desiring the Kingdom: Worship, Worldview, and Cultural Formation* (Grand Rapids: Baker Academic, 2009), 54.

2. C. P. Snow, *The Two Cultures,* (Cambridge: Cambridge University Press, 1998), 3.

3. David R. Smith, "Do Scientists Read Enough Fiction?" *EMBO Reports* 22, no. 2 (February 2021), 2.

4. Snow, *The Two Cultures*, 14.

pages, the texture of the worn, softened cover, and the feeling of flipping through its pages. Prominently positioned on everyone's workspace are their lab notebooks, usually open to a reaction in progress, a pen always nearby or tucked within the pages. On a shelf, we keep the lab notebooks of all previous group members, a collection of reference material only as helpful as their level of detail. Our lab notebooks are ours, but not really—they belong to the lab, and in them, a more comprehensive but still sorely incomplete account of our time in the lab is preserved. While including some of the half-projects, failed reactions, and mistakes not in our published work, they fail to capture all of someone's vision and thought process. These handwritten records, infused with an individual's unique style, are sharply juxtaposed against all the sterile inscriptions produced by sophisticated instrumentation analyzed on computer screens. As a dynamic resource, we constantly refer to and update these pages. Not a day goes by without me using my lab notebook for some reason or another. They are a truly a staple in the scientific research lab, and the practices related to the lab notebook are worth analyzing as formative liturgy.

When I start a new reaction, I open my lab notebook to the next blank page, and mindlessly run my hand over the center crease, my mind already racing several steps ahead and all that I need to do that day—new reactions to set up, NMR samples to run, crystal batches to check, lab maintenance to perform, papers to read. I breathe and methodically print my name and the date at the top of the page. One step at a time, I remind myself. Right underneath that, I title the reaction, for example, "Reaction of *[X]* with *[Y]*-Trial *[#]*." I breathe and re-focus. This is what I need to do right now. Next, I draw the scheme, blue pen hovering above the arrow where I will list my reaction conditions. It all seems so simple. X + Y makes Z. But I know the working up that needs to follow. I make my reaction table, scribbling the headings as I have done countless times: Reagents, MW (Molecular Weight), Amount Used, Molar Amount, Equiv. (Equivalents). I list my chemicals and solvents below, some of these in widely accepted abbreviations and others in a shorthand particular to our lab due to their common use. I head into the lab with a sticky note to weigh out my first reagent, writing down the mass on the note to be transferred into my notebook. Back in the office, I quickly punch the numbers into my calculator, filling out the columns in my table, and writing the ideal stoichiometric amount for the other reagent on my sticky note before going back into the lab to weigh it out. Again, I mark down the actual mass on the sticky note and check the calculations in the office, faithfully updating the table in my lab notebook before throwing away the sticky note.

Below the table, I create a new section, "Procedure." Here I number my steps, writing down every action I take as directions, removing myself from the process, with notes in the margins about the time, color, and other observations. I notate every NMR sample run, writing down the experiment number, solvent, and any changes (or the lack of changes) as well as all attempts to grow crystals, detailing the solvent combinations and results for future reference. The lab notebook is essential to deciphering the results of the NMR spectra, which I number based on the notebook page. If running a known or successful new reaction, I include the calculations for the theoretical and percent yield of the isolated product. The reaction worked! But if not, I write down the results: "NO REACTION," "COMPLEX MIXTURE," or "REACTION DISCARDED" in all capital letters at the bottom of the page for future reference, and I move on. Often I will include rough musings of what might be occurring or what to try next, marked by question marks, with no other knowledge besides a messy collection of spectroscopic data and a chemical intuition. I have several reactions, and therefore, several lab notebook pages, actively being worked on at any given time, so I try to update my notebook as immediately as possible because I know I will forget details that might be important later.

Unlike some of the more discipline-specific procedures of base bath, NMR spectroscopy, and x-ray crystallography, the practice of keeping a laboratory notebook is a widely known and acknowledged part of all fields of scientific research. Latour and Woolgar describe scientists as "compulsive and manic writers," with everyone having "a large leatherbound book in which members meticulously record what they have just done against a certain code number."[5] While they were unsurprised by the vast amounts of literature that scientific researchers read, Latour and Woolgar were surprised by the quantity of documentation produced in the lab, a system that begins with and centers around the lab notebook. In his ethnographic study of a chemical physics laboratory, Chad Wickman notes that "the notebook, however, among all the texts I observed being used in the laboratory, is the only one that is actually assembled in tandem with specific laboratory tasks."[6] However, despite the lab notebook's unique and prominent place in the scientific research process, he also characterizes the frequent writing in lab notebooks

5. Bruno Latour and Steve Woolgar, *Laboratory Life: The Construction of Scientific Facts*, 2nd ed. (London: Sage Publications, Inc., 1979; Princeton: Princeton University Press, 1986), 48. Citations refer to the Princeton edition.

6. Chad Wickman, "Writing Material in Chemical Physics Research: The Laboratory Notebook as Locus of Technical and Textual Integration," *Written Communication* 27, no. 3 (2010): 269.

as “a more or less mundane part of laboratory life,” an activity not particularly unusual or relevant.[7] Because the lab notebook is that deeply embedded within the scientific life, or as Smith would say, “more and more automatic…part of the very fiber of our character, wired into our second nature,” writing in a lab notebook constitutes a formative liturgy within scientific research.[8]

In addition to their repetition, practices involving the lab notebook are especially formative due to their role in storytelling, and Smith has remarked on the power of stories in capturing people’s imagination, and by extension, shaping their desires. Occupying “a negotiated space between the scientist’s contingent response to exigency in the laboratory and the genre-specific strategies that he deploys to communicate his work outside the laboratory,” the lab notebook is the first place that scientists confront the stories of their research.[9] Wickman argues that the lab notebook should be understood as the locus facilitating “a reflexive process whereby inscriptions are used both to interpret a-perceptual chemical phenomena in time, and, through their inclusion and integration in the notebook, to discipline that interpretation over time.”[10] The practice of keeping a lab notebook is most fundamentally a ritual of storytelling. Through the very act of updating the lab notebook and compiling in one place a seemingly haphazard collection of procedural steps, observations, and data from inscriptions, scientists begin trying to make order out of disorder, one of science’s fundamental goals. As the scientists’ first attempt

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7. Wickman, “Writing Material,” 270.

8. Smith, *Desiring the Kingdom*, 86,

9. Wickman, “Writing Material,” 264-265.

10. Wickman, “Writing Material,” 265.

to tell the story of their research, the lab notebook is the most specific, detailed, and chronological.

Related to scientists' quest for objectivity previously discussed in Chapter 3 with inscriptions such as NMR spectra, the lab notebook also reflects this preference for depersonalization. The procedure is written as commands, not in a historical or autobiographical style of the work I have done. Similarly, Wickman notices the use of passive sentences in the lab notebooks he studied, which "objectifies laboratory activity by placing emphasis on objects…and actions," rendering the scientist almost invisible.[11] As a result, Wickman argues that the practice of writing in a lab notebook "constitutes a move to objectify material processes and highlights the 'known,' that is, that which is documentable and replicable."[12] While not an explicit rejection or denial of the role scientists clearly play in scientific research, such standard styles of writing in a lab notebook do reflect certain cultural norms and values, including an implicit association between objective truth and the distance between the scientist and the science. In first formulating their stories about their own research, scientists immediately remove themselves from the picture in favor of the substances, processes, and data.

Group Meetings: An Exercise in Transparency

While the lab notebook is a more personal account of one's research, primarily for oneself and perhaps a few select others trying to duplicate reactions, group meeting presentations are for one's supervisor and fellow lab members. On a regular basis, the

11. Wickman, "Writing Material," 274.

12. Wickman, "Writing Material," 273.

lab assembles for group meeting, for example, on Wednesdays at 9 AM. All labwork screeches to an abrupt halt as we grab our notebooks and walk to the reserved conference room. Awaiting us is the lab member assigned to present his or her research progress, the title slide already projected onto the screen. We take our seats; the meeting will begin once our PI (Principal Investigator) arrives. We listen to the presentation and review the schemes, spectra, and structures presented as evidence of their hypotheses. Many times, the PI will stop the speaker to ask questions, which might be for clarification, correction, or something else to consider trying. Occasionally, one of the group members will jump in with a recommendation or a question as we all try to help think through our coworker's current roadblocks. "Have you tried…? What about…? Maybe this would…" Meanwhile, the presenter is taking notes, especially on what the PI advises. That must be done by the next set of individual meetings. After the presentation, we tackle any group business. Our boss asks for any updates about ordering, lab maintenance, and other assigned group tasks, also filling us in on other news relevant to the group, such as the status of grant proposals, the hiring of any new lab members, or departmental news. The meeting adjourned, we walk back to the lab together. It's time to get back to work.

On my weeks to present, I flip through my lab notebook, refreshing myself on all the work I have done since my last group meeting. Mentally, I start grouping together my reactions into their respective projects, instead of the strict chronological order of the lab notebook. I create the new slides, outlining the presentation in the titles, double-checking that I have not missed a new reaction, even failed or inconclusive ones. Next, I start making the reaction schemes on ChemDraw, careful to be consistent with standard group practices, especially with colors and abbreviations. After drawing out the scheme, I add spectra from the reaction, *in situ*, crude, and clean, depending on the status of the reaction. Unlike the pages of writing in the lab notebook, my group meeting presentation is dominated by figures, whether they are reaction schemes, NMR spectra, x-ray crystal structures, and the occasional photograph, with very minimal text. If I started a new project, I might add a slide of background and include my proposed synthetic route, but otherwise, everything included in the presentation is simply my work in the past few weeks. I conclude my presentation with a slide on "Future Work," check for any typos or mistakes in my schemes, close my laptop, and head into the lab.

Although the time spent in an hour-long weekly group meeting may seem negligible when compared to the long working hours of scientific research, the ritual of group meeting is a deeply formative and common part of the scientific research life. In a qualitative study of "research exemplars" from various scientific disciplines, the top lab management practice cited by interviewees (83%) was holding regular team meetings, described as "the cornerstone of rigorous research."[13] One participant even states that "the lab meeting that we have each week is probably one of the most important hour to two hours that we spend together because everybody has to be able to show their raw data, everybody has to be able to talk about these difficulties."[14] As PIs, these scientists say that the multifaceted nature of group meetings achieve several explicit purposes: sharing data, coordinating group activities, providing accountability, building

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13. Alison L. Antes, Ashley Kuykendall, James M. DuBois, "The Lab Management Practices of 'Research Exemplars' that Foster Research Rigor and Regulatory Compliance: A Qualitative Study of Successful Principal Investigators," *PLoS ONE* 14, no. 4 (2019): 8.

14. Antes, Kuykendall, DuBois, "Lab Management Practices," 11.

relationships, and learning. The key value repeatedly emphasized with regards to group meetings is transparency, for "this routine helps lab members feel comfortable putting their data, findings, and interpretations on display for others to critique."[15] In other words, in group meetings, scientists learn to tell a story of their research. Even when not presenting their own research, group meetings play an important role in the formation of scientists' understanding of good science, openness, and truth.

But how exactly are group meetings related to this subtle shaping of our desires through our practices that Smith discussed? As described above, in a literal sense, group meeting presentations are composed primarily by images: NMR spectra and x-ray crystal structures and ChemDraw reaction schemes. To scientists (who know how to interpret these figures), these images merely serve as evidence, representations of real chemical phenomena. In a liturgical, symbolic sense, these figures function as illustrations to a compelling story being told about the work, visual representations of the particular story being told about someone's research, but also indicative of the larger currents about how science works. Central to Smith's framework are these "images of the good life," which capture our imaginations, and by extension, our hearts. He argues that "such pictures are most powerfully communicated in stories, legends, myths, plays, novels, and films," compared to abstract, disembodied sets of rules or ideas.[16] Therefore, group meeting presentations are not only powerful due to the concentration on images, but also because they are an activity of story-telling. When making the slides, the scientist takes a step

15. Antes, Kuykendall, DuBois, "Lab Management Practices," 9.

16. Smith, *Desiring the Kingdom*, 53.

back from a single lab notebook page to consider the recent work more holistically, making decisions about how to arrange that narrative, looking for patterns, and trying to puzzle through any discrepancies. As the audience, through someone else's work, scientists also engage more deeply with their own story, perhaps inspired by what to (or not to) strive for. The liturgical power of the group meeting is found in its roots as a practice of story-telling, in addition to its goals of transparency and accountability.

Publications

The culmination of a scientific research project is rarely a group meeting presentation, or even a poster presented at a conference, but rather, the classic scientific journal article in a peer-reviewed journal. In Smith's description of the mall, the consummation of worship is at the altar where the priest (read: sales associate) "presides over the consummating transaction…[in] a religion of transaction, of exchange, and communion."[17] Although the last stop in a consumer's journey into the mall, occurring only as a result of all the forces of formation already embedded within the images, practices, and space, with the ritual of the transaction comes the end of the experience. Perhaps the scientific journal article is similar within the realm of scientific research. The bench labwork has been completed, the glassware cleaned, the samples run, and the data collected. Yet looming over all of these activities is the potential for publication in a journal article, whether that be setting the standard for publication-quality of raw data or

17. Smith, *Desiring the Kingdom*, 22.

even how scientists understand the impact of their own work.[18] The practices surrounding and the very structure of a scientific journal article informs how scientists understand and approach the rest of labwork.

As I successfully synthesize and isolate new compounds of interest to a project, I begin compiling the SI (Supplemental Information), a very tedious process of formatting the data. First, referring back to my lab notebook, I write a formal procedure for the reaction and work-up, all in passive voice, and include key details about appearance and solubility, next to a neat ChemDraw figure of the compound's structure. Switching back between Microsoft Word and Mestrenova (our NMR spectra processing software), I manually list all the peaks in each NMR spectra (such as ^{1}H, ^{11}B, ^{13}C, ^{31}P) as well as their locations, appearance, integration values, and any coupling constants. I also copy the processed NMR spectra, one by one, each on its own page, overlaid with the ChemDraw figure of the compound, for others to reference, even doing zoomed-in versions for certain regions of interest.[19] My mouse clicks along; my left hand knows the keyboard shortcuts as I switch between windows. My mind is tempted to wander at the monotony, but I shrug off the boredom. I need to stay focused. There are too many small details that will get missed if I am distracted.

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18. For an interesting discussion about the complicated factors motivating scientists, Latour and Woolgar offer an interesting alternative to the simplistic economic models about credit in their chapter on credibility and cycles of credit. See: Latour and Woolgar, *Laboratory Life*, 187-233.

19. For an example SI that I compiled (and later reformatted over the course of several painstaking days), see the SI for my first publication: Greta K. Wiofsky et al., "Supporting Information for: 'Ligation of Boratabenzene and 9-Borataphenanthrene to Coinage Metals," *Inorganic Chemistry* 60 no. 24 (2021).

Eventually, once enough of the research has been completed, the writing of the paper itself begins. Besides compiling the heavily detailed SI, in the process of preparing a manuscript for publication in a scientific journal, as an undergraduate, I have significantly less firsthand experience compared to the time I have devoted to other scientific research practices described in this thesis. For the one published journal article I have to-date, I was the co-first author with another former undergraduate in the lab, so I did make the first attempt to write the Results and Discussion section, which is typically the section written first, summarizing as much data and experimental data in as few words as possible.[20] However, most of the manuscript was written by my PI, with some parts written by our external collaborators. I did spend hours creating and editing figures and tables, especially for our x-ray crystallographic data. Also as one of the primary authors, my PI tasked me as responsible for all the references, including managing the Endnote database and constantly revising the formatting. There is a very specific way that the story must be formatted and told.

Although I may have only worked on a few papers, I have read too many to count. When searching for particular information or insight, I intuitively scan the sections I am less interested in while closely examining every word, number, or figure in my sections of interest, trained to maximize my efficiency in processing such large quantities of information. In his provocatively titled speech in 1964, "Is the Scientific Paper a Fraud?" Sir Peter Medawar describes the standard format of a biological sciences paper into the

20. The manuscript referenced here is: Greta K. Wisofsky et al., "Ligation of Boratabenzene and 9-Borataphenanthrene to Coinage Metals," *Inorganic Chemistry* 60 no. 24 (2021): 18981-18989.

following sections: introduction, previous work, methods, results, and discussion.[21] Now, at least in chemistry, previous work is usually incorporated into the introduction, with methods often included with the results or in the SI, but the general skeleton remains the same. In the introduction, "you merely describe the general field in which your scientific talent are going to be exercised," and in the section of previous work, "you concede, more or less graciously, that others have dimly groped towards the fundamental truths that you are now about to expound."[22] Although harsh, Medawar is criticizing not only the placement of the introduction in the scientific paper (which is usually written near the end of the writing process) as misleading but also for the ways introductions attempt to frame the scientific work in relation to other work, even if only tangentially related.

Related to Medawar's critique of the introduction and previous work sections is a section he does not explicitly mention but is paramount to almost all scientific journal articles: references. Reflecting on my many tedious hours formatting the citations for our paper, the overwhelming majority were located in the introduction, often in groups after a single sentence. We did not refer to most of these papers while in the research process, yet here we are, building our narrative in relation to them. Many scholars have been interested in this phenomenon of citations, especially because citation-related metrics are

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21. Peter Medawar, "Is the Scientific Paper a Fraud?" in *Communicating Science: Professional Contexts*, ed. Eileen Scanlon, Roger Hill, and Kirk Junker (London: Routledge, 1999), 27.

22. Medawar, "Is the Scientific Paper a Fraud?," 27.

used by scientists to evaluate the relative significance of their research and careers.[23] In one study of chemists, the majority of respondents (51%) say that they cite papers for a documentary reason, for "completeness," not because "a significant part of the cited work (theory, measuring methods) is utilized" (only 15%).[24] An article with minimal citations (such as to work that substantially influenced the methods or can be directly compared to the results) is unthinkable to scientists. Regardless of their degree of direct impact on the research, references are an essential part of how scientists can even begin to tell their own story, even retroactively.

When considering the general anatomy of a scientific journal article and the context of the vast amount of writings produced within the scientific lab, it quickly becomes evident that a scientific paper is a highly tailored means of telling the story of scientific research. Medawar argues that "the scientific paper is a fraud in the sense that it does give a totally misleading narrative of the processes of thought that go into the making of scientific discoveries."[25] Medawar does not claim that the scientific papers are full of wrong or mistaken information, but that the format belies the true process of scientific research. Kuhn also notices this disconnect between the stories scientists tell about their research and how science actually works, commenting that "the result is a

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23. For a detailed review of studies about various aspects of scientists' citing behaviors, see: Lutz Bornmann and Hans-Dieter Daniel, "What Do Citation Counts Measure?: A Review of Studies on Citing Behavior," *Journal of Documentation* 64 no. 1 (2008): 45-80.

24. Bornmann and Daniel, "Citation Counts," 59-60. See also: Peter Vinkler, "A Quasi-Quantitative Citation Model," *Scientometrics* 12 (1987): 47-72.

25. Medawar, "Is the Scientific Paper a Fraud?," 31.

persistent tendency to make the history of science look linear or cumulative, a tendency that even affects scientists looking back on their own research."[26] While endeavoring to accurately and precisely describe the results of scientific research, in the story-telling process, the scientific journal article becomes disconnected from the very thought processes that produced the work.

Instead of accurately representing the scientific process, the goal of the story in a scientific research article is to create order from an organized disorder. As Medawar says, the scientific paper makes it seem like "out of a disorderly array of facts an orderly theory, an orderly general statement, will somehow emerge."[27] Commenting further on this disconnect between history and truth for scientists, Kuhn writes that "the depreciation of historical fact, is deeply, and probably functionally, ingrained in the ideology of the scientific profession, the same profession that places the highest of all values upon factual details of other sorts."[28] Kuhn attributes part of the reason is to minimize the role of humans in the progress of science, for "more historical detail…could only give artificial status to human idiosyncrasy, error, and confusion," asking "why dignify what science's best and most persistent efforts have made it possible to discard?"[29] Similar to the lab notebook, the story scientists tells renders themselves

26. Thomas S. Kuhn, *The Structure of Scientific Revolutions*, 3rd ed. (1962; repr., Chicago: University of Chicago Press, 1996), 139.

27. Medawar, "Is the Scientific Paper a Fraud?," 28.

28. Kuhn, *The Structure of Scientific Revolutions*, 138.

29. Kuhn, *The Structure of Scientific Revolutions*, 138. Existing in tension with this value of objectivity and the minimal role of the scientist is the realistic and honest assessment that publications are instrumental to the career and credentialing of scientists. While there may be no direct competing financial interest, scientific papers are key to

almost invisible in this quest for unbiased, objective truth, but Medawar criticizes "the starting point of induction, naïve observation, innocent observation [as] a mere philosophic fiction."[30] He argues that all observations are biased and influenced by preconceived ideas, and scientific work is not the result of this seemingly straightforward path to truth guided purely by the collected data. Further emphasizing this impossible ideal of objectivity within scientific research culture are the ubiquitous declarations about no conflicts of interest, somewhere in the paper, as required by publishers.[31] In one sense, the scientific paper is focused on presenting a certain view of science as objective and disembodied, choosing to ignore how scientists actually carry out the scientific research process.

Conclusion

While not as deeply embodied as the practices of the bench laboratory, these three office-based scientific research practices—writing in lab notebooks, attending weekly group meetings, and preparing scientific journal articles—all embody different forms of story-telling within science. Although intended for different audiences with varying

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these systems of credit within scientific research. See: Sahra Jabbehdari and John P. Walsh, "Authorship Norms and Project Structures in Science," *Science, Technology, and Human Values* 42, no. 5 (2017): 872-900.

30. Medawar, "Is the Scientific Paper a Fraud?," 29.

31. For example, for papers published in journals under the American Chemical Society, the author guidelines specify that "A statement describing any financial conflicts of interest or lack thereof is published in each ACS and partner journal article." See: "Important Manuscript Submission Requirements and Notices," Journal of the American Chemical Society, ACS Publications, last modified January 21, 2022, https://publish.acs.org/publish/author_guidelines?coden=jacsat.

degrees of refinement, all three of these practices share certain characteristics, which also reflect features of scientists' images of the good life. From hand-drawn reaction schemes to digitally mastered figures, images are prominent in all three kinds of stories. For Smith, images are much more effective than words at touching our affective nature, but what are the images in the stories of scientific research? Instead of advertisements of smiling people enjoying a company's line of products, the images inundating scientists communicate data. Rather than a vision for happiness (through consumption), the figures in a lab notebook, presentation, or publication advocate for the pursuit of truth and order amidst chaos. The data in these figures is presented alone, detached from the messy process of scientific work and the role of the scientist. The images characteristic of scientific stories project a sense of order, objectivity, and truth, which are also reflected in how scientists imagine the good life.

Another key aspect of scientific research culture illuminated by the group meeting presentation is the social dimension of science. The stories scientists both receive and tell are meant for a community. Good science is done with other scientists, shared with other scientists, and reviewed by other scientists, as evidenced by the proliferation of research conferences, collaborations, and journals, but even the existence of the multi-membered research group.[32] Drawing from Charles Taylor's work, Smith discusses the idea of the "social imaginary," which is "an affective, noncognitive understanding of the

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32. Scientific collaborations have been the subject of numerous studies due to how much science is a social activity, not an individual one. For some foundational work on this topic, see: Donald D. Beaver and Raymond Rosen, "Studies in Scientific Collaboration, Parts I-III," *Scientometrics*, 1, (1978) 65-84; 1, (1979) 133-149; 1, (1979) 231-245.

world…described as an *imaginary* (rather than a *theory*) because…it is made up of, and embedded in, stories, narratives, myths, and icons."[33] What gives the social imaginary its social character is twofold; "on one hand, it is a social phenomenon received from and shared with others; on the other hand, it is a vision *of* and *for* the social life—a vision of what counts as human flourishing, what counts as meaningful relationships."[34] Group meetings, among other social practices of sciences, are part of this social imaginary of scientific research culture. Going beyond the formative impact of specific practices at the individual level, the social imaginary broadens Smith's idea to discuss the formation of a community and its loves, values, and visions.

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33. Smith, *Desiring the Kingdom*, 68. See also: Charles Taylor, *Modern Social Imaginaries* (Durham: Duke University Press, 2004).

34. Smith, *Desiring the Kingdom*, 66.

CONCLUSION

In this thesis, I begin by reviewing several influential accounts of scientific research culture from various perspectives, including philosophical (Snow, Kuhn, and others), sociological (Merton), and anthropological (Latour and Woolgar). However, there is a gap in scholarship relating the moral dimension of science and the actual reality of scientific practices in a research lab. Therefore, I apply the work of theologian James K. A. Smith, who explores the deep link between our embodied practices, our hearts' desires, the power of stories, and the embedded images of the good life. Through the three lab-based practices I analyze—washing glassware, preparing NMR samples, and growing crystals—a particular vision for the good life (as offered by science) is formed by the embodied, sensory, repetitive rituals in the lab. I also consider three other scientific research practices—writing in a lab notebook, attending group meeting, and preparing journal articles—which are all activities of storytelling informed by and intended for the larger scientific community. These stories inundating scientists obscure the role of the scientists behind the research, prioritizing the communication of data above all else. When considering both the embodied practices and types of stories within science, a vision for the good life begins to emerge, one which associates truth with purity, objectivity, and order.

I wrote this thesis to reflect on the inarticulable tensions I have experienced between the different visions for the good life embedded in the research lab and in my church, humanities classes, and residential community. Although science is by no means antithetical or incompatible with the Christian life, I think the issue lies in how its all-encompassing nature competes for the primary allegiance of my heart. Perhaps the vision for the good life ingrained in scientific research practices is too narrow, its view of truth, too limited.

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