UNIVERSITY OF OKLAHOMA

GRADUATE COLLEGE

HOW METEOROLOGISTS LEARN TO FORECAST THE WEATHER:

SOCIAL DIMENSIONS OF COMPLEX LEARNING

A DISSERTATION

SUBMITTED TO THE GRADUATE FACULTY

in partial fulfillment of the requirements for the

Degree of

DOCTOR OF PHILOSOPHY

By

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Norman, Oklahoma
2011

HOW METEOROLOGISTS LEARN TO FORECAST THE WEATHER:
SOCIAL DIMENSIONS OF COMPLEX LEARNING

A DISSERTATION APPROVED FOR THE
DEPARTMENT OF EDUCATIONAL LEADERSHIP AND POLICY STUDIES

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Dedication

This work is dedicated to:

My late Uncle, Dr. Christos Papastravros

for encouraging me to pursue a Ph.D.
I'm so sorry you missed this.
I would have loved talking to you about my studies.

Dr. Charles Doswell, III

for immediately recognizing my potential,
and telling me what you saw.

and

My Husband, Mr. James G. LaDue

for believing I have something to contribute,
and helping make that happen.

Acknowledgements

First and foremost, I am indebted to Dr. Robert D. Fox, my original advisor. I absolutely adored him for all that he was to me and was so lucky to find him right here in Norman! He provided many things, including a voice of my academic ancestor, Malcolm Knowles. He and Dr. Barbara Greene taught me how to wade in to the swamp, then Bob left me to figure out how to get back out. I will never forget how he *heard* me, welcomed me, and was adamant that I had a place.

Many thanks, too, to Dr. Connie Dillon. I am grateful for all the time we spent early on, trying to find a convergence between my original interests in informal education and hers in distance education. Our efforts helped feed my hunger to consider all the fascinating things I was learning. Many thanks as well to Dr. Kathleen Rager, for support throughout, and to Dr. Juanita Vargas, for help at a critical point during analysis.

Thanks go to Dr. Harold Brooks for being particularly encouraging at a key point. I was working with him on educational outreach for the NOAA National Severe Storms Laboratory when I first applied to this doctoral program. He wrote one of my reference letters and I still, to this day, can hear him walking down the hall after leaving my office, talking to me and then to himself that yes, yes, he was happy to write a letter, very pleased, and that my interest in pursuing this doctorate was a very good thing for me.

Although there were many key moments along this journey, and likely several people I'm not remembering to thank, one moment stood out in particular.

Many thanks to Cristal Sampson for being willing to come to Norman! I appreciated her candid insights, and an excuse to work on my dissertation got me back on track during the summer of 2009. She and Jennifer Newman (summer 2007) showed me that mentoring is not only a pleasure, it is a very effective way to learn.

Many, many thanks also go to Dr. Pam Heinselman for bringing me into collaborative efforts before I finished. Likewise to Ed Mahoney and others at the NWS Warning Decision Training Branch. It was very encouraging to have opportunity to explore how I can contribute after I've finished, and Pam modeled many qualities critical to being a productive researcher.

And finally, the most important thanks go to my husband, Jim, and to Dylan, my Honey Bunches! I finished this work *despite* having a baby and *because* I had a spouse who deeply believed in what I was doing. Whoever said babies sleep all the time never met mine! Dylan was just too little and too alert, a "mommy's boy" to the end. He needed me, and I was there for him. The intense, erratic, controlled, uncontrolled, balanced, unbalanced, creative, crazy dance of not-ever-quite-balancing work, family, self, and hobby (this work) commenced once he was born. And Jim shared all that, and suffered as much as I did. It was rough at times, but we made it.

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Abstract

Weather and climate persistently affect individuals, corporations, and governments, sometimes in significant ways: a poor forecast leaves people unprepared to prevent damage or deal with disruptions to their daily routines, and studies show anywhere from 3.4-25% of the US economy is sensitive to weather. Despite the intangible and tangible significance of good forecasts, weather forecasting is rarely explicitly taught and there is little written about how meteorologists learn to forecast the weather. Literature within meteorology is scant; mainly descriptive. The few empirical studies of professional forecasters addressed the nature of the warning task, forecaster decision making, and forecaster performance, revealing the complexity of the domain without explaining how forecasters are learning. In education and other literature, several constructs may apply, including expertise, learning through reflection, and self-directed learning, but none of these have matured to the level of theory. There is currently no single, comprehensive theory for learning that describes how and why someone would learn to take a body of knowledge and apply it in non-linear ways to real world problems.

This study therefore takes a grounded theory approach, aiming to identify the elements and relationships characteristic of a theory of how meteorologists learn to forecast the weather. Interviews with 11 forecasters resulted in two models. Participants were from two employment sectors, had forecasted several types of weather, and had a range of time in service. The first model describes the triggers for learning and how those change over time. The second describes how forecasters built their ability to forecast the weather. A central, repeating theme about a strong sense of professional identity with their role as a forecaster was consistently important to how the participants engaged in learning, particularly when they were poorly supported and had to create strategies to learn. A second strong theme emerged: learning was faster, forecasters were happier, and their resulting knowledge was better connected and more thorough if participants had good social support. Results are well supported through triangulation with the experiences and observations of training officers, empirical studies and published reflections of forecasters, empirical models of adult learning, and indigenous science learning.

Chapter One

Introduction to the problem

On 24 January 2000, forecasters trusted computer models too much and failed to recognize precursors to a record snow event that caught millions of people unprepared as it moved up the eastern seaboard from North Carolina to the Washington, D.C., New York, and Boston metro areas. The storm dropped a record 20.3" of snow where it developed in the Raleigh-Durham, North Carolina area. Even as real-time weather data began to foreshadow an ominous change in the expected evolution of the event, all three numerical weather prediction models in use at the time continued to develop the storm sufficiently far offshore to avoid impacting the dense east coast population areas. Human forecasters ignored the signs in real-time weather data and continued to trust the models. About the time that snow began falling at surprising 1 to 2 inch per hour rates in North Carolina on the evening of the 24th, models finally began to correctly place the storm track over land (Bosart, 2003). Human forecasters scrambled to change their forecasts during the evening hours, but Washington, D.C. was particularly affected by the timing: most people in that area go to bed before the late night news (Bosart, 2003). Unaware the forecast had changed, they did not leave extra time for shoveling driveways or a longer commute. Officials responsible for activating sand and salt crews in the D.C. area were able to call in staff and mitigate some of the effect (Sipress, 2000), but the snow fell hard and fast during the overnight hours and into the morning, overwhelming snow-clearing efforts on the Metro rails and major roadways (Layton & Sipress, 2000a, 2000b). It was hardly a routine commute to work for D.C. area residents the next morning. A good forecast is a necessary precursor to the myriad of decisions individuals, corporations, organizations, and governments make, yet despite its importance, forecasting is rarely explicitly taught and there is an absence of literature describing how one learns to forecast.

Individuals and governments are not unique in their susceptibility to weather. A recent study by Lazo (2006) estimated an annual variation of 3.4% in US economic output due to variability in the weather. Other studies have suggested significant and wide-ranging impacts. The National Research Council report *Fair Weather* (2003) included the following summary of studies on the impact of weather and climate:

- Industries sensitive to weather and climate account for approximately 25% of the U.S. gross domestic product (GDP). Industries with direct sensitivity account for almost 10%.
- Estimated losses due to drought are $6 to $8 billion annually.
- Tornados, hurricanes, and floods account for an additional $11.4 billion in losses each year.
- The strong El Niño of 1997-1998 resulted in $2.6 billion in losses, $2 billion of which were from crop losses.
- 70% of air traffic delays are caused by weather, resulting in $4.2 billion in lost economic efficiency.
- Disease transmission by insects and ticks are affected by variations in temperature and humidity. Humans are directly affected as well,

because weather impacts or causes many ailments including allergies, rheumatism, and heat stroke.

- Distributions of native and invasive plant species are also affected by weather and climate.

Collectively, corporations and organizations of all kinds are vulnerable to the same range of weather hazards that affect this country. One corporation in particular is singularly susceptible to the full range of weather because its 3,400 stores, warehouse clubs, and distribution centers are scattered throughout most of the United States. In his talk to the 2006 National Severe Weather Workshop, Wal-Mart's Director of Business Continuity said that during hurricane Katrina alone, over 100 Wal-Mart stores were damaged, some heavily, and a few stores were submerged in flood waters (Jackson, 2006). Corporations like Wal-Mart operate in-house Emergency Operations Centers to continually determine how to best mitigate losses and prepare for weather impacts. Despite the clear and significant impact of forecasts on lives and livelihoods, few attempt to teach weather forecasting and it has rarely been studied.

A review of meteorological and other literature fails to produce much scholarship in the area of learning to forecast. As meteorology was becoming a science in the mid-18th century, the British government nearly banned forecasting (Hontarrede, 1998). British scientists had been pressuring their government to stop what they saw as an activity similar to that of astrologers and charlatans. Historical writings on the founding of meteorology departments (e.g. Koelsch, 1996) have described a struggle for an identity for the discipline – was it a branch of natural history or a physical science seeking to identify general laws? Eventually, just as the discipline emerged in the early 1940s, schools temporarily shifted their focus to prepare forecasters for operations during World War II (Allen, 2001), but how they did so was not described.

Forecasting contests are a common activity for meteorology students in colleges and universities, but literature about contests is small and erratic in emphasis. One paper described forecasting merely as a way to assess student learning (Harrington, Cerveny, & Hobgood, 1991). Other papers almost suggested forecasting contest performance is unscientific: more of an art than a science. For example, Gedzelman (1978) found that students gained most of their skill by the 30th forecast, and Roebber and Bosart (1996) showed no significant difference between faculty and their students, despite faculty having much deeper knowledge of the science. In perhaps the only experiment that investigated learning in forecasting contests, students showed a significant rise in skill for precipitation forecasting on days when they had to write a forecast discussion (Market, 2006).

Other concept papers address the increasing tension between human and computer forecasts because advances in computing, numerical techniques, and the science of meteorology have greatly increased the skill of numerical weather prediction models (e.g. Bosart, 2003). So while people have attempted to forecast since ancient times (Neumann, 1989), little is documented about how they learned to do it. Perhaps this is not surprising because the science of human learning in complex domains is still an emerging one. There are several constructs that may prove relevant to this study of how meteorologists learn to forecast.

Forecasting appears to fall within the description of expertise summarized by Glaser and Chi (1988). For example, experienced forecasters quickly recognize meaningful patterns, are much faster than novice forecasters, and gain a deeper understanding of what they see. Experienced forecasters seem to spend the time to gain a stronger qualitative understanding of the state of the atmosphere before they attempt to make a forecast. Studies of expertise have tended to deal with domains or problems that are conducive to study because expert performance can be specified, such as the game of chess and the solving of homework problems in physics and computer science (Chi, Glaser, & Farr, 1988). A more recent compilation of work on expertise highlights research in many dissimilar domains such as transportation, software design, professional writing, professional judgments and decision making, arts, sports, games, etc., and one similar domain: medicine (Ericsson, Charness, Feltovich, & Hoffman, 2006). In the domain of medicine, Norman, Eva, Brooks, and Hamstra (2006) note the difficulty in defining expert performance. Ericsson and Lehmann (1996) had earlier emphasized an idea advocated by many that expertise researchers should restrict their studies to standardized conditions where performance can be reliably and validly measured. Perhaps expertise studies have not been extended to forecasting because it is a muddy, indeterminate – and relatively small domain.

The domain of forecasting may be small, but it has significant impacts on lives and livelihoods. When forecasts are poor, decisions made by individuals, governments, and corporations are compromised. An exploration into how forecasting is learned has great potential impact: presumably if that learning is better understood, support for that learning can be created or improved. Potentially useful insights may come through consideration of several emerging constructs in the science of human learning and professional performance. Learning to become a good forecaster may involve reflection-in/on-action and self-directed learning.

Although forecasting is a science-based profession, real-word practice problems are rarely a straight-forward application of theory and technique. In his seminal work on reflective practice, Schön (1983) asserted that applied science problems tend to be muddy and indeterminate, requiring the practitioner to frame a relevant, manageable context while also considering how the larger situation might impact the problem at hand. In other words, this nonlinear application of science is, itself, something that needs to be learned. A few professions like medicine and architecture teach the application of the science during residency or studio programs but this notion has not been applied in higher education programs in meteorology. Baum (1975) argued that because forecasting is a particular application of the science of meteorology, it falls outside the bounds of university preparation for the more general meteorologist. An investigation into the course offerings of the approximately 90 undergraduate meteorology programs in existence today confirmed that few schools attempt to directly teach forecasting. This leaves the bulk of the task of learning to forecast on an individual's post-school time. If forecasting is an area of expertise, it may require the 10-year rule of preparation found across the cognitive domains thus far included in expertise studies (e.g. Ericsson, et al., 2006; Ericsson & Lehmann, 1996), though papers on forecast contests may have called this notion into question.

Those individuals entering the National Weather Service in intern positions will go through a forecaster development course on the job. The bulk of the course content, however, is on data interpretation, understanding numerical weather prediction model output, and basic rules for writing various forecast products (text formatting, etc.). The approach restricts learning in the forecaster development course to the knowledge underlying the forecast task and fails to spend much time on the forecast task itself. This leaves nearly all the task of learning to create a forecast as a self-directed learning endeavor after the course and on the job.

In order to take such a complex approach to forecasting, a forecaster must have excess cognition available while also choosing, displaying and understanding the gigabytes of weather information available. Anderson's theory on the Adaptive Character of Thought (2005) describes how learners move from simply knowing things and being able to follow steps through to the application of ideas and eventual automation of tasks that frees working memory for other tasks for higher-order thinking. In a learning setting, cognition is freed for deeper and more complex learning while in a professional setting cognition is freed for a focus on metacognitive strategies, including reflection. Professionals do not necessarily use excess cognition in this way, and are not necessarily encouraged to do so. But for learning in a complex domain, like meteorological forecasting, cognition once needed for thinking through how to display and understand data becomes freed for thinking through potential weather scenarios. Perhaps meteorology formal education – even that done during the early professional years – spends so much time on the underlying tasks that the last step of the formation of a forecast is neglected.

Perhaps the construct of self-directed learning will prove insightful in recognizing the lifelong learning efforts of forecasters. Characteristics of adult self-directed learners in general led to the development of a self-directed learning readiness scale that has been used to study professionals and non-professionals in several job sectors. While those studies may not provide a foundation for the fundamental questions involved in this study, the constructs may assist in recognizing self-directed learning strategies of meteorologists. Recent work in this area, however, has suggested that people who are incompetent also have poor metacognitive skills (Kruger & Dunning, 1999). Learning needs are not generally recognized, and when they are, poor metacognitive skills result in poor choices of learning strategies that hampers gaining more competence.

Meteorologists seem to agree that forecasting is not a prescriptive activity. Although they have attempted to outline an approach to creating a forecast (e.g. the forecast funnel by Snellman, 1982), an outright prescriptive approach to creating a forecast has not been identified. The act of forecasting is a high-level cognitive domain where specific steps in creating a forecast cannot be specified. A more generic approach is to look daily at the ingredients necessary for certain types of weather events and assess whether those ingredients are available in sufficient quantity or balance to cause those types of weather. This so-called ingredients-based approach has been shown to be useful in certain types of forecasting tasks like flash flooding (Doswell III, Brooks, & Maddox, 1996). In order to use an ingredients-based approach, a forecaster must know which ingredients are critical in each particular weather event and region because many necessary ingredients are present at any given time and the balance of those ingredients varies from event to event and region to region. The ingredients-based approach proposed and taught by Doswell III et al. underscores the idea that forecasting is an ill-defined problem and requires complex, rather than prescriptive thinking. Unfortunately, ingredients-based forecasting papers on subjects other than flash flooding have not yet been written.

It may also be the case that changes in how forecasters learn are affected by adult and professional development over the course of the forecaster's career. Studies in nursing (Ramming, 1992) and medicine (Fox, Mazmanian, & Putnam, 1989) have shown many non-cognitive impacts on how individuals in those professions learned and how that learning changed over the course of an individuals' career. Further, Houle (1980) wrote more generally on phases of learning over the lifespan of a professional, noting that most have considered learning to be a ladder of development when, in many cases, professionals show a more complex pattern of movement between job specialties and responsibility that impact learning. The educational and other constructs mentioned above neglect these non-cognitive impacts on learning, yet they may prove important to understanding how meteorologists learn to forecast.

Purpose

Due to the apparent absence of theory adequate to explain forecaster learning, this study is designed to propose the elements and relationships characteristic of a theory of how meteorologists learn to forecast. Accordingly, further exploration of educational constructs will be done during the analysis stage. Forecasting is likely an area of cognitive expertise, but it has not yet been studied under that framework and other studies of professionals go beyond how cognitive expertise has been studied to include how career stage and development drives professional learning. Forecasters probably learn by reflecting in and on experience, engaging in constructive, self-directed learning with and without the assistance of others, and, as their expertise increases, deepening their knowledge using formal resources.

While a good forecast is a necessary precursor to the myriad of decisions individuals, corporations, organizations, and governments make, forecasting is rarely explicitly taught and there is an absence of literature describing how one learns to forecast. This study will propose the elements and relationships characteristic of a theory of forecaster learning to inform the education and professional development of meteorologists. It will also guide the development of better explanations of how and why professionals learn in ways that affect their practice.

Research Questions

This study ultimately seeks to answer the fundamental question: how do meteorologists learn to forecast the weather? Meteorologists are not specifically taught this skill and there are few educational opportunities available that attempt even a portion of this task. This fundamental question is broken down into the following aspects of learning:

- What initiates efforts involved in learning to forecast?
- Why do forecasters make the efforts they do to learn to forecast?
- How do forecasters go about choosing resources and forming strategies to learn how to forecast?
- What is the role of social interaction in learning to forecast?
- What is the role of context in learning to forecast?

Significance

There are a myriad of decisions corporations, governments, and organizations might make to mitigate impacts from, and sometimes exploit the weather. The National Research Council report *Fair Weather* (2003) included a few impacts from improved weather forecasts.

- Increased accuracy and precision in hurricane watches and warnings have saved as much as $2.5 billion annually in damage costs.
- The improved forecasts have also allowed for more focused evacuation and other preparedness, resulting in an estimated $600,000 to $1 million savings per coastal mile omitted from hurricane warnings.
- El Niño forecasts have saved an estimated $265 to $300 million annually due to changes in agriculture practices.
- Other government-sponsored studies, such as the Intergovernmental Panel on Climate Change, are just now summarizing and publishing the potential impacts from global warming on the world's economies.

Returning focus to the US, corporations like Wal-Mart apparently save more than the cost of running an Emergency Operations Center in order to justify having one, but the monetary payoff from good forecasts to private corporations is unknown. Despite what is becoming an increasingly clear advantage of good forecasts, weather forecasting is rarely explicitly taught and there is little literature about the science of learning to forecast.

If how meteorologists learned to forecast were better understood, those efforts could be better supported and the metacognitive skills required to learn throughout the professional years could be taught and honed beginning during formal preparation for the career. Humans still have an important role in the forecast process, particularly when numerical weather prediction falls short. At such times, it is critical that a human is prepared and able to see the error in the model forecast and intervene in the process.

Forecasting is a muddy, indeterminate domain where expert performance is difficult to specify. Other professions are likely similar to forecasting in either major or minor ways. By taking a different approach to studying this particular type of professional learning and development, that of meteorologists learning to forecast the weather, new insights will result that can inform the study and practice of supporting learning in other professions.

Assumptions

A few assumptions are made in order to conduct this study. First, that a post-positivist perspective is appropriate to the study of how meteorologists learn to forecast. That is, forecaster learning is not so idiosyncratic as to preclude any consistency in patterns of learning, even if those patterns vary by forecast task, context, and over time as careers evolve and expertise develops. Second, that forecasters are sufficiently aware of how they learn that they will describe those efforts. Some learning efforts may be quite small and may be deemed insignificant to the forecaster, but will be important to the development of a theory of learning to forecast.

Summary

Weather and climate persistently affect individuals, corporations, and governments, sometimes in significant ways. When forecasts are poor, people are left unprepared to mitigate how weather affects their lives and livelihood. Governments run emergency operations centers specifically to prepare for, mitigate, and respond to all kinds of natural and human-made disasters. Some corporations not only work to mitigate weather impacts, but to exploit weather to increase profit. In one of the few areas quantified, improved El Niño and hurricane forecasts have saved billions of dollars in recent years. Yet despite both the intangible and tangible significance of good forecasts, weather forecasting is rarely explicitly taught.

Meteorologists have written little about how meteorologists learn to forecast and rarely attempt to explicitly teach it. Only 150 years ago, British scientists disdained forecasting as much as astrology. In more recent writing about forecasting, meteorologists have stated that it falls outside the purview of the university: forecasting is an application of the science, and thus is best left to the employer. Although universities encourage students to enter forecasting contests, and participation has impacted student learning, writings also state that most forecasting skill is gained quickly and that students can easily out-forecast their professors, despite knowing far less about the science. These and additional writings will be considered further in Chapter 2, along with how employers of forecasters apparently regard their role in explicitly teaching forecasting.

Educational and other literature may prove to contribute important, relevant frameworks, but none of the existing constructs appear adequate to explain forecaster learning. It may be that forecasting can be understood as an area of cognitive expertise. If so, it may take 10 years to gain expert status, leaving much of the learning to occur on the job. As such, forecasters are apparently self-directing much of their learning, and may particularly find reflection-in/on-action and coaching as key mechanisms for growing their expertise over time. Education for professional meteorologists appears to mainly take the approach of teaching the prerequisite skills necessary to ease cognitive load during the forecasting task. That is, professional education tends to teach the building blocks necessary for future integration of complex topics in the forecasting task but fails to spend much time on the actual nonlinear integration of all those pieces to real world practice problems. The task of learning to forecast simply is not taught and has not been studied in a systematic way.

Chapter Two

Introduction to the Literature

This chapter identifies and explores the landscape of existing literature and how it may or may not inform this study. Unfortunately, how meteorologists learn to forecast has not been established. Educational and other literature have explored learning in many cognitive domains, some of which are similar to forecasting, yet have fallen short of establishing a comprehensive theory for any of those domains. As such, the educational and related literature cannot provide a single theory of learning that might be applied and tested with how meteorologists learn to forecast.

Modern meteorology is considered to have begun approximately 150 years ago. In the early days of the science, forecasting was likened to the activity of astrologers and charlatans, and was thus disdained and discouraged by many meteorologists. Meteorology is now a formal discipline, with many applications. Forecasting is just one such application, although an important one with frequent major and minor impacts on lives and livelihoods. Meteorologists have neglected, however, to explicitly teach forecasting itself. As an application of the science, forecasting falls outside the domain of formal education. Employers whose training efforts are known also fail to explicitly teach forecasting, focusing instead on the substantial and evolving body of knowledge, skills, and attitudes that underlie the forecasting task. Although literature in the field of meteorology does not establish how forecasting is learned, it reveals some attitudes and thoughts about forecasting which suggest some potential linkages to other literature and considerations for the design of this study.

Literature outside meteorology provides a variety of conceptual lenses regarding the nature of forecasting, how it may be learned, factors that may affect learning to forecast, and instructional techniques that may be helpful for this learning. These lenses at times intertwine, yet at other times fail to intersect – even when multiple lenses appear relevant. Forecasting may be a realm of cognitive expertise, though it has not been formally established as such. Writings on how expertise is learned provides a partial, tentative framework for this study. That framework appears incomplete, however. Forecasting may be learned through reflection, particularly as conceived by Schön, when practitioners conduct the nonlinear application of a science to real-world problems of practice. Forecasters appear to coach each other through both formal and informal means. But the near absence of formal education on the forecasting task leaves professionals to self-direct the majority of their learning and to learn by doing their jobs. Learning to forecast may be affected by how well meteorologists can regulate their learning, by their career stage, the necessity to automate many underlying skills, and contextual, socio-cultural factors.

Forecasting is a complex, non-linear application of the science of meteorology to the poorly-measured, poorly-understood atmosphere of the earth. Information upon which to base a forecast is rarely sufficient, leaving the forecaster to infer processes not explicitly seen in atmospheric data. No comprehensive theory that might encompass forecaster learning exists in the literature today.

Forecaster Learning

Even while initially being disdained by scientists in the mid-1850s, forecasting was already becoming an important application of meteorology. In the early days of modern meteorology, forecasting took a prominent role in maritime activities where people were particularly vulnerable to the vagaries of weather (Hontarrede, 1998). Forecasting became more sophisticated after development of the telegraph and other long-distance means of real-time communication meant that weather maps could be constructed. World wars benefited from training and utilization of forecasting skills, after which military forecasters sought civilian applications for their skills (Spiegler, 1996). Over this period of approximately 100 years, forecasting became an increasingly legitimate activity and useful for a variety of purposes.

Formal Preparation. At the same time, meteorology as a discipline was taking shape. In the early days, meteorology departments were sometimes an outgrowth of natural history but at other schools meteorology was seen as a physical science that sought to identify general laws (Koelsch, 1996). Meteorology is considered to have emerged as discipline in the 1940s, when approximately five graduate programs existed (Allen, 2001). Those departments were asked to shift focus during World War II to train forecasters for military service. Allen failed to describe what changes were made. In the years afterward, many more departments were formed, but even today, meteorology programs are often found in a variety of departments ranging from geography to math, physics, and even engineering, rather than as an independent department. It remains a relatively small discipline, with less than 68 doctorate, 88 masters and 89 undergraduate atmospheric science programs in North American colleges and universities (American Meteorological Society, 2003).

Despite growth in forecasting as a specific application of meteorology, most universities have continued to neglect teaching the nonlinear application of meteorology to forecasting. In an address to the World Meteorological Organization, Baum (1975) asserted that forecasting was an application of the science, and therefore outside the purview of the university. Although they were not directly teaching forecasting, several meteorology departments formed forecasting contests and encouraged students to participate. An intercollegiate forecasting contest was started by the mid 1970s (Meyer, 1986).

Several papers have documented experience with or observations of these forecasting contests. One paper described forecasting merely as a way to assess student learning (Harrington, et al., 1991). Other papers essentially suggested that forecasting contest performance was unscientific: more of an art than a science. For example, Gedzelman (1978) found that students gained most of their skill by the 30^{th} forecast, and Roebber and Bosart (1996) showed no significant difference between faculty and their students, despite faculty having a much deeper knowledge of the science. An empirical paper on forecasting contests showed a significant rise in skill for precipitation forecasting on days when students wrote a forecast discussion (Market, 2006). Other authors have shown that students regularly outperformed faculty in weather forecasting contests (Gedzelman, 1978) and appeared to learn a surprising level of skill more rapidly than faculty expected them to (Sanders, 1973). Empirical papers rarely directly address how and whether learning impacts performance.

Some of the few undergraduate institutions that have courses on forecasting have taught them before much of the science of meteorology has been learned. For example, St. Cloud State requires only an introductory meteorology course as prerequisite to their forecasting course. Iowa State University incorporated a forecasting activity into an introductory meteorology course taken by non-majors (Yarger, Gallus Jr., Taber, Boysen, & Castleberry, 2000). The University of Oklahoma encourages meteorology students to start forecasting as freshmen through the student-run Oklahoma Weather Lab (http://weather.ou.edu/owl/info/). While the latter example uses forecasting as a way to maintain students' interest in meteorology during the time students must take several necessary prerequisite mathematics and physics courses, Yarger and his colleagues used forecasting in a different way: to encourage problem-solving, collaboration, and communication between students in the course. All these examples suggest that an ability to anticipate weather changes apparently does not require much background in the science of meteorology. Yet forecasting is an application of the science – one of many ways someone might practice meteorology after formal schooling is complete.

Role and Nature of Forecasting. A few papers and reports go beyond the limited scope of the university to address professional aspects of forecasting. Although there is some question about the future role of humans in the forecast process it seems clear that humans will remain necessary, particularly for unusual or extreme events. Several works are conceptual, at least in how they discuss the nature of forecasting. These works remain unchallenged in the literature, so are included as important to understanding how meteorologists are conceptualizing forecasting. Only a few empirical studies have been done; they addressed the nature of the warning task, forecaster decision making, and forecaster performance. The studies presumed that forecasting was an area of cognitive expertise, but their results did not clearly parallel other work on expertise from other cognitive domains. How these papers inform this study is addressed now.

The first major strand in the literature is the tension between humans and numerical weather prediction, or computer models. Advances in computing, numerical techniques, and the science of meteorology have greatly increased the skill of numerical weather prediction models. At times these models outperform humans and call into question the future role of humans in the forecast process. But humans retain an important role in the forecasting process (e.g. Bosart, 2003; Targett, 1994), particularly for high-end, significant events like the 24 January 2000 east coast snowstorm described in the introduction to this work. Even for ordinary weather events, humans have an ability to infer – something a computer simply cannot do. Although forecasters performed poorly during that east coast snowstorm, Bosart is one of many who have argued that teaching and honing meteorologists' forecasting skills remains important and that such behavior would have prevented the forecast debacle described at the outset of this study.

Bosart (2003) suggested that one way to characterize the weather analysis and forecasting task was through the following six elements: 1) what happened, 2) why it happened, 3) what is happening, 4) why it is happening, 5) what will happen, and 6) why it will happen. The availability of numerical weather prediction allows and perhaps even encourages forecasters to focus solely on item 5: what will happen? Numerical weather prediction increasingly offers a good answer to that question. Further, when model output is consistent from one run to the next, forecasters failing to consider the other five elements may develop confidence in a bad forecast, as they did in the hours leading up to the 24 January 2000 snowstorm.

Other meteorologists had long ago noted an interesting aspect of the nature of forecasting. Doswell, Lemon and Maddox (1981) pointed out that weather forecasting is apparently both science and art. Forecasting is an application of the science of meteorology, yet meteorological training is unnecessary for acquiring short-range forecasting skill. It is common for farmers, pilots, fishermen, mountain climbers, and others to develop such skill, perhaps by virtue of long periods of exposure to the elements while working or pursuing their hobbies. An observant person might notice, for example, increasing numbers of low-level cumulus clouds that begin to extend taller than they are wide – a good signal that the atmosphere is becoming conducive to thunderstorm development. The air might become still as the cloud base above becomes dark – a good sign you are under an updraft to a storm and rain or lightning might be imminent. This art may be developed through perceptive observation, correlating events together in time and remembering previous evolutions or outcomes of observations. The atmosphere reveals many clues that allow mainly short-term forecasting to be something of an art. Perhaps studies of forecasting contests that showed students gaining surprising levels of skills quickly and being able to outperform faculty were capturing these two aspects of the nature of forecasting: students who do well may be simply learning an art to tweaking model forecasts.

Despite all this, many forecasting contests were created specifically to provide students an opportunity to test their knowledge through application of the science (e.g., Harrington, et al., 1991). Forecasting is seen as an application of the science of meteorology and for some forecasting problems, such as general day-to-day forecasting driven by large scale dynamics, this science can be captured adequately in numerical weather prediction models. These models can—and often do —outperform humans, leading some to call into question the future of humans in the forecast process.

One outcome of the growing tension in the debate about the future role of humans in an increasingly automated forecast process was a forum held at the 2004 Annual Meeting of the American Meteorological Society (Stuart et al., 2006). Approximately 200 members widely representing the international meteorological community attended. Most relevant here, there was "remarkable consensus" on nearly 20 characteristics of a good forecaster (p. 1498). These characteristics appear to fall into two broad categories, meteorological/technical skills and personality, and are summarized in Table 1.

Forum participants recognized that operational tools have thus far failed to adequately present inherently three-dimensional atmospheric data in three dimensions, severely limiting a forecaster's ability to recognize and apply conceptual models of weather processes while engaged in the forecast task. At the same time, technological advances such as artificial intelligence, fuzzy logic, and

Table 1: ***Proposed Characteristics of a Good Forecaster***

Meteorological / Technical Skills	Personality Components
• technologically proficient • technologically adaptable • synthesize knowledge to useable information • learn from past events • good diagnosis and prognosis skills • assimilate and integrate wide variety of data/information • retain objectivity about forecast	• aware of user needs, knowledge, expectations • learn from peers • strong interest and passion for meteorology • good management and people skills • acknowledge others' perspectives • honest in communication with other forecasters • withstand criticism • accept accountability for mistakes • stamina for shift work and long hours • dedicated to the profession • provide feedback to developers/researchers

neural networks depart from direct application of scientific principles and prevent forecasters from understanding what may have affected the output of anything using these techniques. In both cases, forecasters are discouraged from applying meteorological knowledge and encouraged to focus instead on pattern recognition and non-analytical decision-making.

Finally, forum participants concluded that the changing role of humans in the forecast process made ongoing education imperative. Entry-level forecasters should have some familiarity with the forecast process and mechanics of producing forecasts for various sectors of the field. Career-long education should include two elements: the science – including diagnosis and prognosis – and operations, or mechanical production of forecasts elements of the job. As duties shift, forecasters may also need good communication skills as they become key in the dissemination of forecasts to anyone who might benefit from forecast information.

The Stuart et al. report, from a consensus-building process at a workshop, along with the other conceptual work reported above builds an understanding of how meteorologists view the role and nature of forecasting. These works suggest forecasting to be both an art and a science, an application of meteorology, yet also an indeterminate domain where intuition and experience may play key roles. Forecasting was one of the earliest applications of meteorology, but as an application, falls outside the purview of the university. Next, the few empirical studies of forecasters are reviewed, followed by a brief description of some current formal professional training opportunities.

In one of only three empirical studies found before the outset of this study, Pliske, Klinger, Hutton, Crandall, Knight, and Klein (1997) of Klein Associates were contracted by the U.S. Air Force to identify the knowledge and skills of expert weather forecasters and recommend changes that would improve the performance of Air Force Weather. The researchers eventually met with over 42 forecasters, 29 of whom were affiliated with Air Force Weather (AFW); all but one of the remaining participants were experienced National Weather Service forecasters serving at the Olympic Weather Support Office for the 1996 Olympic Games in Atlanta. The AFW forecasters mainly worked in base weather offices; seven had combat forecast experience A few were base weather chiefs. Their experience ranged from four months to 21 years, with an average of 10. One forecaster was female; the remaining 28 were male.

The Klein Associates research team used focused the Critical Decision Method (CDM) around situations where, at the time the forecast was made, the forecaster was correct but others believed they would be wrong. Each such event was reviewed during the interview to solicit information on important cues, the forecaster's assessment of the situation and basis for that assessment, their expectations for how the event would evolve, and what options they had evaluated and chosen. A knowledge audit was also used to glean information in following areas: diagnosis and prediction, situational awareness, perceptual skills, how they developed and decided to use various "tricks of the trade," improvisation, metacognitive skills, recognition of anomalies, and compensation tactics for equipment limitations.

After analyzing all information from the NWS and AFW phases of their study, Pliske et al. (1997) concluded the following items helped distinguish between expert and non-expert forecasters. Expert forecasters identified the main challenge for the day, looked at the weather from a larger-scale perspective, used their own senses as well as weather data, made flexible use of tools and procedures, formed a mental representation of current weather, and easily applied that model to whatever form a forecast or request for information required. In contrast, non-experts relied on computer models, used a fixed set of procedures, had a narrow focus, failed to consider larger scale weather features, and ended up being reactive to subsequent evolution of weather during the period they were forecasting for. The authors stated that Klein Associates had never studied such a "widely divergent" group of people with "enormous variability" in how they described their forecast process. Also among the findings: skill levels varied extensively, current training was inadequate preparation for the job, and there was a mismatch between the technology available and the forecasting task. The Klein Associates team recommended many changes to how training was approached and conducted with Air Force Weather forecasters.

Meteorologists involved in training National Weather Service personnel contracted a cognitive task analysis of the warning forecaster task after reading the Klein Associates' Air Force Weather study. In what Hahn, Rall, and Klinger (2003) called a preliminary study, seven forecasters from Alabama, Oklahoma, Texas, and Missouri participated in 1.5–2 hour interviews. Six of these forecasters had extensive experience (12 to 20 years), four were currently in Science and Operations Officer positions, and two were Meteorologists in Charge of their office. The seventh forecaster was a journeywoman with three months experience including two severe weather warning events. In each interview, Critical Decision Methodology focused around a specific case that was first described beginning to end. After this initial recounting of the event, the interviewer led the forecaster back over the event once in order to verify the timeline and identify decision points and a second time to seek additional detail about the cues, expectations for the event, options evaluated, and options chosen. A third review of the event was done with a few of the participants in order to explore vulnerable points in the decision making process.

Hahn et al. (2003) grouped their findings into seven categories. First, forecasters are very aware of the public impact of weather and work hard to communicate threats within the forecast products they issue. Second, forecasters talked about a strong social component to their work. They took opportunity to train others in their office, get feedback on their conceptual models or ideas of how weather would evolve, and to gain confidence in their decisions. Third, forecasters saw technology as a tool with strengths and limitations. The forecasters interviewed for this study did not rely on technology and wanted to know how various algorithms and automated techniques worked so they would be better able to interpret the information coming from them. Fourth, individual weather events, particularly unusual ones, were used to build their experience bases. The forecasters said it was important to gain direct feedback on how the weather impacted people so they could relate those effects to the data they had had to work with as the event unfolded. They would later analyze an event in detail, particularly after failing to issue a warning prior to an event.

The fifth category was simply a description of the general approach forecasters took to their job. They described an engagement with weather that started before they arrived in the office and continued through an event. They would take a dynamic approach, constantly looking for signals of an unusual event unfolding. All but one forecaster who participated in this study was in a management position and would make staffing decisions for an event. This may account for why staying ahead of the weather was such a notable characteristic for this group. Likewise, the sixth category of mental models also included an aspect of anticipating changes. These forecasters formed their initial mental models for an event before arriving at work and would proactively investigate possible outcomes. They would project their model in time and watch for signals indicating an event was becoming unusual. Receiving reports of weather impacts in real or near-real time was critical to confirm these models. Last, the forecasters talked about several types of decisions where their expertise had significant impact on the performance of the NWS during an event. The Klein Associates researchers highlighted three of these decisions because they appeared to have the largest impact in the domain of meteorology: identifying significant, high-end events; predicting which part of a line of storms would become significant; and recognizing the severity of a storm.

No other literature studying forecasters has been identified, though a 2006 report by Hoffman, Coffey, Ford and Novak (2006) described a knowledge elicitation exercise to create concept maps for training. This work was also contract work for the U.S. Air Force. The problem motivating the work was similar to the first Klein Associates study: the Air Force was concerned with the loss of knowledge of expert forecasters. They were also wanting to capture geographic-specific, or local effects on weather, to assist new forecasters that transferred to a particular, Gulf-coast location. Hoffman et al. (2006) tallied time-in-service as one measure of expertise, but also looked at forecaster performance and reasoning styles. In light of Pliske et al. (1997) and student versus faculty performance in forecasting contests (e.g. Gedzelman, 1978; Roebber & Bosart, 1996), Hoffman et al. was likely wise not to rely on time-in-service, an often-used measure to assume achievement of expertise. The researchers eventually studied eight forecasters, four of whom had been designated as experts by the researchers. During each approximately 1.75 hour concept map session, one researcher played a role of facilitator while another created a concept map that was projected onto a screen. The facilitator coached the participant through the map as it developed, frequently proposing alternate phrases for concepts and propositions. This procedure produced 24 concept maps that then formed the core of what the researchers referred to as their knowledge model. Each map had an average of 46 propositions. At this point, the researchers used one retired U.S. Navy chief petty officer to validate the model. About 10% of the propositions were modified by this single individual. At this point, the study was considered complete and the model became a training tool. There was no test of reliability or robust test of validity, only comment on the "efficiency" of the technique in creating the knowledge model and on the reactions of forecasters that used the tool to learn. Not surprisingly, younger forecasters liked the computer-based, interactive tool and older forecasters did not, preferring instead to have a book with a table of contents and an ability to print out or otherwise extract portions of the information. An actual comparison of the efficacy of the researcher's new learning tool with previous forecaster education was not conducted.

The above studies are certainly interesting, but reveal the complexity of this domain rather than contribute solid work upon which to base this study. First, these studies provide some information on forecaster behavior and learning, despite that not being a direct goal of their work. Pliske et al. (1997) found that expert forecasters began by identifying the forecast challenge for the day, modified tools and procedures to suit the particular forecast, formed a mental model of how they thought the weather would evolve, and adapted that model to whatever type of information a customer needed. Hahn et al. (2003) identified several items related to learning in their cognitive task analysis of warning forecaster behavior. Warning forecasters interacted with others to train them and got feedback on ideas about how the weather would evolve, and to gain confidence in their decisions. Warning forecasters wanted to learn how tools worked so they could properly weigh the information coming from those tools. They strongly desired immediate feedback, or ground truth, about the impacts of the weather as it evolved. And warning forecasters often conducted post-event analyses of weather events to relate the information they had with post-event damage and other reports, especially if they had failed to issue a warning in advance of a severe weather event.

Although the above findings identify some potentially useful characteristics of forecasting and forecaster learning, they also revealed some complexity for this domain that may not be present in other domains studied under the construct of expertise. Two of the research teams commented on this complexity, while the third appeared oblivious to how that complexity could compromise their work. Both of the Klein Associates' studies found that forecaster reasoning was highly varied, yet the Hoffman et al. study assumed that studying a small sample of participants could result in a single, useful knowledge model. Because Hoffman et al. never verified that resulting knowledge model, they have not established that it widely applies to what might be a diverse group of professionals. It may be that these studies were at least partially challenged by what another researcher has established: that many thoughts and procedures bypass working memory, having become automated (Anderson, 1996). Eliciting such thoughts from an expert is difficult because they are no longer conscious thoughts. A think-aloud procedure is likely to fail to reveal them (Lajoie, 2003). The Klein Associates' studies, on the other hand, used in-depth interviews about particular weather events and cognitive task analysis. Both procedures have a better chance at allowing unconscious thoughts and procedures to be revealed, but only to the extent the skill and insight of the research team can recognize key points the interviewee is neglecting to verbalize. These studies may also be challenged by having presumed forecasting was an area of cognitive expertise similar to other, studied domains without first establishing it as such.

Professional Preparation. So although there are several decades of writings and a few studies that touch into weather forecasting, little progress has been made in precisely articulating the characteristics of forecasting or how it is learned. Perhaps it is no surprise, then, that forecasting is not explicitly taught. Thompson (1987) pointed out in an address to the 67th Annual Meeting of the American Meteorological Society that much of what is taught in university courses comes from research, particularly that of the professors. Particularly on the graduate level, Thompson said, today's students become the tomorrow's researchers. Many of those researchers go on to work in universities and the result is a continued focus in university courses on the latest scientific endeavors. Meteorology programs are not placing much emphasis on forecasting – that is, when universities attempt to teach it at all. And learning to forecast has yet to gain sufficient attention as a research area to document how meteorologists learn to forecast.

Where most of that application is learned is apparently on the job. Few schools explicitly attempt to teach forecasting and most do not see the specific application of meteorology to forecasting as within their mission. There are many applications of meteorology and forecasting is just one of them. The role of the university is to educate meteorologists generally, not weather forecasters specifically (Baum, 1975). Further, employers do not expect their graduates to be prepared for a specific job, Baum asserted. This is still largely true today, though several undergraduate-only meteorology programs in the U.S. are geared toward students seeking to become employed after they complete their undergraduate degrees. Most jobs available to meteorologists at the bachelor's degree level are in forecasting or broadcasting.

Turning to documentation of profession-level training, the National Weather Service Instruction 20–103 (National Weather Service, 2002) requires new meteorologist interns to complete a Forecaster Development Course (Table 2). Little of the course content directly addresses the act of forecasting, however (National Weather Service Training Center, 2006). An examination of units 3 and 4 (see http://www.nwstc.noaa.gov/nwstrn/d.ntp/fdp/fdp.htm#pcu3), which both purport to cover forecasting, reveal instead a focus on atmospheric dynamics, specific types of data and instrumentation, analysis, numerical weather prediction models, and rules for issuing forecast products. There is a significant body of knowledge, skills, and attitudes that underlie forecasting. The units appear to neglect how to apply this important knowledge to the creation of a forecast.

The Bureau of Meteorology in Australia accepts applicants with any science degree and has them go through a 9-month training program before beginning to work in daily operations (H. Richter, personal communication, 2006). The course is essentially an accelerated bachelor's degree program, covering conceptual topics in

Table 2: ***Overview of the NWS Forecaster Development Program***

National Weather Service Forecaster Development Program
Revised February 2007
Comments appear in italics following the module titles.

I. Organizational Structure and Administration
   Essentially an employee orientation covering the organization; its structure, personnel and administration policies; and various electronic communication tools.

II. Operational Instrumentation, Remote Sensing, Interpretation and Data Management
   Basics of observational data: how it is collected, how to interpret it.

III. Forecast Process
   Only one section on the forecast process; the remainder covers atmospheric dynamics, a heavy emphasis on numerical weather prediction, rules and basics of national guidance to incorporate into a forecast, and how to use the software tool that defaults to the model forecast.

IV. Forecast Science and Operational Programs
   Similar to above, but the focus turns to the types of weather that are the focus of NWS products. Some sections address the science underlying the forecast, with only two – the production of warnings for severe and winter weather – having much depth in coverage.

V. Operational Applications, Troubleshooting, and Dissemination
   Use of software/technology to do the job.

VI. Customer Service and Outreach
   Communication skills for both internal and external customers.

VII. Professional Development
   Overview of non-meteorological training such as computer security, proper use of email, etc.; encouragement to talk with local office management to determine the individual's focal point duties; participate in outreach to the public; etc.

meteorology, plus how to use operational software and details about the products that forecasters will be responsible for issuing.

These two professional programs have in common an emphasis on the elements required for the task of forecasting rather than the actual forecasting task. Perhaps such emphasis in early-career training is necessary. Mr. Richter intuitively recognized that learning underlying knowledge, skills, and attitudes was necessary before a forecast could be attempted. He said he must first train on how to use the software required for the job. Such skills are relatively simple, something his eight-year-old could almost accomplish. Mr. Richter then teaches meteorological concepts before finishing with simulations that integrate everything in context. When asked how he decided to do things that way he paused a minute and responded, "I don't know. I think I just figured out what works."

Mr. Richter's observations make sense in light of Anderson's (1996) theory of the Adaptive Character of Thought, or ACT: that a beginning forecaster would feel overwhelmed working through steps to display and interrogate meteorological data before trying to understand that data in order to make a forecast. The resulting tax on working memory may overwhelm the forecast task early on, limiting capacity for reflecting on what they are seeing. Recent work on scaffolding, which will be considered later, argued based on other studies that a whole-task approach is more effective than a part-task approach. In any case, it is important that forecasters learn good skills for lifelong learning, if not have direct opportunities for continuing learning through their careers.

Summary of Literature on Forecaster Learning. In summary, meteorologists and others studying them have written a little on forecaster learning or the nature of forecasting. Meteorologists have commented on how forecasting appears to somehow be both a science and an art. Humans bring insight to forecasting that remains important, particularly during high-impact events, but also for certain forecasting tasks where numerical models have not yet outperformed humans on a day-to-day basis. But at the same time, the profession of meteorology clearly regards forecasting as an application of the science. Unfortunately, this means that forecasting falls outside the purview of the university and is left to employers.

Very little is documented on learning to forecast during formal schooling or professional years. Few universities attempt to explicitly teach it and those who do sometimes encourage students to forecast before learning the underlying science. Most, if not all learning to forecast is left to one's professional years. Some employers of forecasters have training programs—some do not. Of those programs that are known, there is an emphasis on the underlying knowledge, skills, and attitudes, and little on how to then incorporate those skills into the creation of a forecast. There are a handful of empirical studies of forecasters, but what literature there is raises a number of questions. Is forecasting an area of cognitive expertise? Researchers like Pliske et al. (1997) found that forecasting followed many of the characteristics identified by Glaser and Chi (1988), but they also found, as did Hoffman et al. (2006), that normal rules regarding the time needed to develop expertise found consistently in other cognitive domains did not apply to this particular domain. Hahn et al. (2003) found that some forecasters had learned to proactively anticipate weather, but their participants were nearly all managers, for whom such an approach may have been an obvious self-learning need given the responsibility inherent in their position. The three empirical studies discussed above all presumed forecasting to be an area of cognitive expertise without first establishing it as such. They each found some aspect of their results to be in conflict with characteristics of expertise found in other domains.

None of the studies appear to have directly addressed how learning is taking place and whether those strategies change over time as expertise develops. Perhaps the literature outside of meteorology can provide some insight into how forecasting may be learned and factors that might affect learning to forecast.

Explanations of Learning in Other Professions

Although there are several existing constructs that may apply, there is no overarching theory that encompasses all aspects of those constructs that are likely relevant to forecasting. Forecasting appears to be an area that would fall in the cognitive realms of expertise studies. Few such areas have been researched because expert performance is difficult to specify, isolate, and study. If forecasting is such an area, studies in other domains suggest it may require 10 years before expert status can be reached. This has already been called into question by the minimal research on forecaster performance. Still, the bulk of learning to forecast must be in-context and situated on the job due to the enormous amount of requisite knowledge and skills required to do more than simply rely upon models to determine what will happen. Forecasters are likely learning through reflection-in/on-action and coaching. Although professional development opportunities exist, those tend to focus on keeping up with advances in the state of the science, new technology or procedures, or directly address high-profile poor performance. In the absence of such training, forecasters are left to self-direct their learning, situated in the context of their particular geographic region and forecast task(s). If forecasting were taught, scaffolding and coaching are likely to be useful instructional strategies. They are already used to some extent. Finally, learning efforts are likely to vary over time as a result not only of development of expertise, but also by career stage and developmental forces. How these constructs may be realized within meteorology may be affected by social and cultural forces found both within the workplace and the profession as a whole.

Expertise. Glaser and Chi (1988) note that although the seeds of expertise studies were introduced in 1972, it wasn't until Anderson's second edition of *Cognitive Psychology and Its Implications* published in 1985 that the term was used in a major textbook. Expertise studies have advanced quickly, resulting in the 2006 publication of *The Cambridge Handbook on Expertise and Expert Performance.* Still, there is much to be learned and not all cognitive domains have been studied. Ericsson & Lehmann (1996) pointed out that to study the characteristics of superior performance, characteristics of expert performance must be determined and then isolated sufficiently with standardized conditions in order to study expertise in any particular area. Although educators of professional forecasters favor past weather cases where they believe they can adequately identify key steps necessary to making a good forecast, there is no documentation supporting the notion of a single, or correct way to create a forecast and Pliske et al. (1997) found "enormous variability" in how forecasters described the forecast process.

In their overview chapter to *The Nature of Expertise*, Glaser and Chi (1988) summarized seven points regarding characteristics of how experts organize knowledge. The first is that experts excel mainly in their own domain. Expertise in one area does not imply superior performance in any other domain. Second, experts are able to recognize large, complex patterns within their domains. The most famous of these studies shows that expert chess players are able to recognize and duplicate sensible chess board layouts but not non-sensical ones (Anderson, 2005). Third, experts are very quick performers and can solve problems in their domain much faster than novices. Fourth, experts perform beyond the capability of working memory because they have automated portions of thinking needed for tasks. Some aspects of cognition bypass working memory, freeing working memory for thinking a novice is unable to do. Fifth, experts see problems in more depth and complexity than novices. Sixth, experts spend more time understanding a problem before attempting to solve it. Glaser and Chi noted a study showing this is most pronounced for ill-defined problems. Finally, experts are more cognizant of making errors and are generally better able to monitor their performance.

Many of these points are likely critical to being a good forecaster. A weather map is a large, complex pattern of information with many potential implications regarding future weather. These complex patterns are likely what the empirical studies of forecasters found when forecasters described using conceptual models to help them sort through data and anticipate future weather (e.g. Hahn, et al., 2003; Pliske, et al., 1997). An ability to bypass working memory when seeing such patterns would free the forecaster's attention to think about how a particular weather event is similar and different from past events. Perhaps forecaster development training must spend much time on the underlying tasks to help forecasters automate procedures for displaying and understanding information available to them. Spending time thinking about the current weather before engaging in the forecast task might be a key element in avoiding problems like the "surprise" snowstorm described at the beginning of this work, as Bosart asserted (2003). The final point ties directly to one's ability to effectively self-direct learning.

Expertise studies have had a tendency to focus on determining what constitutes expertise and on exploring how experts perform differently than novices. Several cognitive domains have been studied to determine what constitutes expert performance, though not weather forecasting. In these other domains, differences have appeared in how experts organize knowledge and solve problems. In most domains, experts reason forward through a problem, using inferences to guide them, but in some domains like computer programming, experts reason backward and use a broad approach to solving the problem (Anderson, 2005). For example, by thinking ahead, an expert computer programmer is able to write a generic subroutine to calculate an average of values that can be used again for another part of the problem. When working forward, the novice programmer explicitly calculates one average, only to later realize that another average must be calculated. Similarly, in Smith's (1990) study which used both genetic counselors and university faculty as experts, genetic counselors and novices both used a means-end approach to solving problems. Such an approach had generally been taken as characteristic of a novice who has difficulty solving problems, but the genetic counselors in Smith's study outperformed both students and faculty experts. Smith suggested the genetic counselors may have done so well because they were able to ignore irrelevant information, had developed procedures to solve various types of problems, and were able to focus on the surface features of the problems in effective ways.

Smith's (1990) study contributed the key notion that there may be more than one kind of expertise for a discipline. Up to then, expertise studies compared novices and experts by comparing undergraduate student with faculty performance. By including a practitioner in the discipline, specifically, genetic counselors, Smith showed that practitioner experts not only organized knowledge differently than faculty experts, but solved problems differently and more effectively than faculty experts. Smith's approach to his seminal study on expertise in genetics is particularly relevant to the design of studies on expertise in weather forecasting. A clear implication from Smith's work is that a study of forecasters must use their lived, and especially post-school experiences with learning to forecast as the primary source of data.

A few cognitive psychologists involved in expertise studies have tangentially touched into weather forecasting (e.g. Hoffman, et al., 2006; Pliske, et al., 1997), but they have done so without actually establishing that forecasting is an area of cognitive expertise. The researchers of two of these studies reported they could not establish a clear definition of expertise and commented on how surprisingly varied forecaster behavior was (Hahn, et al., 2003; Pliske, et al., 1997). The Hoffman, et al. study presumed they could establish expert forecaster behavior and verified their resulting concept maps with a single expert. All but the Hoffman et al. report discussed the variation found, and although they proceeded to use the construct, they admitted they could not establish a clear definition of expertise from their interviewees. Therefore, this study will use expertise as a potentially important construct, but focus on how forecasting is learned without pre-supposing that forecasting is an area of expertise. Much of the literature on expertise focuses on differentiating experts from novices, but there is some literature on the development of expertise, or learning to become an expert in a cognitive domain, that may inform this study. That literature also remains incomplete.

Learning to Become an Expert. Less appears to have been written on how someone gains expertise than on what characterizes expertise. Of those domains that have been studied there is significant disagreement on what characteristics contribute to the development of expertise. Some authors are adamant that deliberate practice can account for the development expertise (e.g. Ericsson, Krampe, & Tesch-Römer, 1993) while other authors assert that suggesting deliberate practice alone can account for expertise is "absurd environmentalism" (Detterman, Gabriel, & Ruthsatz, 1998). Intellectual and other abilities are likely important, particularly in cognitive domains (e.g. Gagné, 2004). Genetic research, such as studies of twins raised in different environments, has established that some characteristics, like intelligence, are inherited. Failing to comprehensively cite the latter types of studies, Krampe and Charness (2006) say research has shown that innate ability and genetic factors account for more rapid gains in expertise only during early stages of learning. A recent commentary article in *Behavioral and Brain Sciences*, published along with 30 commentaries from peer experts, showed the vigor of disagreement and difficulty coming to definitive conclusion about the role of innate ability on the development of expertise (Howe, Davidson, & Sloboda, 1998). Several commentaries pointed out weaknesses in recent research and in the difficulty in defining clearly researchable questions on this topic.

Researchers have shown that surgical nurses and avionics experts did not have a single, definable, ideal solution path for solving ill-defined problems, nor do they have a single path to follow in learning to become an expert (Lajoie, 2003). In the avionics study, Lesgold, Lajoie, Logan and Eggan (1990) found that at most stages of a problem solving exercise experts' solution paths varied. Only at one stage did all experts take the same path. Novices, on the other hand, took less focused and disjointed paths through the problem space. The authors concluded that more than one path through the problem space was legitimate and that validating any particular solution path involved studying the pattern of relationships between performance and knowledge in light of the cognitive psychology of expertise.

The *Cambridge Handbook on Expertise and Expert Performance* includes a chapter on educators and expertise. In this seemingly promising chapter, Amirault and Branson (2006) spent much of the chapter winding their way through time, proposing and then rejecting various views and approaches to education aimed in two directions: to take a high number of learners to minimal competence and to take a small number to high levels. They then summarized current thinking, noting that constructivist learning environments appear to effectively promote lifelong learning skills in students and that an emphasis on real world complexity and ill-structured learning are particularly effective in promoting transfer of learning to performance. They also highlighted Ericsson's work showing that expert performance is often achieved through deliberate practice, rather than being explained by innate ability. Amirault and Branson concluded by saying that an empirically-verifiable model encompassing all variables involved in the phenomenon of learning expertise was a worthy goal; such a model did not yet exist.

Despite the lack of a single model to explain development of expertise, there are partial models in the literature that have thus far withstood some testing. In Alexander's (2003) summary of the Model of Domain Learning, she cited a decade of research in domains as varied as astrophysics, social studies, and physical education that supported the hypotheses of the model. In this model, knowledge, strategic processing, and interest all interplay throughout the development of expertise. In early stages, surface-level strategies help learners acquire knowledge in an initially overwhelming domain. Later, learners are able to use deep-processing to think in a more critical, analytic way. When learners possess a broad, general interest, they engage in multiple forms of situational learning triggered by events or surroundings that later focus into more strategic learning aimed at achieving professional goals. Alexander defines situational interest as being piqued by current events or the immediate environment. These three components then interplay in varying ways as individuals on their way to expertise advance through an acclimation stage to one of competence, and finally proficiency/expertise. During acclimation, for example, learners work to orient themselves as they gain fragments of domain knowledge. Situational interest plays a key role in motivation to persist through this difficult stage where learners have trouble discerning the quality of information in order to develop a comprehensive knowledge of the domain. Those who persist transform their knowledge into a more cohesive structure in the competence stage. Their interest becomes less dependent on particular situations or the environment. Achieving expertise requires further development of knowledge into a broad, deep base from which experts also push the boundaries of knowledge in their domain through what Alexander calls problem finding. Interest is now quite high and individuals in this stage stay engaged over time.

Alexander's model may prove useful for thinking about the development of expertise in meteorology. Many meteorologists attribute their interest in weather from a childhood event, such as a nearby tornado. The first stage of expertise development requires meteorologists learning to forecast to navigate through a muddy, unclear domain where the relevance of any particular type of weather data may be important today but not tomorrow. Interest likely broadens through time, as meteorologists become increasingly aware of different types of weather events and factors that influence how weather develops. Where Alexander's model may fail to intersect with other literature is learning during professional years. The studies Alexander cited all involved student learning, so it is unclear if the model has been tested for professional learning and the ongoing development of expertise that occurs after formal education is complete. Alexander's model also may not adequately address the supposed waning of situational interest as expertise is gained. It is likely that much of the important, complex learning of any professional is driven by particular situations that surprise or challenge the professional in some way. Further, Schön (1983) did not restrict such reflective learning and the importance of coaching to formal education, as Alexander's model might suggest.

A more recent work by Prins, Veenman, and Elshout (2006) tested three models with varying relationships between intellectual ability, metacognitive skills, and learning in order to explore which of those factors is most important at varying levels of challenge. Participants included 44 first year psychology students, 10 of whom were relatively low intellectual ability novices, 12 were high intellectual ability novices, 13 were relatively low intellectual ability advanced learners, and nine were high intellectual ability advanced learners in a previous study. Age and sex characteristics of the four groups did not differ and participants received study credits for their participation. Through a computer-simulated learning environment, participants conducted experiments in a 3-phase optics lab of differing complexity. Participants were asked to think aloud during the easy, intermediate, and complex phases where they were to determine rules of optics, and during pre- and post-tests. Novice learners were able to learn through every phase, with metacognitive skills being most important during the easy phase. Metacognitive skills and intellectual ability had only limited impact in the intermediate and complex phases. All stages may have been beyond the boundaries of novice learners' prior knowledge. For advanced learners, metacognitive skills were most important in the intermediate phase, where these learners reached the boundaries of their prior knowledge. In the complex phase, a marginal significant correlation was found between intellectual ability and learning outcomes. This finding was similar to an earlier study by the authors that showed that intelligence may be a key determinant of performance on very difficult problems where conceptual abilities may be key.

These works, when considered together, suggest that deliberate practice alone cannot account for the development expertise and that intellectual and other abilities may also be important in cognitive domains. Again there is a body of literature that is, as yet, incomplete in how it might inform this study. Expertise may be a useful concept, but expert performance is difficult to determine, as it often is in complex, cognitive domains. Some existing models may explain portions of expertise development, but these do not yet appear to be comprehensive. As will be addressed next, these models do not incorporate notions of how reflective practice or adult development impact and also explain professional learning. So while expertise studies are useful and can inform the design of this study, they do not provide an answer to the research question.

Other authors have suggested links between expertise literature and other educational constructs like scaffolding. Anderson's (1996) theory on the Adaptive Character of Thought (ACT) helps explain the necessity of scaffolding learning. ACT implies that acquisition of knowledge must include both learning the declarative knowledge – chunks of information – and the procedures for effectively dealing with those bits of knowledge. Effective forecast task performance requires activation of the relevant knowledge and procedures when they are needed. Anderson cautioned that the human brain is highly tuned to context and notes this provides a circular situation where learning basic chunks, yet learning in context, are both critical. The natural behaviors of meteorologists support Anderson's dual-condition for effective learning: meteorology students interested in forecasting are generally attempting to forecast long before they have the scientific basis of concepts to use in creating a forecast.

Studies in scaffolding instruction support Anderson's concern for authentic task learning. Various works have shown that situating learning within real-life contexts produces the most effective transfer of learning to practice (e.g. Brown, Collins, & Duguid, 1989; Choi & Hannafin, 1995; Rosenshine & Meister, 1992). van Merriënboer and colleagues (2003) agreed that scaffolding whole task practice was necessary, but pointed out that it could be done in two ways. The more successful approach was to first work through worked examples, then parts of complex tasks, and finally whole, authentic tasks. Forecasters in the National Weather Service and other workplaces may be led through just such a progression, as they gain additional forecaster duties while in the intern positions.

It would also be interesting to learn whether forecasters are routinely and increasingly reflecting on how to think through creating a forecast as they learn to forecast. Reflection in learning is a whole construct in itself, with a significant number of studies and writings on the subject. Scaffolding complex tasks will only be effective if the learner is able to gradually automate more and more of the underlying knowledge, skills, and attitudes necessary to successfully produce a forecast. The excess cognition freed through automation must become available so the forecaster can continue to progress toward the completion of the whole task – to be able to routinely produce forecasts in a reasonable amount of time so that those forecasts can be made available to the individuals, governments, and corporations that use them.

The Role of Reflection in Learning. Several writers have shown that reflection is a necessary aspect of becoming competent and maintaining that competence while practicing a profession. Reflection is considered directly as an activity one might do when given time or capacity to think about what is happening or what happened. It has also been conceptualized as an ongoing way of thoughtfully and productively conducting professional practice, referred to in this second case as reflective practice.

Reflective practice is addressed in many professions and is specifically identified as a desired competency in some (e.g. medicine: Academy of Medical Royal Colleges, 2005; and nursing: College of Nurses of Ontario, 2005). But while it appears several professions assert the importance of reflective practice, there appears to be a lack of consensus as to whether all adults reflectively practice (Ferry & Ross-Gordon, 1998) or if reflective practice is regarded positively by all adults (Orland-Barak, 2005; A. Smith & Jack, 2004). Further, while most studies on reflective practice focus on the individual, some studies suggest that reflective practice cannot be considered apart from an organizational perspective (Heath, 1998; Jones & Stubbe, 2004; Mantzoukas & Jasper, 2004).

Anderson (2005) provides a framework for understanding how thought adapts as we move toward expertise and shows evidence that once tasks have become automated the brain is less active. An expert may either exploit or squander the excess cognitive capacity saved through automating tasks. Excess mental capacity can be reinvested productively to create increasingly sophisticated problem solving models (Bereiter & Scardamalia, 1993; Sternberg & Horvath, 1995). But a person may also ignore important, minor surprises in the mundane because they have habituated routine tasks (Heath, 1998) and become subject to boredom and burnout (Schön, 1983). One study of forecasters found that many failed to reinvest any excess cognitive capacity they might have had into increasingly complex understanding and anticipation of weather (Pliske, et al., 1997), while another that studied mainly managers in the National Weather Service found they were vigilant in watching for surprise (Hahn, et al., 2003). Perhaps that was by virtue of being in positions of responsibility.

Despite these concerns about whether reflective learning is – and can be – routinely done by all professionals, reflection remains an important aspect of learning in complex domains. How the above literature may inform this study is considered more fully now.

Building Expertise and Enhancing Performance of Professionals. The notion of reflective practice is prominent in the literature and competencies for medicine, a strongly evidence-based field. A recent Delphi study reports on the consensus of medical educators as to core contents of a continuing medical educator's library (Olson, Tooman, & Leist, 2005). In the list of the ten most important books for a medical educator, reflective practice is prominent in two of the top three (Davis, Barnes, & Fox, 2003; Davis & Fox, 1994) and Schön's own works on reflective practice (1983, 1987) are listed 4th and 8th. Perhaps not surprisingly then, when the Academy of Medical Royal Colleges (2005) developed 10 principles for continuing professional development, they included reflective learning and reflective note taking in two of the principles. Further, when Kaufman (2003) derived seven principles to guide medical educators' teaching practice, his sixth principle was, "Learners should be given opportunities to reflect on their practice; this involves analysing and assessing their own performance and developing new perspectives and options" (p. 215).

Meteorologists generally see the discipline of meteorology as a science (Baum, 1975), even if they refer to it as a *derived* science (Thompson, 1987). The practioner-side of meteorology, however, has also been a source of theory that has contributed important advancements to the discipline. Perhaps studies from nursing, an experience-based field, will prove insightful. Reflective practice takes a prominent role in nursing as well, where it is posed as an important way in which nurses learn. For example, the College of Nurses of Ontario responded to the Canadian parliament's *Regulated Health Professions Act* with a Quality Assurance Program (College of Nurses of Ontario, 2005). Reflective Practice is the first component and assists in accomplishing the second component, Practice Review. The Quality Assurance program uses reflective practice as a means by which nurses develop individual learning plans and evaluate their learning and application of knowledge in their practice.

But despite the emphasis on reflective practice in medicine and nursing, both of which might inform meteorology, studies in those and other disciplines are still exploring how reflective practice works and whether all professionals use reflective practice as an important means for learning. The following studies from education and nursing illustrate aspects of this exploration in regard to an individual's willingness, ability, desire, and natural inclination to reflect.

Implementation of reflective practice was positive overall and valued by participants in Orland-Barak's (2005) study of teacher development in Israel. The author found that reflective language tended to remain technical, with few instances of dialogical, critical reflective language. Orland-Barak suggested that incorporating reflection into a highly-centralized system had a problematic aspect: individuals may feel a "contrived collegiality" and may not feel safe in expressing critical reflection. Despite these reservations, participants valued the reflective activity.

In contrast, participants in a nursing study did not uniformly value the reflective activity included in a continuing education course (A. Smith & Jack, 2004). Smith and Jack undertook their study on students' perspectives after recognizing that while some literature suggested reflection could be a negative experience, little was written on the subject. Although many students in their study used reflection to become more self-aware and confident, and to connect previous knowledge and skills to new learning, they did not uniformly find utility in reflection. It facilitated learning in those who engaged in the activity, but was difficult on uneventful days and some worried about the legal implications of documenting negative experiences.

Just as reflection may serve an important role for growing the knowledge base in nursing, Ferry and Ross-Gordon (1998) recognized that established knowledge is often inadequate for solving problems that arise in the practice of adult educators. In their study of female family living extension educators, Ferry and Ross-Gordon sought to determine the role of experience in the development of reflection-in-action. The authors noted that while Schön believed the competency for reflection was innate and was used to develop expertise, cognitive psychologists tended to view experience as the "master teacher" of skill needed to develop expertise. The authors found that some educators were reflective and some were not, regardless of years of experience. Those educators who were reflective used reflection as a means to solve problems and as an ongoing process through which to expand proficiency, contextualize problems, and reflect on abilities. The authors concluded that expertise seemed to rely on how experiences were used for learning. Experience alone was not sufficient to result in expertise.

The above studies on professional reflective learning appear to indicate that while reflective practice may be desirable for adults, it is not a characteristic consistently found in adults. Ferry and Ross-Gordon found that some of their experienced educators were not at all reflective. Similarly, Smith and Jack found that some nurses were reluctant to engage in reflective behavior and did not see themselves as being reflective learners. In their literature review, Smith and Jack mentioned that traditional nursing education did not encourage nurses to question knowledge and to expect external direction for their education. In other words, nurses were traditionally cultured in their profession to become dependent learners. If Schön is correct that reflection is an innate predisposition, however, perhaps it is worth nurturing reflective behaviors beginning in higher education as meteorology students are beginning to be cultured in the discipline. Several authors recognized this behavior as a result of student participation in forecasting contests (e.g. Harrington, et al., 1991) and one author specifically used a writing activity as a means to encourage reflection on the forecast process (Market, 2006). In summary, adult learning emphasizes reflection as an important informal, ongoing, experience-based means for building competence. Any effect early practice in reflective thinking might have on adult reflective learning, however, does not appear to be addressed in the literature.

Professional Reflection in Organizational Context. Up to this point, discussion of reflective practice has centered on individual reflection. Schön himself, however, began to conceptualizing reflective practice into organizational learning and dynamics before his death in the late 1990s (e.g., Argyris & Schön, 1995). Organizational learning necessarily involves taking a systems perspective in looking at both individual and group behaviors (e.g., Senge, Scharmer, Jaworski, & Flowers, 2004). To what extent are individuals able to act independently of the organization in which they belong? It would not be fair to work on improving individuals' ability to reflectively learn if they are unable to then change their practice based upon this reflection. At least one meteorologist who spent several years in a position where he was responsible for the training of his unit saw forecasting as a team endeavor (R. Johns, Personal Communication, 2006). Most forecasters work within an organization of some kind.

One of a growing number of studies situating reflective practice within an organizational context is a report of an interdisciplinary effort begun by Jones and Stubbe (2004) to link sociolinguistics (language in the workplace) and organizational communication. The authors developed a Communication Evaluation and Development Model (CED), which used sociolinguistics and organizational development to improve communication processes through action research, whereby researchers and practitioners collaborated within the practitioners' context. Practitioner knowledge became the basis for reflective practice, through which practitioners identified strengths and built on successes in what the authors referred to as appreciative inquiry. The authors suggested implementation of their model could take one of several forms, all involving action learning and analysis tools they developed, but do not describe.

In their paper, Jones and Stubbe (2004) reported on attempts to pilot the CED model with a particular work group within a government organization and with two individuals in a second organization. They encountered resistance to this participatory, action research approach from practitioners, who preferred receiving a prescriptive set of actions from the researchers rather than co-creating a process to improve communications. The authors identified a second form of resistance that went much deeper: the researchers found themselves engaging in organizational change, which extended beyond the bounds of the disciplines involved in their study.

Many professionals work within an organization rather than in a truly autonomous sense, so the challenge of individual change implying organization change that Jones and Stubbe encountered is likely true for many professionals. As mentioned earlier, nursing is one of many fields incorporating reflective practice as an important competency necessary for both individual development and to grow the nursing profession. But if individuals are deeply embedded in teams of professionals, as nurses are, the incorporation of reflective practice is challenged by organizational dynamics. Organizations may, in fact, prevent individuals from incorporating the outcomes of reflective learning, as Mantzoukas and Jasper (2004) discovered.

In their study of 16 practicing nurses, Mantzoukas and Jasper (2004) found that strong power dynamics from both doctors and managers severely limited nurses' actions and decision-making abilities. They also found that experiential knowledge, a foundational aspect of nursing, was devalued relative to scientific evidence in organizational decision-making. The researchers concluded that reflective practice was essentially invalidated as a means of knowledge acquisition and so was ineffective in improving the practice of the nurses in the study.

The nurses and unnamed professionals in the two studies discussed above appeared challenged to effectively navigate sociopolitical relations with colleagues as they worked to increase their professional skills. Heath (1998) echoed that concern in her position paper on how remaining mindful to reflectively practice was important in mitigating problems caused by habituation of tasks. Developing strong reflective skills and a willingness to remain alert to surprises was critical. Heath argued that reflective skills were a vital competency for nurses to develop. Heath did not ignore the larger context of the nursing practice, however, and recognized that nurses may need to consider broader ways to frame the practice problems on which they are reflecting. Framing might begin with individual actions, but then widen to include the context of team and organizational dynamics when individual actions cannot adequately resolve the problem under consideration.

These tensions have occurred in meteorology, as well, where forecasters have had to develop knowledge in the absence of theory. Some of this knowledge has stood empirical testing while some has not. For example, pioneers in tornado research were military forecasters who studied tornado outbreaks and events. They identified many important factors for tornado formation that hold true today. They also believed, however, that dry intrusions of air in the middle levels of the atmosphere were necessary for tornado formation. Years later, Gilmore and Wicker (1998) established through modeling studies that such dynamics were not necessary. In many cases, the culture of meteorology has encouraged and supported the efforts of some forecasters to formalize their operational knowledge through empirical studies that confirmed their observations and experience. Examples include the identification of how northwest flow can result in tornado outbreaks, revival of the term "derecho" to describe particularly long-lived damaging wind events, and the conditions under which bow echoes can form from convective storm complexes (Johns, 1982, 1984, 1987, 1993). But the culture of meteorology generally disdains knowledge derived through practice because little of it is ever verified through empirical studies.

Summary of Literature on Reflective Practice. The studies highlighted here were similar in that all generally found reflection as positive and helpful to learning. Two studies specifically incorporated reflection into continuing education (Orland-Barak, 2005; A. Smith & Jack, 2004) while another assessed the reflective abilities of novice and experienced educators (Ferry & Ross-Gordon, 1998). All three found reflection as a positive contributor to professional learning.

A few of the studies highlighted here differed in suggesting that while adults generally benefited from reflection, some adults were more inclined than others to use reflection as a metacognitive tool (Ferry & Ross-Gordon, 1998; A. Smith & Jack, 2004). It is not clear whether non-reflective adults were naturally less reflective or whether they were discouraged to reflect while being cultured in their profession (A. Smith & Jack, 2004). Several studies touched on organizational dynamics and suggested that adults may be discouraged from being reflective by the organizational structures around them (Jones & Stubbe, 2004; Mantzoukas & Jasper, 2004; Orland-Barak, 2005; A. Smith & Jack, 2004).

While these studies collectively showed that reflection is a valuable skill for managing how one learns, the studies did not establish how reflective practice was learned. While Schön (1987) emphasized that professionals must first frame ill-defined problems before they can effectively solve problems, he asserted that schools did not generally teach this non-linear application of knowledge within a domain. The essence of how professions conceptualize reflective practice seems to be the linking of professional knowledge with experience to learn in the context of practice. This makes reflective practice something inherent in the professional practice for many adults. Not only would it be worth explicitly developing and exercising the ability to do this well, Schön asserted that creating a reflective practicum required each profession to engage in a new area of research: that of determining the characteristics of reflection of competent practitioners in that particular profession. Following such studies, research into how to best coach and learn by doing would provide individual professions an understanding of how to create a new dual curriculum that linked the theoretical knowledge of the profession with the real-world problems of practice in that profession.

In the current practice of most professions, where reflective practice is unconscious, it may be a native inclination of someone to reflectively practice that distinguishes those who excel professionally and those who do not. Further studies may help close these gaps in understanding and show how any person may develop an ability to more effectively learn from experience through reflection. Because much of that learning is self-directed, the construct of self-directed learning in adult education provides yet another lens that is closely related, yet has unique contributions to this study.

Self-Directed Learning. The construct "self-directed learning" originated from adult education where research showed that nearly all adults engage in learning projects. These projects can be quite extensive: a series of activities that eventually constitute a deliberate, systematic, sustained learning effort (Tough, 1979). General studies of adults showed that the subjects adults pursued arose from problems encountered or skills needed in their professional and social roles in life, personal curiosity, and desire to interact with others (Houle, 1993). A major professional learning study of physicians by Fox, Mazmanian, and Putnam (1989) found that all physicians made changes to their practice and that self-directed learning was involved in the majority of these changes. The changes occurred after a variety of forces, ranging from social to professional and personal, led the individual physician to want to change their current practice in some way. Given that meteorologists are not explicitly taught how to forecast – either within or after formal schooling – much of their learning is left to self-direction.

Adult educators have discussed the construct of self-directed learning in two distinct ways relevant here: 1) as a goal, or set of skills critical to the future professional, and 2) as a process describing how professionals engage in learning. Educators preparing students for a profession might think of the ability to self-direct ones' learning as an important goal and incorporate development of skills students must learn and practice in order to excel in the profession later in life. Particularly for professionals, self-direction is an important personal attribute that is congruent with the notion of a professional taking responsibility for their ongoing development. Self-directed learning can also be thought of as a process that benefits from facilitation at several steps including assessment of learning needs and reflection on learning. In order to effectively self-direct, each professional must be able to recognize learning needs, identify appropriate human and material resources, engage in learning strategies that are effective for them and appropriate for the particular subject, and reflect upon and assess their learning. Thinking about lifelong learning as at least a partially self-directed endeavor acknowledges the characteristics of autonomy desired in professionals while clarifying the assisting role others play in individuals' self-directed learning.

There are two commonly-used, multi-faceted definitions of the construct. A leader in adult education, Knowles (1975) wrote one of the first and most commonly-quoted definitions of self-directed learning:

> In it's broadest meaning, 'self-directed learning' describes a process in which individuals take the initiative, with or without the help of others, in diagnosing their learning needs, formulating learning goals, identifying human and material resources for learning, choosing and implementing appropriate learning strategies, and evaluating learning outcomes. (Knowles, 1975, p. 18)

Hammond and Collins (1991) later modified Knowles's original definition to emphasize that social awareness often causes adults to realize learning needs, and that reflection and analysis of learning are important aspects of high-quality, effective self directed learning. As such, their term *critical self-directed learning* is modified to:

> . . . describe a process in which learners take the initiative, with the support and collaboration of others, for increasing self- and social awareness; critically analysing and reflecting on their situations; diagnosing their learning needs with specific reference to competencies they have helped identify; formulating socially and personally relevant learning goals; identifying human and material resources for learning; choosing and implementing appropriate learning strategies; and reflecting on and evaluating their learning. (Hammond and Collins, 1991, p. 13)

It is Hammond and Collins's second definition that is emphasized in the continuing professional development literature in a similar applied science profession to meteorology, that of medicine. Both definitions insist that self-directed learning is not a solitary endeavor. Rather, the naming of the construct merely reflects that the individual is primarily responsible for determining learning goals and methods.

Most writers agree with the notion that being able to decide what and how to learn is an appealing ideal (Garrison, 1997), particularly for our democratic society (Candy, 1991). Learner-control promises individuals the ability to overcome limitations in educational opportunities and choose strategies that work well for them, which fosters internal motivation (Candy, 1991). There are limitations preventing adults from reaching this ideal, however, that provide opportunities for a profession to facilitate and encourage self-direction. Candy pointed out some limitations to learner-control: rapid changes can leave adults unsure how to proceed, self-direction involves skills adults may not possess, and some adults have actually learned helplessness through school or work culture. The previous discussion of reflection included an example from nursing of how cultural barriers can inhibit learning. That discussion also addressed the notion that excess cognition must be available for reflection, but that the knowledge, skills, and attitudes necessary for forecasting the weather can easily overwhelm the beginning forecaster. In a broader perspective, Kegan (1994) said it is unrealistic to expect adults to consistently be self-directing: the demands of modern life are simply too mentally taxing for us to have the capacity to self-direct in all areas and at all times. Because professional learning takes place in the midst of many other life events, professionals may at times find they have little capacity to grow their expertise.

Researchers of self-directed learning consistently find a social dimension, which may ease other limitations on one's ability to effectively self-direct. This has caused writers to always include, and sometimes expand upon the concept of self-directed learning to articulate that managing the learning process usually includes a facilitator of some kind while the individual retains responsibility for their learning (Brockett & Hiemstra, 1993). Other researchers articulated the organizing circumstance around which both planned and fortuitous actions and environments cluster to have a profound impact on self-directed learning (Spear & Mocker, 1984). These researchers found that individuals and organizations can deliberately increase the likelihood of valuable informal learning opportunities through such actions as maintaining collections of professional books and publications; attending conferences, meetings, and symposia that maximize interactions with others in similar practice; volunteering for leadership positions in professional societies; and strategically locating a practice or business near colleagues or clients. Such strategies might be particularly important for sole practitioners or those with unique specialties in a group but they are important for all professionals.

Studies on Self-Directed Learning of Professionals. Research on the self-directed learning of professionals and other workers have taken a variety of forms. Given the importance of self-directed learning in the personal and professional lives of adults, several authors have attempted to create instruments to identify self-directed continuing learners (Oddi, 1986), or at least determine an individual's orientation toward self-directed learning (Merriam, Caffarella, & Baumgartner, 2007). The latter of these, the Self-Directed Learning Readiness Scale developed by Guglielmino, has been studied more than the others and has been found useful despite serious validity issues (Merriam, et al., 2007). Other professions, however, have thus far found such scales inadequate, and attempted to create their own scales. For example, recent work claims to have validated the Jefferson Scale of Physician Lifelong Learning (Hojat, Veloski, Nasca, Erdmann, & Gonnella, 2006).

None of the studies discussed below suggested that self-directed learning was the only way professionals learned. At least one study recruited participants from those taking formal job-related training courses. Rather, the studies suggested that self-directed learning was an important strategy through which professionals learned.

Three studies using Guglielmino's Self-Directed Learning Readiness Scale (SDLRS) showed that adults with lower education levels, lower job positions, or lower job performance all tended to have lower scores on the Self-Directed Learning Readiness Scale (Beitler, 2000; Durr, Guglielmino, & Guglielmino, 1996; Guglielmino & Roberts, 1992). None of the studies attempted to address part of their initial discussions, which were that some subjects are not conducive to self-directed learning (Beitler, 2000), or that job performance was related to self-directed learning readiness (Durr, et al., 1996). Durr, Guglielmino and Guglielmino only reported comparisons across manager categories, not within a category by job performance. Neither one of the studies with international comparisons (Durr, et al., 1996; Guglielmino & Roberts, 1992) mentioned relative performance of the U.S. and foreign companies, thereby failing to move beyond their cursory report to provide evidence that SDLRS had any bearing on global competitiveness. These three study reports may have been intentionally incomplete; the authors do not state whether they had corporate funding for their studies, but that would explain the sketchy nature of the analyses, findings, and conclusions.

Meanwhile, a recent study of librarians (Varlejs, 1999) took a more exploratory approach to investigate how prevalent self-directed learning was among librarians and what librarian and institutional characteristics influenced self-directed learning. Like many fields, library science was undergoing rapid changes. The framework from which Varlejs built her multivariate, inferential model drew from several works including Candy's work on self-directed learning and Stone's studies on the professional learning and development of librarians. Varlejs found that librarians spent a significantly greater amount of time learning on their own than from formal continuing education ($p < .01$). Further, she found significant positive relations between self-directed learning and autonomy, but found a negative relationship with administrative support measures. Further analyses showed that seniority, rather than time spent learning, was highly correlated with the professional activities Stone had previously used to determine achievement. One cause Varlejs proposed was that management responsibilities may lead to a mode of consistently ongoing, reflective learning that dealt with ill-defined problems of practice that would be difficult for respondents to identify on her survey as a learning project. Ultimately, the multiple regressions indicated that the model provided a reasonable, but incomplete framework. Varlejs concluded that a qualitative phase might better reveal complexity and additional factors not considered in the model built upon previous research on self-directed learning.

Varlejs proposed that ongoing, reflective learning was a primary learning mode of librarians with management responsibilities. Borduas, Gagnon, Lacoursière, and Laprise (2001) deliberately incorporated the notion of ongoing, reflective learning into their study of physician learning. Like meteorology, medicine is constantly evolving in the state of scientific knowledge, technological advances, and other factors. It is critical that physicians are able to update their knowledge on a nearly continuous basis, just as the managers in Varlejs's study may have been doing. With these considerations in mind, Borduas, Gagnon, Lacoursière, and Laprise designed a formal continuing medical education event around a longitudinal case study based upon the real case of a hypertensive patient who had been treated over a 15-year period. The reality of physician practice is that data are nearly always incomplete and patient situations evolve. The case was designed to encourage physicians to reflect upon which actions they would take at several points in time, discuss those decisions with colleagues in small groups, compare their actions with those of the original physician, investigate various options for treatments and alternatives, determine sources of information relevant to the case, and identify relevant theory that guided their actions. The formal event included feedback from a specialist as the case proceeded.

The effectiveness of the instructional design was tested with a convenience sample of 37 general practitioners, mostly male, with three to 20 years of experience, practicing in urban areas. Comments on the workshop evaluation forms were very positive and highlighted the reality, yet clarity of the practical case. Although the authors could draw on others' work to suggest that participants were learning and practicing Schön's reflective learning to extract knowledge from real-world situations and that they had opportunity during the workshop to identify knowledge gaps that would motivate learning, the authors did not attempt to measure a long-term outcome from their approach.

Another study of physician learning, this one by Casebeer, Bennett, Kristofco, Carillo, and Centor (2002), was designed to study physicians' online medical information-seeking behavior. Casebeer et al. hypothesized that a) previous information-seeking experiences and demographic factors might influence information-seeking behavior, and that b) the utility of the Internet in finding information would be a key determinant of motivation to use the Internet. The researchers also recognized that much of the continuing education available online was not designed with this type of perspective in mind.

Random samples were drawn from the American Medical Association's 324,000 members until researchers had 2,200 usable surveys to analyze. Results showed that 80% of physicians used the Internet to find medical information. Specifically, they reported doing literature searches, accessing on-line journals, and searching for both general and specific information. Just over half reported using the Internet at least weekly; 18% reported only rarely using the Internet. Perhaps surprisingly, nearly 70% rarely or never used the Internet for online continuing education. Instead, a particular patient problem was ranked as being the most important motivation for seeking information. For those searchers, 36% said the Internet was very helpful and 45% said it was occasionally helpful. Among the other results, male physicians reporting having more experience and confidence using the Internet than did female physicians, physicians in urban locations had used the Internet longer and more frequently, specialists had also used the Internet longer than primary care physicians, though the latter used the Internet more frequently. Finally, primary care physicians focused their Internet use on particular patient problems while specialists reported using the Internet for literature searching, finding research results, and professional association updates. Although this was all self-reported data, 62% said they usually found the information they were seeking and 28% said they occasionally did. When information was found, 95% of physicians reported at least occasionally using that data; 70% usually or always did. Casebeer et al.'s discussion included the recommendation that continuing medical education providers include effective Internet use strategies and that they consider designing resources to help physicians locate and integrate multiple sources of information in order to facilitate these largely self-directed learning efforts undertaken by physicians.

Casebeer et al.'s paper on learning through Internet resources supports the notion of self-directed learning as a productive, natural activity frequently undertaken by professionals. While Varlejs's study on librarians did not focus specifically on Internet use, it also showed that self-directed learning was a dominant way in which librarians learned. Other studies discussed above addressed the notion of self-directed learning readiness and how that correlated to job or company performance. In the latter two studies the authors did not attempt to objectively determine the effectiveness of that learning, relying instead on self-reported data. The studies using the SDLRS purported to have such an outcome in mind, but did not take the studies far enough to show that higher levels of self-direction were actually correlated to company performance.

And so we find that instruments and studies related to self-directed learning do not adequately address the fundamental question underlying this study about how meteorologists learn to forecast. Instead, they might be used in attempt to assess whether forecasters have the skills or are ready and expect to be responsible for their own learning. To some extent answers to those questions are unimportant to this study. Forecasters must self-direct much of their learning because it is not explicitly taught. But the degree to which those self-directed efforts are effective is unclear and could vary widely. Without addressing the quality of the learning strategies of the forecasters participating in this study, the resulting data from this study will contain learning strategies with varying effectiveness. A few, recent studies call into question an individual's ability to effectively identify learning needs and subsequently learn on their own.

Can Individuals Effectively Self-Direct? Even at the time of Candy's work, serious questions were raised about an individual's ability to effectively determine and fill learning needs. More recent work by Kruger and Dunning (1999) provided empirical evidence supporting this concern. Kruger and Dunning conducted four studies on humor, logic, and grammar with undergraduate students at a northeastern university. They consistently found that 75% of study participants overestimated their competence, while the remaining, top quartile consistently underestimated their competence. The authors went a step further in one phase of their study to link the ability to recognize competence with the metacognitive skills necessary for choosing good learning strategies. By directly manipulating competence, they both increased actual competence of undergraduate participants on logic tests and decreased those participants' perceptions of their competence to something closer, but still above, actual competence. Kruger and Dunning concluded that the majority of people are both incompetent and unable to realize it due to poor metacognitive skills. Perhaps writers on self-directed learning recognized this potential problem years ago. It could explain their emphasis on a social component to self-directed learning.

Kruger and Dunning's study has been partially replicated in medicine. Violato and Lockyer (2006) conducted a similar study using internal medicine, pediatric, and psychiatry physicians and produced similar findings. The researchers studied 304 physicians registered with the College of Physicians and Surgeons of Alberta (CPSA) whose specialties were evenly divided between psychiatry, pediatrics, and internal medicine. A 38-item survey covering four sub-scales of patient management, clinical assessment, professional development, and communication skills, developed for the Physician Achievement Review Program of the CPSA, was given to 25 patients, eight medical colleagues, and eight non-medical colleagues. It was also rewritten to the first person and given to the physician participants in the study. The survey had found it was able to account for 70% of the variance in those four factors and the instrument overall had a Cronbach's alpha of great than 0.90.

The physicians' own assessment was then compared to that of eight medical colleagues. Both were broken into four quartiles: < 25^{th} percentile, 26–50^{th}, 51^{st}–75^{th}, and > 76^{th} percentile. Results were shown by each of the four sub-scales within each of the three physician specialties. Physicians who were rated by peers to be in the lowest quartile rated themselves 30–40 percentile ranks above how their peers had rated them, and the converse was true for those physicians who's peers ranked them in the highest quartiles. The authors conclude, among other things, that accurate feedback is critical to a physician recognizing learning needs and competence.

Violato and Lockyer's study showed that most groups rated themselves to similar competence levels, despite their peers' assessments being much more broadly distributed. This is similar to Kruger and Dunning's results, where participants' self-assessments were slightly above average and did not differ much amongst the quartiles. Violato and Lockyer's study differs from Kruger and Dunning's study in that the highest quartile of physicians rated themselves so much lower than did their peers. In Kruger and Dunning's study a truly objectives measure, such as scored knowledge tests, were used to compare with participants' self-ratings – a key difference between these two studies that may have long-reaching effects. Those providing guidance to other researchers studying expertise caution against using peers to determine the "goodness" of the expert (Sosniak, 2006). Expertise researchers instead make clear that objective determination of expertise is critical. When peer opinion is used, the data fall prey to popularity and other irrelevant factors. Unfortunately, the requirement for objective determination of expertise has meant that expertise studies have been limited in complex cognitive domains where ill-defined problems dominate.

Self-directed learning is thus left as an important construct that may inform how questions are asked and how data interpreted, but in itself, does not provide a complete and mature framework upon which this study could build. Forecasters have limited formal learning opportunities, so meteorology as a discipline is relying on forecasters' abilities to self-direct their learning.

Career Stage and Development. Just as expertise studies and Anderson's theory on how thought adapts suggest that learning will vary over time, other literature further expands on how career stage and development may affect learning. The latter takes into account non-cognitive aspects of adult and professional development that affect career direction, choices, learning strategies, and more. These lenses complement but do not overlap sufficiently to preclude the consideration of both.

As Houle (1980) expanded upon the classic model of professional education he drew attention to phases of learning during the lifespan of the professional. Many have traditionally considered lifelong learning to be a ladder of development, but Houle noted that writers who studied the allied health professions showed a more complicated variation of movement – upward, downward, and even sideways, to other careers within allied health. A jungle gym is likely a better analogy to describe career development and this movement implies learning of more than simply forecasting skills.

Forecasters may experience ladders or jungle gyms. Those who stay within an organization may move mainly up ladders of development. For example, forecasters in the National Weather Service generally move from the intern through journeyman to lead forecaster positions. But even within this hierarchical organization, forecasters might move laterally to hydrology, training, information technology, applied research, or other positions. They also move geographically. Not only does the frequency of different types of weather vary from place to place, but so does available instrumentation. Increasingly, meteorologists also move between the public and private sectors. Some forecasters have left federal service to forecast for private interests ranging from ordinary forecasting to more adventurous activities like weather futures and other entrepreneurial ventures. At the same time, other forecasters have left the harsh and volatile climate of business in the private sector to pursue a more stable and predictable forecasting career within the government.

No literature exists within meteorology to address how these career shifts affect learning, though a few other professions have studied how learning changes over time and as careers evolve. Two such studies are summarized below from medicine and nursing. These studies have shown that learning may occur in stages.

Ramming's (1992) study was motivated by a need to understand how nurses learn despite their professional learning needs often being neglected in favor of primary care. Using a random sample of 500 of the 17,700 registered nurses holding licenses in the state of Oklahoma, Ramming sent a survey containing seven common clinical practice problems. Each problem had nine to 12 possible learning resources listed and respondents marked which they had used for that problem. About one third of respondents agreed to follow-up interviews; Ramming chose 25 and conducted semi-structured interviews.

Ramming's demographically-representative survey respondents' top resource choice from the five resources listed in every situation was another nurse, with 45% of respondents saying they "usually" consulted another nurse to learn. Forty-nine percent said they occasionally consulted another nurse. Differences in how respondents marked resources were related mostly to their job responsibilities, though age, years of experience, and education preparation also affected resource utilization. Ramming found that younger nurses relied more on other nurses than on in-service education, continuing education, audiovisual resources, articles, or studies. Lower numbers of years of experience showed a similar pattern. Finally, nurses with the highest degrees tended to more frequently use the nursing educators as a resource.

Ramming's follow-up interviews helped explain some of her findings. Time constraints were a major factor in use of both formal and informal resources. Although many hospitals had a nursing educator on staff to facilitate formal learning efforts, that person was often not available or was busy. Literature may not have been used much in part because hospital libraries either had limited hours or were off-limits for the nursing staff. But even for self-directed learning efforts, low staffing meant that time was a major constraining factor limited resource use.

The following aspect of Ramming's findings not only compliment other literature discussed, it may prove insightful for how meteorologists are learning to forecast. Both nurses and forecasters are dealing with a complex, poorly-measured, poorly-understood system – the body or the atmosphere – and an incomplete scientific basis upon which to approach problem-solving. Ramming found that younger nurses preferred informal, social learning resources while more experienced nurses turned more often to formal courses and expert sources to deepen their knowledge. Younger nurses found that talking with more experienced colleagues was more immediately helpful in solving problems. Perhaps these nurses were essentially gravitating toward a coaching situation in order to learning how to think about problems of practice. Until a nurse develops a significant repertoire of strategies for dealing with practice problems, there is little excess cognition available with which to reflect. Finally, if more experienced nurses are being queried routinely by younger nurses, they might naturally wish to develop a deeper understanding of why their practical knowledge works. It will be interesting to see if forecasters also begin to shift toward more formal resources for learning as their proficiency increases.

A study of physician learning and change also provided some insight into how adult and career development affect professional learning. Three notable studies investigating whether changes resulted from CME were well-designed and thorough, taking a classic approach to answering this question, all looking at education as the cause and change as the effect (Lloyd & Abrahamson, 1979; Sibley et al., 1982; Stein, 1981). The results were inconclusive, with the studies contradicting each other. Variables affecting change were either un-accounted for or difficult to control. Fox and several others associated with the Society of Medical College Directors of Continuing Medical Education proposed a new study that would turn the question around, starting with changes and investigating how and why they occurred (Fox, et al., 1989). That major research effort, now commonly referred to as The Change Study, took the approach of systematically collecting and analyzing stories of change.

A total of 356 interviews were conducted in the U.S. and Canada by 26 trained interviewers. Interviews averaged 2.2 descriptions of changes. After discarding internally inconsistent or otherwise unusable data, a total of 775 stories of change from 340 physicians were used for the analysis. This extensive study, reported in the form of a book, had far more results than can be conveyed here.

Perhaps most relevant here, Fox et al. found that physicians tended to use experiential learning when attempting to solve specific problems. These were more frequently encountered in the earlier stages of in a physician's career as the physician attempted to reconcile the complexity of practice with what was learned and practiced during formal schooling. Career stage also affected learning. Mid-career physicians, for example, often made major changes to their practice. Those changes were mainly driven by factors that were personal, such as a new baby at home, or professional, such as the desire to specialize and distinguish one's practice from the mainstream. Although these results were from a study of physicians, the model of change and learning created in this study has been generally confirmed in a variety of other settings including architecture (Price, 1997), law (Katzman, 1996), dentistry (Hinely Jr., 1998), and teacher professional development (Blanchard, 1992).

Summary

This chapter identified and explored the landscape of existing literature and how it informs this study. Unfortunately, how meteorologists learn to forecast has not been established. Meteorologists have written about and studied some aspects of forecasting, yet have come short of documenting the activity sufficiently to describe how forecasting is learned. It is rare for meteorologists to attempt to explicitly teach forecasting, and nothing is written that could represent a consensus regarding what such pedagogy should look like. Educational and related literature have addressed learning in many cognitive domains, some of which are similar to forecasting, yet have fallen short of establishing a comprehensive theory for any of those domains. As such, the educational and related literature cannot provide a theory of learning that might be applied and tested to how meteorologists learn to forecast. The literature instead leaves a variety of conceptual lenses regarding the nature of forecasting, how it may be learned, factors that may affect learning to forecast, and instructional techniques that may be helpful for this learning. These lenses at times intertwine, yet at other times fail to intersect – even when multiple lenses appear relevant. No comprehensive theory for such learning exists in the literature today.

Chapter Three

Introduction to the Design

There is an absence of literature describing how meteorologists learn to forecast, yet meteorologists are learning it. Only a handful of studies have been done on forecasters, and they did not directly study forecaster learning. Still, those studies suggested that expert forecasters began by identifying the forecast challenge for the day, modified tools and procedures to suit the particular forecast, formed a mental model of how they thought the weather would evolve, and adapted that model to whatever type of information a customer needed (Pliske, et al., 1997). Warning forecasters reported interacting with others to train them, get feedback and ideas about how the weather would evolve, and gain confidence in their decisions; wanted to learn how tools worked so they could properly weigh the information coming from those tools; desired immediate feedback, or ground truth, about the impacts of the weather as it evolved; and often conducted post-event analyses weather events to relate the information they had with post-event damage and other reports, especially if they had failed to issue a warning in advance of a severe weather event (Hahn, et al., 2003). These studies provide some information with implications for learning, this body of literature about forecasters is very small, and these studies did not attempt to establish how meteorologists learn to forecast.

While several constructs from other fields like cognitive psychology, adult learning, and philosophy might explain aspects of this type of learning, those constructs are not developed sufficiently to be a holistic explanation of such learning. The constructs mentioned in Chapter 2 have implications that are guiding choices being made in the design of this study. Those constructs – expertise, reflection-in/on-action, self-directed learning, and career stage and development – are from different disciplines. They may each have a unique contribution to understanding forecaster learning. For example, if expertise studies done in cognitive domains capture elements of how forecasting is learned, the bulk of learning that takes a forecaster to expert status may take place over a10-year period of time. If reflection-in-action and reflection-on-action are key ways forecasters learn to apply the science of meteorology to real-world, muddy problems of practice, then forecasters will talk about the necessity of effectively reacting to surprise. How forecasters currently deal with those surprises will reveal some of the metacognitive strategies they use. Experiences of both forecasters and those who train them may provide evidence of a realization of the need to scaffold learning in this complex domain. If stories show that forecasters have found coaching a useful strategy, we may see both confirmation of the importance of reflection as well as that there is some organizational or cultural support encouraging reflective practice. And because forecasting is rarely explicitly taught, forecasters are left to self-direct their learning, particularly over the multi-year period necessary to gain expertise in similar cognitive domains. What are forecasters doing to learn at various stages of their career? Do their learning patterns or preferences change as they navigate their careers? None of the constructs are sufficient to explain all aspects of how forecasters are likely to be learning. Therefore, this study falls in an area where practice can provide information that leads to theory. Through this study, the elements and relationships characteristic of a theory of how meteorologists learn to forecast will be identified.

Method

The source for this research problem combines two of several possible sources of research problems identified by Strauss and Corbin (1998). That is, both personal experience with learning to forecast and four bodies of literature about several constructs that may apply were used. Personal experience of the researcher is limited mainly to a year at the end of formal schooling, when participation in a forecasting contest was encouraged to supplement learning in a course, and to more than a decade of observing friends and colleagues pursue forecasting careers and reflect upon the nature of forecasting. Personal experience and observation provide some insight free from bounds of existing theory to draw upon. Also important, many constructs in four bodies of literature—meteorologists' writing on the role and nature of forecasting, studies of forecasters, adult learning literature, and expertise literature—may apply to learning to forecast. These constructs are sufficiently unique that no one construct appears adequate to explain forecaster learning, but they provide additional potential insights. Many of these constructs are at the stage of substantive theory – a middle range of development that Glaser and Strauss (1967) asserted is often necessary inspiration for the development of formal theory. Glaser and Strauss go on to say that substantive theory also provides some initial direction for the development of categories and properties. All this suggests that this topic of how meteorologists learn to forecast requires further development and merits an exploratory approach. The primary source of data is the stories and experiences forecasters convey about how they have learned to forecast and what forms their learning is taking to build and maintain competence.

Potential participants were initially approached based upon pre-conceived ideas about how the forecast task varies: type of forecast, environment being forecast, and time-in-service. As the study commenced, theoretical sampling as defined by Strauss and Corbin (1998) dominated. Reasons for subsequent sampling choices emerged as a collection and analysis strategy aimed at theory development began.

Variations in Grounded Theory Methodology. At least three writers are prominent in grounded theory methodology. Glaser and Strauss wrote the original work in 1967, then later parted ways and developed grounded theory in different ways. Their recent writings are each considered below. A prominent feminist writer, Charmaz (2005), takes a third stance, emphasizing the constructivist elements of grounded theory. She focuses attention on ideas related to social justice, namely: "fairness, equity, equality, democratic progress, status, hierarchy, and individual and collective rights and obligations" (p. 510).

Glaser and Holton (2004) wrote to clarify their conception of grounded theory and object to what they saw as the reduction of grounded theory to a qualitative data analysis procedure. The result of grounded theory is a context-independent theory, a set of hypotheses derived from a core category around which other concepts ground in the data are organized. Grounded theory does not simply result in a description. After spending considerable time criticizing others' writings on grounded theory, they began the section titled Getting Started by saying, "A good GT analysis starts right off with regular daily data collecting, coding and analysis. The start is not blocked by a preconceived problem, a methods chapter or a literature review" (p. 11). Literature is only to be considered along with data. This is a departure from the original work Glaser did with Strauss, where they wrote that substantive theory provides a "most desirable, and usually necessary" start in formulating theory from data (B. G. Glaser & Strauss, 1967, p. 79).

One problem with this conceptualization is that no social phenomenon is completely context-independent. A more serious problem is that Glaser and Holton insist that research begin with data collection because a literature review would provide preconceptions to how the researcher approaches the problem. First, without a literature search of some kind a researcher cannot establish that a study is original. Second, researchers educated in a discipline cannot possibly set aside what is known in the discipline in order to conduct a study. Instead, a conceptualization of grounded theory that helps one deal with preconceptions while analyzing the data is the only practical one for most situations. Researchers must remain sensitive to emergent themes and can do so using techniques designed to help researchers confront their biases.

In addressing the historical background of grounded theory methodology, Strauss and Corbin (1998) differentiate the direction they have taken as being strongly influenced by qualitative traditions whereas Glaser had been strongly influenced by development of quantitative traditions. Strauss and Corbin also point to years of teaching grounded theory methodology as influencing their 1998 work, which was written to guide researchers through the process of developing theory from data.

The Roles of Literature and Bias in Grounded Theory. As in all conceptualizations of grounded theory, Strauss and Corbin advise concurrent collection and analysis of data. They include, however, allowance for the researcher to initially consider existing theoretical constructs that might apply to the current study while assuring the researcher will become increasingly sensitive to emergent ideas. It is common, Strauss and Corbin say, for a researcher to recode data collected early in the study after previously-overlooked concepts are realized as important (1998, p. 206). By following this conception of the techniques and procedures for developing grounded theory, existing constructs can be effectively integrated with new constructs that emerge from the data. Strauss and Corbin have conceived of a methodology that allows for researchers to study a topic that falls within the rapidly-advancing fields of social science. It is increasingly unreasonable to expect there to be areas of research for which no existing constructs can provide at least a partial explanation.

From the various writers on grounded theory, Patton (2002) concluded that grounded theory is fundamentally "realist and objectivist in orientation" (p. 128). The grounded theory approach emphasizes a discipline and a procedure through which a researcher works past bias. Of course, any researcher is still guided by bias. As Charmaz (2005) points out, the questions researchers ask and the ways they theorize from their data are not neutral, but reflect their views. And so two of the prominent writers in grounded theory methodology acknowledge the inherently biased center of qualitative research: the researcher as instrument. This study will follow grounded theory techniques and procedures as outlined by Strauss and Corbin (1998), while remaining mindful of Charmaz's notions of biases that arise from issues related to social justice. The latter was done by retaining an emic perspective during coding, and by looking within and across interviews to consider how participants appeared to be received by their coworkers.

Participants

A pilot interview with three forecasters helped refine wording in an interview guide designed to elicit stories of their learning efforts. These pilot interviews cut across some of the pre-conceived ways that learning may vary. They included a college student majoring in meteorology who participates in a national collegiate forecasting contest and forecasts for his storm chasing hobby, a forecaster with several decades of experience, and a mid-career forecaster who addressed different types of weather and forecasts. The pilot interviews were not included in the study data.

The refined guide was used with 11 forecasters from a range of forecast locations and tasks. These forecasters were identified through personal networks, first by the pre-conceived potential variations that might be caused by type of forecast, environment being forecast, and time-in-service. Later sampling was done through a theoretical sampling strategy. Interviews focused on recent learning efforts, though all forecasters were asked to reflect on whether learning strategies and patterns have changed over time. Other studies of professional learning have found it productive to focus on learning that took place within the past year (e.g. Fox, et al., 1989). Because expertise studies suggest that cognitive task learning in domains similar to forecaster learning take place over at least a 10-year period, but writings about forecaster performance suggest expertise may not require such a lengthy time, a broad range of forecaster time-in-service was included in the study.

Data Collection

Data collection was primarily through interviews that aimed to answer the basic question, how do meteorologists learn to forecast? This very fundamental question was broken down into the following:

- What initiates efforts involved in learning to forecast?
- Why do forecasters make the efforts they do to learn to forecast?
- How do forecasters go about choosing resources and forming strategies to learn how to forecast?
- What is the role of social interaction in learning to forecast?
- What is the role of context in learning to forecast?

The above questions represent the aspects of the phenomenon of learning that are typically considered in contemporary research on adult learning. The landscape of contemporary research is far larger than that considered as the basis for this study, so the following neglects other good work in favor of relating interview questions to the particular literatures considered in Chapter 2. The reasons behind physician learning efforts was a critical aspect of Fox, Mazmanian and Putnam's (1989) change study. Their model of physician learning described how social, professional and personal forces resulted in an image of change that physicians then worked to achieve. A variety of resources and strategies were then used to learn. Resources and strategies are also a focus for studies of self-directed learning. Both the change study-inspired literature and that of self-directed learning also highlight the important roles of social interaction and context in adult and professional learning.

Because the acquisition of competence in forecasting was of direct interest, the main interview questions were formed by blending the notions of critical incidents (Dunn & Hamilton, 1986) with changes in practice (Fox, et al., 1989). Supporting questions addressed observations of forecasters as a professional group, and items that arose during the consideration of literatures in Chapter 2. For the former, participants were asked when they first started forecasting because many meteorologists had a deep interest in weather as children. This also allowed exploring the idea that forecasting may not require formal schooling. Participants were asked where they did their formal education, although the small sample size would not allow clear patterns or dependencies on schooling to arise; participants were asked how they felt their schooling affected their learning. Questions that arose when reviewing the literature were a source of several other interview questions. Some questions probed whether learning strategies had changed over time or were different for different types of weather. They were asked if they had a favorite way to learn, and whether that had changed over time. The role of social interaction was probed with several questions, as were barriers to learning. By then using the interview guide with a number of participants across a range of years of experience I hoped to capture the varying types of learning incidents undertaken as competence develops.

The initial interview guide was used with three forecasters during the pilot stage (see Appendix A). The youngest participant was able to think of several critical incidents, but the mid- and late career participants were somewhat perplexed by the approach. Those two participants had much to say about learning and various events and changes over the years. They also valued and spoke of learning they had done that then served to increase the general state of knowledge about forecasting.

The guide was then modified to what is included as Appendix B, a guide consisting of open-ended questions about learning. Those questions prompted the 11 forecasters in the study phase to respond with a wide range of learning efforts they had undertaken. By asking questions in this way, their stories were not limited to learning prompted by critical incidents. Stories included learning events prompted by curiosity, changes in technology, changes in organizational structure, a request to give a talk to a particular audience, and personal observations of atmospheric anomalies. Other stories were things that would arise during a critical incident technique, such as investigating some apparent inconsistencies of information during weather events, unexpected damage from a storm that did not appear to be severe, or large errors in forecasted temperature.

The 11 forecasters were from a variety of geographic locations and from both the public and private sector—a few of the preconceived ways learning to forecast might vary. As interviews progressed, a few questions were added. These addressed: asocial learning, where they were on a learning curve toward competence, and whether they thought forecasting could be taught. A pause after the seventh interview allowed refinement of goals for theoretical sampling. The remaining participant interviews were used to confirm the emerging model, seek full variation on emerging themes, and seek counter-cases.

Data Analysis

This study built a conceptual model of how meteorologists learn to forecast. As with all models, it is a simplification of reality, capturing a portion of the variance in the data. Participants' stories were rich with information. Each researcher's analysis is driven by their interests and what they are able to see in the data, meaning each dataset could lead to multiple models (Strauss & Corbin, 1998). Ryan and Bernard (2000) articulate a related idea, that in building a conceptual model a researcher must make decisions about how much the model is supposed to describe. This researcher is most interested in how an individual learns to forecast and how his or her context, experience, relationships, and interests mediate that learning. Strauss and Corbin provide guidance for how to proceed and it is their approach that is followed most closely.

Before breaking down the components of developing a grounded theory, Strauss and Corbin demonstrated what they referred to as "the free-flowing and creative aspects of analysis" (p. 71). In their example, they showed how a researcher might interact with their data, cycling between intense analysis of a single word to deep reflection a step or more away from the interviewee's words. Following that demonstration, they present several tools individually but are cautious to say that:

> Although each is discussed separately and in a somewhat structured way to facilitate understanding, it is the ability to put them together in a flexible and creative ways through microanalysis that enables the analyst to rise above the commonplace and develop truly grounded theory. (p. 71)

Charmaz (2006) also spoke of this nonlinearity in analysis when she stressed the importance of theoretical playfulness, or trying out ideas to see where they lead. She added that grounded theory allows for a flexibility to return to data and create entirely new codes. Coding is more than just "sifting, sorting and synthesizing data"; it is an "adventure that enables you to make the leap from concrete events and descriptions of them to theoretical insight and theoretical possibilities" (Charmaz, 2006, p. 71). The following description attempts to explain how I moved between the data and types of coding, other tools, and conjecture, to allow a theory carefully ground in the data to emerge.

Focusing on a Single Interview. Following Strauss and Corbin (1998) and other's (e.g. Charmaz, 2006) conceptualizations of grounded theory, analysis began with a nearly line-by-line coding of "Henry's" interview. It quickly flowed into tentative axial and selective coding. Of the initial codes, some were *in vivo* codes – literally the words of the interviewee – and some were abstracted concepts. As data were interpreted and reflected upon, code notes were written that included questions and thoughts. Initial codes were collected into overarching categories, in part through two basic operations: questioning to instigate inquiry, and comparisons to reflect on the properties and dimensions of the categories that began to emerge from the data.

Category development involved a number of analytic techniques. Strauss and Corbin suggest questioning: analysis of words, phrases, and sentences; and several forms of comparisons. Comparisons can take the form of turning concepts upside down, doing systematic comparisons of two or more phenomena, and specifically looking for researcher bias, belief, and assumptions in the data.

The purpose of grounded theory analysis is to create theory, so while specific cases are studied and even individual words analyzed in detail, the ultimate goal of the analysis is to move from specific detail to general concepts and relations. Within an interview individual learning incidents were identified and compared. What were the issues, problems, or concerns the interviewee had for each learning event he or she described? Memos were used to collect these general observations and other reflections throughout analysis. Two additional analytic tools, questioning and comparison, were used here as well. For example, in the first interview analyzed, Henry said that he was "dealing" with issues. He used the same word later when explaining that he got to know colleagues through "dealing" with weather events. Does he mean the same thing in both cases? This notion of comparison was later extended to learning events across interviews.

At that point, open coding commenced and formal categories and subcategories were identified, with their properties and dimensions specified. Structure notes of conditions and processes were also determined. Those became the building blocks for the emerging, initial theory. Axial coding followed, wherein categories were related through their properties and dimensions.

Strauss and Corbin acknowledge that it can be difficult initially to get to a central phenomenon, and at this stage in analysis their students usually felt overwhelmed with the number of codes they had generated. It was appropriate, then, to begin a more concerted effort to collect initial codes into abstracted, overarching categories. A second pass was made through the interview to take the first level codes to a second level of abstraction. For example, in the first interview, "dealing with issues" during a "big event" suggested that something was going on that was part of the job, but a new or extreme situation. This participant said he had to become more reliant on others because of this—a changed condition of the job.

Fairly early in analysis, Strauss and Corbin suggest asking, what is this research about? In the example above, Henry spoke about dealing with issues during a big event that caused him to become more reliant on others. Many of the stories in Henry's interview involved his role. This interviewee had a very strong sense of his professional role and worked very hard to fill that role. The tentative answer to this question, based solely upon one interview, was that this research is about a forecaster's strong sense of their professional role.

At this point the analysis returned to the codes and resulting categories to examine the extent to which properties and dimensions were identified. Not surprisingly, it was inconsistent. This step back also served as a check against whether the analysis fell too quickly into the researcher's ways of viewing and understanding the world. Charmaz (2006) suggested, among other things, examining codes to assure they demonstrate the participant's point of view, looking to see that analytic constructions are clearly generated from the data itself, and checking whether codes reflect the context of what the participant was talking about. Several forms of comparisons were also done, as Strauss and Corbin suggest. Those comparisons took the form of turning concepts upside down, doing systematic comparisons of two or more phenomena, and specifically looking for researcher bias, belief, and assumptions in the data.

These initial categories and diagrams were applied to a second interview deliberately chosen as different from the first by forecaster task. The categories did not appear to match well. In retrospect, an aspect of the process of grounded theory had been misunderstood, with analysis taken farther with a single interview than would normally be done.

Strauss and Corbin also suggested focusing on how and why things are happening as a tool for identifying processes involved. The nine learning incidents Henry described led to identifying how and why learning happened for him at this stage in his career. A first hint at where this study design would lead came at this point and when comparing Henry's lists with how and why a second, younger participant learned. The range of time-in-service included meant that this study was looking at learning in a general sense rather than focusing on the initial learning to forecast. This study captured how learning is not only achieved but maintained, and how the focus of learning efforts shifts over time.

Just as writing is an effective reflective tool for expert writers (Scardamalia, Bereiter, & Steinbach, 1984), diagrams are a useful tool for exploring the processes emerging from the analysis. At first, these diagrams may be simple, but Strauss and Corbin note that the analyst may be the only one who sees them.

Diagramming was useful throughout analysis to explore and document observations about how codes related to one another. During the second coding attempt diagramming while coding various passages from interviews resulted in 10 diagrams and approximately 24 pages of notes and memos.

Theoretical sampling was done throughout this study. Data collection had continued based on preconceived factors upon which learning strategies might vary. More female participants were added to assure sex was represented. Participants were also chosen based upon seeking confirming instances and opposites to what the earliest analyses were revealing.

Strauss and Corbin warn that young researchers may find themselves overwhelmed if they collect too much data too early in the analysis process (p. 207). After initially feeling overwhelmed, this researcher discovered a positive aspect of having diverse data in-hand. It provided an opportunity to experiment with an alternate analysis technique that was akin to the constant comparative method, but involved several interviews. In Corbin's third edition of *Basics of Qualitative Research* (2008) she clearly states that there is no one right way to do grounded theory. She said, "Each analyst has his or her own repertoire of strategies for analyzing data and there is considerable variation" (p. 67). She included thirteen analytic tools in this version of the book, and stated that only two had been a "mainstay" in their own analyses: questioning and making comparisons. As a young researcher I have no favored repertoire. This work has been an adventure in experimentation as I explored what techniques were most useful with the type of data collected.

Broadening Analysis to Several Interviews. After consultation with a new committee member, analysis advanced to include all interviews in-hand. Participants varied in time-in-service, forecaster task, employment sector and sex. The data were first unitized as described by Lincoln and Guba (1985, pp. 344–351), then sorted into "look-alike" or "feel-alike" categories until six to eight cards had accumulated. At that point, a propositional statement was made for the pile that captured cards within it as well as possible. The provisional rule then became the basis for removing and adding cards to the pile. A miscellaneous pile was reviewed periodically for fit into the maturing piles. This technique is similar to the constant comparative method because the unitized sections of interviews are what Corbin illustrated as "incidents." Each unitized piece had "the potential to bring out different aspects of the same phenomenon" (2008, pp. 73–74), as Corbin demonstrated with a woman describing struggle with both her "placement" and "loss" after her husband of 65 years passed away.

Other strategies used on the first interview were extended to additional interviews individually, and to the new dataset as a whole. Commonalities amongst the participants emerged. Two central, repeating, and related themes emerged. These two themes were also related well to remaining central categories. The analysis returned to the various analytic tools of grounded theory as described above and several summary diagrams resulted.

Understanding grounded theory. A return to literature on grounded theory methodology was key in providing the courage to embrace the core categories and move a set of descriptions to an explanation of learning that collected data supports. Initially, Charmaz (2006) was one of the only writers found that included discussion of the actual construction of theory. After explaining differences between constructivist and objectivist grounded theory, Charmaz provided examples of both types of grounded theory studies. This study takes an objectivist approach, attempting to remove the influence of the researcher and any possible affects of the interaction between the researcher and participant. It does not, however, "erase" social context nor deny the previous affects on data. The underlying phenomenon involves the social interaction of each individual and how they put themselves—and are placed by others—into their unique social context.

A second, helpful work was Corbin's efforts on the third edition of Basics of Qualitative Research (Corbin & Strauss, 2008), published after this research began. While the first seven chapters of the book were essentially the same materials as in the previous edition, she modified how it was written to engage the reader and share her wealth of experience in mentoring researchers using grounded theory. For example, she modified the section on discovering the central category to simplify and clarify the criteria, and added three reasons researchers sometimes have difficulty deciding upon a central category. She also clarifies that the act of memo writing helps the researcher think and formulate their ideas. She further expanded on that idea before clarifying that a final integration of the concepts leads to an explanation, rather than mere description of "what is going on" in the data.

An article written by request of an editor of the *Academy of Management Journal* to clarify what grounded theory is—and is not—was also helpful. In his article, Suddaby (2006) emphasized the importance of creative insight during the abstraction phase of data analysis. In his years of reviewing articles submitted to that journal, he had seen grounded theory techniques sometimes result in a rather mechanical analysis, falling far short of containing the "spark of creative insight" that marked exemplary research (p. 638). Dunbar's (2002) chapter in *The Nature of Insight* might capture what Suddaby, Strauss and Corbin, and other authors are trying to help the researcher do: actively question long-held hypotheses so that insight can occur. In the study Dunbar describes, many scientists were able to make the conceptual leap to new insight in a controlled experiment so long as several pieces of data failed to fit existing hypotheses. Given a sufficient amount of divergent data, researchers were able to abandon and question hypotheses that had, up to then, remained unquestioned in their field. The variational aspects of Strauss and Corbin's theoretical sampling assure data is sought that describes the full range of emergent categories.

The theoretical playfulness encouraged by writers on grounded theory finally started making sense. The diagrams made while coding the multi-interview analysis were mainly descriptive. Arranging and rearranging summary cards on a large table and sketching on a whiteboard for several hours helped reveal how the concepts might relate to each other. These connections were mainly descriptive, but an explanation was nearly contained within them. As suggested by Corbin (2008, p. 106), thoughts about this emerging analytic story were shared with a few forecasters in order to gain confidence. The analysis was exciting because it felt unique and very real, but unnerving because it departed my tendency to focus on the cognitive aspects of learning in the literatures considered at the outset of this study.

To gain more confidence, each story was reviewed and small alterations were made to the diagrams. The diagrams—built from the words of the participants taken apart from the contexts in which they were said—must also be consistent with the stories when taken in whole. They were. Additional quotations were saved that supported the essence of the stories and the diagram. Code(s) assigned to those quotations were checked. They were consistent and supported the relations that had been identified between codes.

Some of the variation in the interviews was found in weaker parts of the descriptions. For example, there appeared to be three distinct paths into the field, a topic not explicitly queried but offered by many. Were these paths somehow related to how forecasters were learning? Later in careers, forecasters were embodying different roles in the profession, with a few of them actively pushing the state of the science through research into forecasting difficulties. What was it that caused one forecaster to apparently be content upon reaching a level of competence, while another actively pushed the boundaries of knowledge? This study needed to focus to come to a stopping point.

Focusing the Theory. As mentioned at the outset of this section on data analysis, Ryan and Bernard (2000) pointed out that researchers must make decisions about how much a model is supposed to describe. Planning for writing, and the process of writing itself, is an additional reflective opportunity to solidify thoughts and gain confidence in findings (Strauss & Corbin, 1998). Many others have also written on this subject. In their seminal work on reflective processes and development of expertise, Scardamalia, Bereiter, and Steinbach (1984) showed that expert writers used the problems encountered in writing to inform the generation of the ideas they wrote about. The act of writing is itself a reflective process.

Qualitative data is very rich, and this set of data opened many intriguing avenues for research into how and why different forecasters are learning. One way to focus this study was to focus upon the diagram that had the most supporting evidence and advance that particular aspect of the study from explanation toward theory.

Trustworthiness

Triangulation of Data, Methods, and Theories. Grounded theory is an extensive, thorough, and deeply reflective research method. The next section addresses several ways an author conveys how they conducted the work so the reader may judge the soundness and grounding of the results from the data. It remains the case, however, that the study rests upon the quality of data and ability of the researcher to reliably glean relevant information and insight from that data.

Quality of the data was triangulated in the following ways. As information from individual interviews was abstracted, these abstractions were verified in two ways. If the abstraction involved a concept or topic that was not directly discussed, the interviewee was asked to confirm and allowed to further comment. Second, abstracted concepts were incorporated into follow-up questions in the evolving interview so that new data could confirm, identify variation, and counter what had been seen.

Quality of the data was also triangulated through discussion with a few individuals involved in forecaster learning. The experience and observations of how meteorologists learn was sought from three Science and Operations Officers (the position responsible for on-site training in a National Weather Service forecast office), forecasters who were not participants, and an individual involved in professional education of forecasters in a private sector company.

Quality of the method and findings were judged by the consistency with which results of this study matched those observations from the few empirical studies done by experienced research groups, such as Klein Associates, and by meteorology's own reflective and/or empirical pieces. Although empirical research on forecasters has not directly studied forecaster learning, that research provides observations with which this study should generally be consistent.

Finally, quality of the resulting elements and relationships characteristic of a theory that result from this study was compared and contrasted with existing literature in adult education and related fields. That work remains incomplete, unable to provide a comprehensive theory of learning that might be tested in this domain of weather forecasting. However, that literature provided many conceptual lenses that sometimes intertwined and at other times provided unique perspectives on how professionals learn.

Conditions That Promote "Quality" Research. In Corbin's third edition of *Basics of Qualitative Research* the chapter on evaluating research was expanded to address changes in understanding about how to think about quality research. First, she stated her preference for the word "credible." She wasn't "comfortable" with terms like validity and reliability; "credible" does not have strong connotations of quantitative research as those words do. But "credible" also indicates that findings are "trustworthy and believable" (p. 302), reflecting the experiences that participants, researchers, and readers of the study have with the phenomenon. The word also acknowledges that the finding "is only one of many possible 'plausible' interpretations possible from the data" (p. 302).

Qualitative research has become very popular in the past decade, leading Corbin add a discussion of the "conditions that foster the construction of 'quality' research" (p. 302). These include:

- **methodological consistency**, meaning that the procedures used are from the same philosophical stance
- **clarity of purpose** regarding whether the aim is description or theory
- **self-awareness** of researcher bias and assumptions
- **training** in how to develop themes, rich descriptions, and an in-depth narratives
- **sensitivity** to the topic, participants and research that allow a researcher empathy and feel for the particpiants' points of view
- **hard work** is undertaken to get things right
- **willingness to play** with the data: brainstorm, explore alternatives, etc.

- **methodological awareness**, meaning understanding implications on credibility from the decisions made during the research
- **desire to do, and enjoyment of the research process** because many students are required to do research despite proclivity toward teaching or practicing a discipline

More importantly for readers of this work, Corbin begins with a different set of criteria for judging the quality of the work before including in one list all 13 of the points she and Strauss included in the second edition. In the third edition, they are listed as necessary "additional criteria" (see below). Her new primary criteria are:

- **Fit:** whether the findings "resonate" for other members of the group being studied
- **Applicability:** whether the findings are useful, including new insights
- **Concepts:** whether the findings have a substance, aiding professionals as they talk among themselves; also whether the concepts are dense, with variation included
- **Contextualization of concepts:** whether the larger setting for the phenomenon being studied has been included; it is often critical for full understanding
- **Logic:** whether the findings make sense and the methodological decisions were conveyed with enough detail that readers can decide if they were appropriate

- **Depth:** whether there is sufficient richness and variability, that is "depth of substance," so the findings can inform policy and practice
- **Variation:** whether variation and examples that don't fit the pattern are included in acknowledgement that life is very complex
- **Creativity:** whether the research is either new, or combines old ideas in a new way
- **Sensitivity:** whether the researcher was sensitive to the data, allowing the analysis to drive the research
- **Evidence of memos:** whether memo writing for reflection, insights, questions, and deep thinking was evident in the final report

Following are the two sets of criterion were proposed by Strauss and Corbin (1998) in the second edition (Corbin reverted to, and included the version published in the first edition). Generally speaking, when grounded theory methodology is followed carefully, verification and confirmation are an active part of the process of data collection and analysis because the researcher continually assesses the quality and thoroughness of the emerging model through data collection, analysis, and comparison with literature. Confirmation may also take the form of member checking, where summaries, or first-level abstractions of interviews, are sent to each interviewee for comment.

Strauss and Corbin listed seven criteria by which readers might judge the quality of the research process. Although even a monograph cannot fully convey all that a researcher has thought and done, Strauss and Corbin suggested the researcher provide some evidence for the following seven verification points:

1. The grounds upon which choices were made for the initial set of participants.
2. The major categories that emerged.
3. The evidence supporting those major categories.
4. Discussion of which categories drove theoretical sampling, and how representative those categories then proved to be.
5. The grounds upon which some of the hypotheses about relations among categories were formed and validated.
6. Instances where hypotheses did not explain what was found in the data, how those discrepancies were dealt with, and whether hypotheses were then modified.
7. And finally, how and why the core category was selected should be discussed. Particularly, whether that core category emerged quickly or gradually and on what grounds final analytic decisions were made.

Strauss and Corbin also listed six additional criteria upon which a reader may assess whether the theory was empirically grounded:

1. Concepts were identified, their sources were identified, they may have been listed in the index, and they were generated from the study itself.
2. Linkages were made between concepts. These may be interspersed within the text; it is unlikely they are presented as propositions or hypotheses.

3. Categories had many dimensionalized properties, and were linked tightly together with each other and with the core category.
4. Variation reflecting different conditions was built in, and at least some of this variation was included in the description.
5. Conditions under which variation were found was included and explained in terms of how those conditions affected events and actions in the data.
6. The overall research process was explained, particularly in terms of how it evolved over time in light of conditions driving the study.

In addition to the above, Creswell (1998) reminded his readers that "supplemental validation" be done by comparing the emergent theory with existing literature. Some literature will support the findings, while some findings may differ. Both aspects of the comparison with existing literature are to be discussed.

In summary, trustworthiness of this study was done in the following ways. Data were triangulated against member checks and non-participant forecasters, later interviews, and discussions with a few individuals involved in professional meteorologists' learning. The findings were triangulated to the extent they could be with what experienced researchers identified from studies of forecasters. Those studies did not directly address learning, but had implications about learning. And the results were triangulated with existing theories from adult education and related literature, none of which had sufficient theory upon which to base this study, but provided many lenses with which the results of this study should remain consistent. Finally, the results of the study are conveyed to provide sufficient transparency to allow readers to judge the quality of the research process and grounding of the results.

Limitations

The following limitations apply to this research. First, forecasters with poor metacognitive skills may be unaware that they are incompetent (Kruger & Dunning, 1999). Lack of awareness of incompetence will preclude needed learning from taking place unless forced externally to the individual. Second, Kruger and Dunning showed that strategies employed by the less competent were relatively unproductive. The implication is that the less competent forecasters interviewed for this study would have used relatively ineffective learning strategies, and these characteristics then became part of the emerging theory. But attempting to distinguish "good" and "bad" forecasters in the sampling strategy was not advised because goodness as determined by others tends to become subject to popularity or other irrelevant factors (e.g. Sosniak, 2006).

Race/ethnicity was not well-sampled or represented in this study. Women were about 25% of the participants, and only in the 0–4 years experience range. As is typical for a physical science, women and racial/ethnic minorities remain underrepresented in meteorology as compared to the general population. Where they are participating, they may advance quickly out of forecast positions. Forecasting usually involves shift work and this results in a tendency for women to move into other positions when they start families.

This study focused on National Weather Service and private company forecasters. It did not include television or military forecasters.

Many researchers, particularly cognitive psychologists, favor studying in parallel what people *actually* do (Atkinson, 1997). This study focused on several aspects of learning that were not directly observable: what initiated learning, how resources and strategies were chosen, etc. As such, grounded theory is a good choice of method. Those who follow on with this line of research may further our understanding of how forecasters or other professionals learn the non-linear application of knowledge to real world problems of practice by taking on other perspectives or approaching their study in different ways.

Summary

Although literature from meteorology, adult education, and related fields provides a partial framework for this study, that literature does not establish how meteorologists learn to forecast. The literature also remains insufficient to provide a single theory from a similar cognitive domain that might be tested with how meteorologists learn to forecast so it becomes one of two possible sources for this research problem. The second source is personal experience with learning to forecast and more than a decade of watching friends and colleagues pursue forecasting careers. Both sources provided insight—and bias for this study, which is designed to identify the elements and relationships characteristic of a theory of how meteorologists learn to forecast. Because literature and personal experience may bias the analysis, the conceptualization of grounded theory by Strauss and Corbin is the most appropriate one to follow. It includes a strongly reflective process as well as several mechanisms specifically designed to assure that findings are truly ground in the data.

Initial interviews were conducted with seven forecasters who had a range of time in service and represented a variety of contexts. Later interviews added questions to further pursue the relationships and characteristics that represent the emerging theory. Subsequent participants were sought with the aim of confirming, providing fuller variation on emerging themes, and representing counter-cases. A total of 11 interviews were done to saturate core categories and develop the elements and relationships characteristic of a theory of how meteorologists learn to forecast.

Chapter Four

"I have discovered over the years that it is one thing to talk about data collection and analysis and quite another to do it" (Corbin, in Corbin & Strauss, 2008, p. 160).

Introduction to the Findings

The first several potential participants were identified according to preconceived ways that the forecasting task might vary: type of forecast, environment being forecast, and time-in-service. Four potential participants agreed, and interviews began, providing data that ranged across all three factors. As analysis progressed, additional participants were added, first along the lines preconceived, and later by the forecaster's sense of identity. A preliminary model was built from 11 participants.

Several analytical techniques were used to explore the data. First, a single interview was analyzed in depth. Concepts were abstracted and then grouped into categories. Analysis was done on process and structure. Diagrams were made. The resulting description and diagrams were applied to a second interview, deliberately chosen to challenge it. Stark differences between the two led to a new approach.

The new approach was to use Lincoln and Guba's (1985) analytic technique of unitizing and grouping what Corbin (Corbin & Strauss, 2008, pp. 73–74) described as incidents. This led to a new coding scheme, and was akin conducting the constant comparative procedure across interviews. The coding scheme that resulted revealed several major categories that are clustered into affective and cognitive domains. Some relations between categories were readily apparent but it proved truly an art to move to an integration of the findings.

This chapter closes with discussion of evidence supporting several diagrams. One sets the stage for the emerging theory by describing the progression of events that led most forecasters into their first attempts at forecasting. Another diagram explains how forecasters describe the progression from simplistic forecasting techniques to an adaptable approach based on a deep understanding. Common triggers for learning and how those tend to vary at certain points in a forecaster's career are shown in another diagram. Finally, the emerging theory is shown in a diagram with three paths through which forecasters build knowledge structures and processes to access that knowledge to forecast the weather. The chapter closes with a discussion of the next steps.

Choice of Initial Participants

The initial four participants were selected to address pre-conceived ideas about how the forecast task varies: by type of forecast, environment being forecast, and time-in-service. Three of the four were males. The participants had four, eight, 17, and 18 years experience. One public sector forecaster did specialty forecasting for a small and specific geographic area in the central plains. The other two forecasted all types of weather for regions in the southwest US or along the Gulf coast. One participant had first worked in the private sector for three years and another had worked in a different profession before returning to a childhood interest to become a forecaster.

The simultaneous, ongoing process of adding participants

Several of the participants were added when the analysis was still rough and unsettled. For example, the first interview was coded and analyzed in depth, after which a second was coded and analyzed independently. Then the first few interviews were analyzed for structure, meaning the conditions and circumstances set the stage for learning. These first looks at the data provided some of the basis for theoretical sampling as data collection went on, as did all other aspects of ongoing analysis described in Chapter 3. Although the addition of participants took advantage of personal and professional travel opportunities, each participant was chosen to add diversity to the emerging data and probe its dimensions. This comprises the theoretical sampling of grounded theory. Participants were chosen as follows.

Henry was the first participant, chosen because he had expressed interest in this study. Mike was chosen because he actively researches—a type of learning. Lisa added a female and someone at an important stage in learning: about four years experience. Forest became the first private sector participant. He had eight total years experience. His first three learning years took place in the private sector, and to some extent learning began again when he transferred to the public sector: he was forecasting new phenomena. Cassie was chosen because she was completing her first year in the public sector, and was female. She was just beginning to have forecast duties and was at a steep point in the initial learning curve. To further explore early learning efforts across sectors, Tyler, and later Travis were added with just over one year and 2.5 years experience, respectively. They also brought in seasonal and marine forecasting. Raymond had an interesting career trajectory of researching weather before moving into a forecast position. Jordan and Janet were brought in to further query the range and impact of social support in the private sector, as well as an emerging construct: professional identity. They were both considering shifting their careers by adding economics or business degrees. Jordan had been working about eight years, while Janet was in her first two years. They both spoke of the steep, initial learning curve forecasters encounter. Shawn added another middle career forecaster, tropical meteorology, and diverse sense of identity: invested in his profession, but with many outside interests.

Employing a Variety of Analytic Techniques

Several analytical techniques were used to explore the data. Each provided complementary insights. Experimenting with analysis techniques helped explore the various methods of grounded theory and what they yielded for this work. In the end, the following analyses were the key ones that led to the emerging theory described in this chapter.

The first interview was analyzed in multiple ways, as discussed in Chapter 3. The result of open and axial coding, constant comparative procedures, diagramming, and analysis of structure led to the high-level synopsis of Henry's learning shown in Figure 1. The figure includes both conditions and variations seen across Henry's stories. Social interactions were increasingly emphasized as learning tasks became more complex. For example, when first starting out he

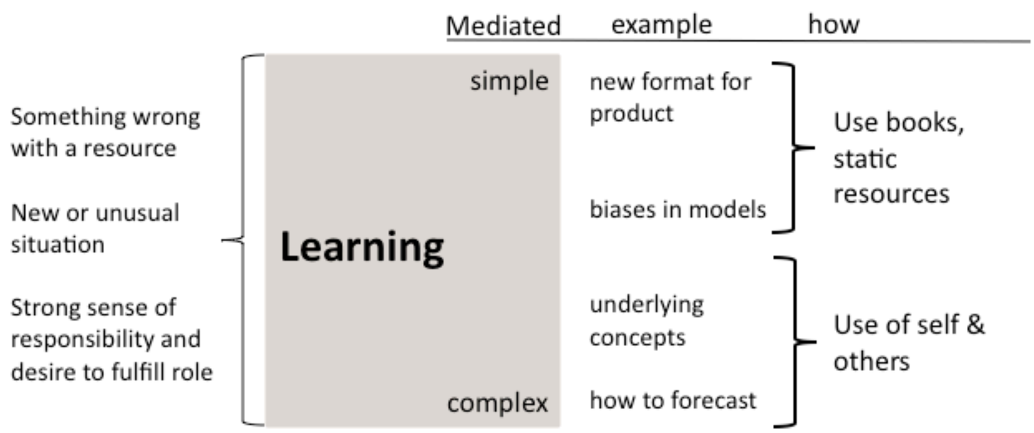

Figure 1: **High-level sketch of variations in Henry's learning strategies**

learned a great deal quickly by working with veteran forecasters. He currently has many established collaborators with whom he works to extend his ability to fill his role. He sometimes used himself as an instrument, such as literally traveling to observe the lay of the land to better understand how it floods.

Coding and other analyses were then applied to Forest's interview. The differences, however, were striking, particularly in terms of the social context of their learning. Forest was much younger, and began his career in the private sector. There was no training program, and high turnover meant other forecasters on staff were also inexperienced and of little help. Forest struggled to learn using what he could find: scientific journals and COMET's Meteorological Education online resources.[1] Henry began his career in a regional forecast center where veteran

[1] The Cooperative Program for Operational Meteorology, Education, and Training (COMET) group has created and made available a free, extensive library of online learning modules (http://www.meted.ucar.edu/).

forecasters actively mentored younger ones, allowing him to quickly learn how to think about the forecast and the tools available. Henry was beyond most of his learning about forecasting itself and was focusing on other aspects of learning to do his job well, including stretching the science. Forest's stories focused on all there was to learn in order to forecast, and how he had learned it. The degree of social support for learning was still important, but less prominent for Henry at his mid-career stage. It was critical and central for Forest's most significant learning incidents to date. Forest had just completed three years at his current employer and geographic location, and eight years in total. The most likely candidate core category from analysis of Henry's interview was the importance of filling his professional role. The second analysis yielded a similar core category—Forest's sense of identity and how it explained his persistence through an unsupportive environment as his career began. These differences between the two led to reviewing the methods of grounded theory, and to a shift in approach.

All eleven interviews were next unitized and coded. Diagrams were sketched throughout analysis, particularly while analyzing interviews individually, and memos captured reflection on the ongoing struggle with analysis. Major categories were then sorted and arranged multiple times to capture the various ways they were related to each other. Diagrams were made and later simplified to the emerging theory. Finally, interviews were reviewed to assure that learning incidents, when considered in whole, fit within the emerging theory. Particular paths traced through the diagram were marked within individual interviews and used to then compile lists inclusive of all 11 participants of how and why learning was occurring across years in service.

The Major Categories

The major categories are organized here into five main areas. These groupings are easier to see now than they were just after coding. As presented here, they begin to hint at a logical relation. First are a few categories that set important conditions for learning. These provided critical context for two long-term strategies forecasters employed. Within those long-term strategies, there was a common progression of events that led to learning. The earliest connections between the causes and resulting weather allowed forecasters to begin to forecast. The cumulative result of many learning events was the ability to see connections—a knowledge structure useful for forecasting the weather. Although these categories are naturally linked, even within them there is evidence of the glue that holds them together: several categories that expressed the self and how the forecaster related to others.

These major categories are explained below before moving into a discussion of how they relate to each other. Participants' words are paraphrased and summarized until the presentation of the central category. Quotations (when permitted) begin with the central category and accompany the explanations of the resulting diagrams that explain how forecasters learn.

The individualism of forecasters' approaches is likely the result of each forecaster being influenced by a unique set of individuals, and of building his or her cognitive structure in a different order because they experienced different events. No two weather events are the same, and types of weather occur in different distributions in different parts of the country. Some types of weather are geographically dependent.

Categories that capture conditions for learning. Three categories[2] set important conditions for learning and are shown in Table 3. The first was the context of experiencing weather: being exposed to weather helped forecasters learn about that type of weather. The more often particular types of weather occurred, the better they learned about those. Second, learning happened faster when forecasters experienced weather within a social setting that allowed for direct learning. These two helped make clear the importance of the social context the forecaster is in. Weather is complex, so being exposed to others' thinking was enormously helpful in learning to forecast.

Table 3: ***Categories That Capture Conditions for Learning***

Major Categories	Proposition (if developed)	Dimensions
Exposure to Weather Impacts Learning	Forecasters are best able to become good at forecasting types of weather they see frequently.	personal experience
Direct Learning Through Interaction	Learning happens faster when experienced forecasters can and do share their knowledge effectively	purposeful mentoring to seeking help
Benefit of Social Interaction	When forecasters are able to interact with peers and experts they figure things out faster.	social context of workplace; role models; your role: learner–peer–teacher

[2] Throughout this section categories appear in bold, propositions in italics.

First, **exposure to weather impacts learning**: *Forecasters are best able to become good at forecasting types of weather they see frequently.* A great deal of learning is done on the job, by working through events repeatedly. All participants learned this way; Lisa attributed half of her learning to it. Henry said most of his learning had been on the job, as did Tyler, though Tyler had the challenge of not seeing repeated events very often due to the nature of his seasonal forecasting. Jordan had learned his aviation forecasting on the job; Janet her marine forecasting. Mike and Cassie both learned a great deal by storm chasing. Lack of experience with weather, or certain types of weather, inhibits learning. Forest and Travis both had instances of missing knowledge because certain phenomena did not occur near where they earned their college degrees. Experience with weather sometimes revealed learning needs, just as lack of experience with weather may have hid learning needs. Cassie desired to become good at forecasting severe weather, but rarely experienced it in her first job location.

This category has an important dimension: personal versus others' experience. Eight participants had clear stories where personal experiences with weather allowed them to learn faster or more deeply. Travis said his professors focused contests on local weather so students would both forecast and experience resulting weather first-hand. Mike and Cassie forecasted outside their schooling for their own storm chases, leading to a daylong engagement and immersion in the very weather they attempted to forecast. Cassie knew well the value of those experiences, noting that while she had lived near mountains at some point in her life, she had never lived by the ocean. Her personal experience facilitated learning the former, while her lack of experiences inhibited learning the latter. Likewise, Lisa's childhood experiences with monsoons helped her forecast them. Janet realized she had a much deeper understanding of weather because of a weather observer job she held. She and her mentors routinely discussed how the clouds were related to airmasses and the resulting weather at the airport. Henry attributed his deeper understanding of flooding issues by personally visiting troublesome areas. Forest better understood marine weather because his mentor connected the science to stories of sailing in the Gulf of Mexico. Jordan also recognized how experience affected someone else: forecasters who lived in the southeastern U.S. better understood and made better forecasts of tropical weather. Exposure to weather is a category that was both a trigger for and factor in learning.

Experience with weather could lead to opportunities to directly learn from others, as just described. **Direct learning through interaction:** *learning happens faster when experienced forecasters can and do share their knowledge effectively,* was itself a category that proved important to the processes of learning identified later. Forecasters described learning ranging from purposeful mentoring to others simply responding effectively to their questions. Direct learning opportunities were structurally supported by workplace design (see Benefit of Social Interaction), and sometimes sought out. Direct learning did not happen if others provided only short answers, did not explain something well, or did not share knowledge at all.

The strongest form of direct learning was purposeful mentoring. Forest, Tyler, Raymond and Shawn each had an experienced forecaster seek them out and initiate an extensive mentoring effort, while Lisa, Janet, Cassie, Henry and Mike each had several experienced forecasters mentor them to lesser extents. These are described in some detail elsewhere. A less extensive form of direct learning was the immediate learning that took place when a more experienced forecaster answered questions clearly and effectively, or helped an inexperienced forecaster work through a particular problem. The three most experienced forecasters cited direct learning from journal articles, formal education, and conferences.

In probing actions and learning opportunities for one forecaster it became clear he was missing several opportunities for direct learning. Travis could only assume other forecasters went back to look into why their forecasts sometimes failed to verify because he had never heard them talk about doing so. He was not sure how they went about investigating poor forecasts. He admitted to losing track of the weather after a few days off, and said that he had to remind the person he relieved when he came on shift, or the briefing would not include any information about what had occurred on his days off. In contrast, Jordan specifically mentioned that his peers would help each other after they had a few days off, and that they shared resources they discovered that helped them forecast.

Benefit of Social Interaction: *When forecasters are able to interact with peers and experts they figure things out faster.* This category was distinct in that it more clearly captures the contextual aspects of social interactions. Direct learning captured the engagement itself.

Forecasters began learning from experts around them. In a few cases, the experts were distant—on internet discussion boards or issuing forecast products.

Mike, Forest, Lisa, and Tyler all spoke of learning through the NWS Area Forecast Discussion product, among other things; Tyler and Jordan mentioned wanting to be able to do those some day. In most cases, it was the structure of the workplace that provided the social environment that participants cited as critical for a majority of their learning. The eight forecasters in the NWS cited the structure of their workplace because it had a mix of many levels of experience in any particular office. One of the private companies was an open workplace that clustered desks; it was designed to encourage interaction while working. The design was effective because forecasters had knowledge to share. In contrast, another private company had no breadth of experience. The design of the physical space was not mentioned; in that particular company, forecasters on shift together had non-overlapping responsibilities and no time to talk. They were doing everything they could to complete their duties on time.

Forecasters began engaging in peer learning as they became increasingly competent. The structure of the job usually helped facilitate peer learning; the last company mentioned being the sole exception. Jordan and his colleagues worked hard to identify and share resources and ideas with each other. Similarly, the younger forecasters in Cassie's office created new tools to support and improve workflow. Mike spoke of a particular class designed to make peer interaction a primary form of learning. In his current career stage he routinely collaborates with peers on projects, and enjoys constant, ongoing learning from peers at work. At a point identified by a few participants as around 3–4 years experience, forecasters began to become the expert who shared with others. Forest, Lisa, Raymond and

Henry found teaching others to be significant. Forest and Lisa found the shift to teaching younger forecasters a milestone in competence. For Raymond it helped remind him when various concepts applied—or did not apply well—to forecasting, and for Henry it was critical in maintaining competence for those who sometimes carried out his duties.

Categories that capture long-term learning strategies. Within the above contexts, forecasters identified two main types of long-term strategies, shown in Table 4. The distinction between these categories was in how the participants spoke of what they were doing. When they employed a strategy they knew others to have used, the strategy was coded as simply **strategy to learn job:** *forecasters develop approaches to learning their job that help them succeed*. Some strategies were described differently, and coded as **create strategy to meet a goal**: *forecasters are conscious of creating their own strategies to meet goals because their situation is unique.*

There are many common **strategies to learn the job** that young forecasters engaged in. These were sometimes quite deliberate, such as Tyler identifying things

Table 4: ***Categories that Capture Long-Term Learning Strategies***

Major Categories	**Proposition (if developed)**	**Dimensions**
Strategy to Learn Job	Forecasters develop approaches to learning their job that help them succeed.	deliberate actions to listening to learn
Create Strategy to Meet Goal	Forecasters were conscious of creating their own strategies to meet goals because their situation was (or felt) unique.	

he wanted to learn and then educating himself on those topics, and Cassie practicing severe weather forecasting by forming her own expectations for weather in other parts of the country and then watching to see what happened. Every participant mentioned some type of review to figure out what they missed (which was a category in itself; see next set of categories). This strategy was employed in hopes of not missing the same event again, or broadening their understanding of how to forecast that particular type of weather. All public sector forecasters were involved in teaching each other, either from their job specialty or their assigned focal point duties. These are common learning strategies. Slightly less common were that Mike, Raymond, Forest, Tyler, and Lisa reported reading as one of their means to learn, while a few young forecasters said reading was insufficient to apply knowledge at their stage. Lisa, Tyler, Forest and Henry had instances of remembering others' experiences and applying them.

Somewhat in contrast, forecasters sometimes highlighted **strategies they created**, that they framed as unique to their situation or being of particular significance to them. Younger forecasters sometimes felt they had to create strategies to learn the job and understand the science, at times without help. Forest's employer had no training program. After a harsh 6-month review, he formed a strategy of working through training modules and reading other materials on his own time. Cassie had neither time to take advantage of training resources, nor much help from forecasters in her first office, so had to reflect on how she learned best and essentially convince others to help as she needed. Jordan's company had won a contract with a client they hoped to impress by advancing the forecasting services.

There was an expectation he and the other young forecasters would innovate beyond what they were learning from the company that lost the contract. They tried to do so. Shawn created a new way to display data after figuring out what he had failed to consider in a forecast that failed. Tyler was forecasting something with a weak knowledge base behind it. His strategy was to take careful notes on what he did so he could later determine the efficacy of his various (seasonal) forecast strategies. Forest's job demanded forecasts at more points than one could reasonably do on one shift, so he developed a strategy of grouping cities in ways he could focus on one and adjust to the others. Older forecasters like Mike, Henry, and Raymond focused on certain topics that most interested them, and figured out how to extend the science.

Categories that capture a sequence of shorter-term learning strategies. The above strategies, whether knowingly borrowed or portrayed as unique, helped forecasters in a long-term sense. In a shorter term and more immediate way, Table 5 shows a common string of events forecasters engaged in after a failed forecast. These **reviews to determine cause** could range from relatively passive efforts, such as when a younger forecaster followed others' efforts, to extensive, personal efforts that transitioned from merely being an event review to being a research project. This category is unbalanced toward missed events. When asked about this, forecasters said there was no story to tell when a forecast went well.

Forecasters reported it was usually easy to figure out what went wrong with a forecast. Forest, Tyler, Shawn, Jordan and Mike all had stories where they quickly realized what they had failed to consider once they reviewed the data. It was not

Table 5: ***Categories that Capture a Sequence of Shorter-term Learning Strategies***

Major Categories	**Proposition (if developed)**	**Dimensions**
Review to Determine Cause		simple to extensive; active to passive
Keying in	Process of figuring out what larger conditions lead to	no idea how to start to exploring plausible leads
Figure it Out	Forecasters can explain missed events when they have enough data or knowledge to put together the pieces. (A culmination of Review to Determine Cause)	successful or not

always easy to identify a cause for a missed forecast, however. Forest, Shawn and Cassie all told of instances where the review failed to resolve the cause of an event. In some of these stories they were still young, and so played a passive role in following the efforts of a more experienced forecaster who did the review. The more experienced they became, the more likely they were to successfully identify the cause of their missed forecast. Reviews could become quite extensive for middle career forecasters who were dissatisfied with the state of the art. Janet, Travis, Lisa, and Henry said they did event reviews, but did not a story describing one in our short time together.

Within the review, two categories captured the moments when learning was taking place. First, the effort to review an event involved **keying in**: *the process of discovering or finding what larger conditions lead to*. Second, if they successfully followed leads to key in on the causes, they could **figure it out**, and were able to learn: *Forecasters can explain missed events when they have enough data or* *knowledge to put together the pieces.* In some cases, forecasters could not figure out what caused an event, and did not even have a plausible explanation. The youngest forecasters did not quite seem to know what to do with these latter mysteries, but they could be a seed for major, longer-term learning efforts by middle career forecasters dissatisfied with the current state of the science.

The two tend to go together. In review forecasters sometimes said they could reason through what they knew, key in on the most important data and concepts, and figure out the causal mechanism to explain an event. They then used what they learned to help them key in ahead of time on similar forecast scenarios to figure out a good forecast. For example, in one recent instance Forest failed to forecast the persistence of marine fog. When reviewing the event he realized a dataset he did not often use would have provided needed information, and said he then incorporated that dataset into his forecasting approach. Lisa reported that her learning became progressively deeper as she approached a particular concept from different directions over time. The process of keying in was helping her figure it out. Shawn mentioned figuring out a way to key in ahead of time on the likelihood of thunderstorms becoming severe in his area. Raymond and Mike each worked hard to key in and figure out items they were researching (the details would likely reveal their identities). In order to do the above, forecasters may have merely noticed something, explored an idea, identified precursor signals to an event, or developed hypotheses.

Social interactions were very common for the least and most experienced forecasters. Cassie and Forest had stories of following the event review that an experienced forecaster did. They closely followed the progression of hunting for clues, and proposed ideas or asked questions of their own as they learned how to think about the processes that might have been at play. On the experienced side, Mike and Henry told of working with others to solve larger problems that worked to advance the state of the science.

Even with help of experienced colleagues, forecasters could not always figure out what caused an event, and certain forecasting situations remained difficult because of poor data. Mike reviewed available data and then researched several possible explanations as he reviewed data. Raymond conveyed that limited data in his area could make identifying a cause difficult at times. Both Raymond and Mike seemed able to leave an event review unsolved, though both also had stories where they went to great lengths to solve mysteries. Some forecasters seemed to prefer to identify a cause, even if feeble. Those with the weaker professional identities did not review events if they had a day off after a bad forecast. Jordan told of doing event reviews because a client demanded it, but this was similar to Cassie's

Table 6: ***Categories that Captured Initiation and Culmination of Learning Efforts***

Major Categories	Proposition (if developed)	Dimensions
See Connections	Through interactions with data, other forecasters, and the weather itself, forecasters see connections between book knowledge and real life, and begin to understand.	ease of connection; extent of facilitation by others; magnitude of the connection; whether it happened at all (no learning)
Beginnings of True Forecasting	Forecasting begins when forecasters realize associations between observations and future events.	

explanation that one event review was pursued to the extent that it was because the media covered the damage caused by the weather event.

Categories that capture initiation and culmination of learning efforts. Continuing along this string of categories, Table 6 shows the cumulative result of efforts like these. Going back farther, these, too, are facilitated by exposure to weather: **see connections** and **beginnings of true forecasting**. The first begins to expand the notion of simply figuring something out to include the social dimension integrated into forecasters' stories and this expansion is evident in this category's numerous dimensions. **See connections:** *Through interactions with data, other forecasters, and the weather itself, forecasters see connections between book knowledge and real life, and begin to understand.* This category has several dimensions: ease of the connection, extent of facilitation by others, magnitude of the connection, and whether the connecting happened at all.

First, the needed connection in knowledge could also be sufficiently easy that a forecaster made it on their own: as children Cassie and Lisa were excited when they connected what they had read in books to the weather they saw. Lisa later sometimes learned by reading Area Forecast Discussions and watching weather across the country. Forest realized why he had been missing overnight low temperatures when he read about a phenomenon that explained it. He had set conditions to allow this, carefully noting as many characteristics as he thought could be important. His observations made the connection to theory easy once he learned about the phenomenon. Alternately, connections could be difficult for a variety of reasons. Mike reported being frustrated with abstract problems—things that could never happen—in a synoptic course in college because they did not promote his learning. Such problems only tested whether he could apply pieces of an abstract line of reasoning. Tyler said that it was difficult to glean much from complex data he found online if it was not accompanied by explanation. Alternately, he learned much of his early forecasting techniques when online resources did explain and connect weather to theory. Finally, Raymond said that some training modules he has had to take emphasized a level of detail too specific to apply to another weather event; other modules reiterated only the very simplest, most basic concepts. Both made it much harder to learn anything useful. Most participants' stories involved difficulties, rather than ease in connecting pieces of knowledge. Connections were occasionally easy, but more frequently needed facilitation and effort.

Connections were often actively facilitated by another person: Simply by virtue of being around experienced colleagues when interesting weather happened, those colleagues helped these participants see connections by showing the participants and/or explaining what was happening in real time. Lisa learned while events were happening because others made a point to explain them to her. After Cassie transferred offices this also happened for her. Jordan and Janet, the only participants who experienced a formal, post-schooling training program, went through a period of intense, hands-on practice that allowed them to connect what they were learning to the forecasts they were making. And further, Jordan's mentor showed him how scientifically meaningful charts combining a certain set of parameters enabled him to quickly answer customers' questions because of what the charts revealed about the state of the atmosphere. Forest, Janet, Henry, Raymond, Shawn, and Tyler had particular subjects for which mentors actively helped them understand. While many participated in forecasting contests, only two participants reported having taken a forecasting course during formal schooling (synoptic meteorology courses are not the same as forecasting courses). For one, it was a graduate level advanced course where students engaged in deep discussions about weather and then had projects to investigate further. The course showed him a way to build connections between theory and real weather, resulting in a deep knowledge base he could use to forecast. For the other, professors deliberately integrated forecasting for the local area into several courses so the students could see and experience first-hand the weather they attempted forecast.

Next, the magnitude or significance of the connection varied. Some connections enabled a fairly thorough theory structure to finally become effectively connected to experiences forecasting, as Forest's example above. Forest also told of two smaller magnitude connections: during his childhood, he related barometer readings to current weather, and during his job, his mentor explained that a distant tropical cyclone was generating swells well ahead of its location and would generate waves higher than otherwise expected. Lisa constantly questioned details in data, leading to a variety of magnitudes of connections others helped her make. Sometimes connections were small, part of building the foundation of useable knowledge. For example, young forecasters avidly read a routine product issued by the National Weather Service called an Area Forecast Discussion, as well as Internet weather discussion boards, to build smaller bits that later became connected with other bits to more fully understand.

Not being exposed to the underlying knowledge, and thereby making connections while learning forecasting techniques may be devastating in its implications. Cassie, for example, was desperate to learn as she first started her career. She described asking every forecaster in her office how they forecasted various things. The other forecasters were shy and reluctant, but would share, prefacing their help with "well, I do it this way, because it is the fastest" or "I do it this way because it seems to work the best." There was apparently no accompanying explanation of the underlying science. Raymond wanted to improve his ability to forecast snow and was frustrated that another forecaster could not articulate what he was thinking as he looked at several parameters and decided upon a forecast snow amount. Three forecasters told stories of weather events they or someone in their office were unable to explain, leaving them with an implausible, weak explanation, likely misapplied, that they had heard somewhere before.

Seeing connections—no matter how simple the association—allowed for the **beginnings of true forecasting**: *forecasting begins when forecasters realize associations between observations and future events*. In other words, early experiences with weather sometimes allowed forecasters to do simple, near-term forecasts. Younger forecasters dominate the instances of this category most likely because interview questions focused on recent learning. These beginnings of true forecasting advanced as they learned. For example, Cassie went from trying to determine the intensity of an incoming squall line to forecasting the type of severe weather for that day. Lisa learned to recognize the weather changes that led to the southwestern US monsoon and would tell her mother about it. Another forecaster developed his interest in forecasting after realizing an association between a low pressure system and good surf. That quickly transitioned to anticipating good surf one or more days ahead of time by watching progression of lows across the Gulf of Mexico. Tyler, who began forecasting in high school, started by noticing associations between plots of current surface pressure and precipitation before incorporating more parameters into his forecasts. Finally, Forest, who began his career with little social opportunity to learn, carefully noted what he saw so he could associate weather observations with phenomenon. When he then saw, for example, precursors to Santa Ana winds in southern California the next year, he understood what was beginning to take place and could forecast appropriately.

Expressions of the self and relation to others. Although presented with some logic and hints at how they relate, the above were stand-alone categories as interviews were coded. They were presented in a way that provided some early hints at how these categories were related. See connections, for example, became the desired ending point of the model: seeing connections is the building of knowledge—the learning—that is needed to forecast. Within the evidence behind the above categories, however, are aspects that foreshadow the remaining categories. The categories in Table 7 also emerged as strong in the unitized data. Further, when sorting and arranging the above categories, the following categories provided critical glue to make sense of how the others related.

Table 7: ***Expressions of the Self and Relation to Others***

Major Categories	Proposition (if developed)	Dimensions
Expression of Interest	True interest manifests itself in actions.	primary or secondary interest; broad/general to specific/deep
Affirmation by Others	Others affirm you when they ask or choose you to fill a role.	critical to shape identity and resolve to less important yet apparent
Unwelcome	Forecasters persisted through being unwelcome when they were determined to succeed.	(a specific counter to affirmation)
Interaction External	Through interactions with others, forecasters learn what others value and need.	particularly motivating to a background consideration
Sense of Professional Identity*	The magnitude of a forecaster's sense of professional identity is echoed in proportion through their emotions, actions, and reactions.	strength and completeness of the identity

*The central category

Four categories touched into the affective domain: **expression of interest**, **affirmation by others**, **external interaction**, and **sense of professional identity**. All four were sufficiently saturated to develop a provisional rule during sorting. **Sense of professional identity** became the central category and is covered last.

Expression of interest: *True interest manifests itself in actions*. Expression of interest manifested in actions—or lack of actions—in adulthood. This category was found in childhood learning stories as well. Five participants had a particularly strong interest in weather before majoring in meteorology in college; four others had interest in weather and science more generally. Of the former, Mike had been interested in storms since he was a baby and related stories of pursuing weather topics throughout his school years; Tyler looked at weather online, participated in weather forecasting discussion boards, and found a weather-related job at a local science center; Lisa and Cassie read books about clouds and weather and related intense excitement at observing the same types of clouds and storms they had read about; and Forest visited his grandfather's farm daily to see what the barometer was doing. Other actions included reading, conducting science fair projects, and actively attempting to forecast the weather. Four participants described a childhood interest to a lesser extent. They also took some actions based upon their interest in weather: Jordan did several weather projects with 4-H, Janet's dad brought home a weather book from a business trip, Travis realized weather could be more than forecasting on TV by watching the movie Twister, and Raymond started noticing what the weather was like on days with good surf. These latter four had interests less focused on weather; not as strong as the first six mentioned. For example, after doing weather projects with 4-H, Jordan moved on to several animal projects, Janet and Travis were interested in science in general, and Raymond's initial interest was his hobby. One participant retained strong memories of weather from his childhood. Shawn's family had moved often, giving him wide-ranging experiences from blizzards to tropical storms and frequent summer thunderstorms. Only Henry stated he did not have a childhood interest in weather.

The type and nature of actions taken in adulthood varied across the eleven participants. Those at middle career stages were past the majority of the basic learning needed. Some used that capacity to engage in activities beyond those required for the job. Henry invested himself fully in his job, routinely going beyond what was nominally expected of him to engage in outside partnerships, collaborate with researchers, and identify and solve reasons for communication issues in recent events. Mike and Raymond both researched challenging forecasts, served as reviewers for journal papers, and pursued their own research. Shawn had many interests outside meteorology, so pursued less intense activities including making a point to engage certain user groups to gain insight into their weather needs.

Those in their first ten years initially struggled to learn the job. As capacity allowed, they increasingly they took actions beyond the job, revealing core, long-standing interests: Cassie and Forest shadowed their Warning Coordination Meteorologists during reviews of severe weather events, Jordan and Janet looked into adding business or economics degrees to move their careers into those directions, and Tyler continued to forecast short term weather in addition to his full-time job. Travis and Lisa mainly described pursuing the assigned focal point duties.

The category **expression of interest** has two main dimensions. First, the weather itself could be a primary or secondary interest, such as a means to support an outdoor hobby. The character of the interest could also vary from broad, somewhat general interest, to a deep, thoroughly engaged interest. The character could also vary from being focused on a narrow set of weather phenomena (e.g., severe storms) to interest in all types of weather. An important implication was seen from lack of interest in certain areas: little or no effort, even if the participant was very motivated in others areas. For example, Raymond had little interest in forecasting flash flooding, but was leading his office in figuring out how to deal with nuances in forecasting severe weather.

Five of the first participants with a strong interest in weather as children had become known as the weatherman or weather girl because they had taken actions based upon their interest in weather. Friends, parents, and teachers asked them what the forecast was going to be. The affirmation they received from others during their childhood had an impact on their motivation and career choice, and helped to cement their sense of professional identity. All eleven are found in the next category, however, regardless of childhood interest. No matter the age, having their interest **affirmed by another** was meaningful: *Others affirm you when they ask/choose you to fill a role.* This category is more than the interaction. It is fun, affirming, and sometimes a happy surprise to be the one asked or chosen.

Participants said that how others reacted to them helped shape their identity and resolve, particularly early in their careers. Two participants had some resolve despite affirmation being misplaced or late in coming. Janet's friends like her career choice and thought she should "be on TV." She said to them it was the "holy grail" for a meteorologist. Forgiving the misunderstanding, she appreciated their support. Travis's parents became excited about his career choice as they learned more about it. Most participants were affirmed clearly and readily. One of Tyler's former professors took initiative to email him the notice for what became his present job because it was a good match for Tyler. Early on the job, Forest, Tyler, Henry and Shawn benefitted from what they saw as personal, high-quality mentoring. Lisa and Cassie described older forecasters responding to their questions, and sometimes taking initiative to share explanations and insights with them. Mike said his lack of success in storm chasing during college became a joke among friends, leading to his current conservative forecasting style: he had seen—first-hand—dozens of ways weather could fail to come together to produce tornadoes. A few participants spoke of affirmation regarding their developing skill. Jordan reported he could often send a specialty forecast without it being checked. Shawn transferred to a forecast office that had just received its WSR-88D radar and found his new colleagues willing to immediately take advantage of his knowledge. Janet has gotten a very positive reaction from a local business college, who says her interests are in high demand at the moment.

Older forecasters were not as cognizant of affirmation affecting them at their current career point. However, the concept remained apparent. Raymond liked to collect cases for training, and his training officer has allowed him a lead role in that aspect of maintaining competence in his office. Henry actively collaborated with colleagues within and outside his office, enjoying the productivity of those interactions. Mike clearly enjoyed the role he has as a researcher-forecaster, clearly feeling accepted and integral to the profession in multiple ways. Shawn specifically agreed to participate in this study because he cared deeply about his profession.

Affirmation was a powerful concept: when others' reactions to Cassie's early learning efforts were in conflict with her own sense of what her competence should be, she felt a great deal of distress. In a related category, **unwelcome** was when *forecasters persisted through being unwelcome when they were determined to succeed.* For Cassie, this eventually led to a transfer to a more supportive office that has been a significant emotional relief. Tyler resisted accepting jobs in another part of the country before finally hearing of a good opportunity within the area he wished to live. For Mike, it meant persisting through a college curriculum meant to "weed out" those with poor math skills. For Raymond, persistence translated into a series of strategies to better forecast snow amounts. A few forecasters had stories of others retiring instead of dealing with the transition to the graphical forecast editor several years ago.

All eleven participants included either stories or description of how interactions with people interested in forecasts helped them see a role to fill. This is similar to the "professional role" from Henry's interview. This led to identifying a category called **interaction external:** *Through interactions with others, forecasters learn what others value and need*. As children, these forecasters wanted to help childhood friends who were interested in or afraid of weather. As adults, they were mindful of what was most important to their users. Henry, Raymond, Mike, Shawn, Forest, Lisa, Shawn, Travis and Cassie all spoke about interactions they or others in their office had had with emergency managers, pilots, departments of transportation, native peoples on tribal lands, and cooperative observers to better understand the impact of weather, but it was three of those working in the private sector for whom customer interactions were strongest. Those interactions with customers helped them understand the meaning and value of their forecasts, which was particularly motivating for learning. Tyler thrived on it, and Janet and Jordan were considering pursuing advanced degrees in business or economics to better understand customer's needs. Overall, knowledge of how users needed weather information appeared to vary in salience for the participants, from being particularly motivating to a background consideration.

The Central Category. A forecaster's **sense of professional identity** emerged as the core category. This category relates to all other major categories and is central to the emerging theory. It meets the criteria first set out by Strauss (as cited in Corbin & Strauss, 2008): it appeared frequently in the data; is abstract, logical, and consistent; ties other concepts together; grew in depth as the categories were related to it; and is sufficiently abstract that it could lead to a more general theory if studied in other substantive areas. Its absence in learning theories considered at the outset may mean this study is generalizing and extending the others.

All participants spoke about their work as if it were part of who they were, as is apparent as their own words emerge. In Raymond, Henry, and Forest's stories it was a strong underlying notion. Raymond had internalized the profession of forecasting, despite having spent several years in research first. He was particularly interested in severe weather, and spoke of the successes of his office as his success, too, even if he was off shift. Henry took his role very personally, referring to himself as something like the specialty kicker brought into a football game. Forest defined several of his key actions as being "as a forecaster" does, placing himself into that group. The others were even more explicit about their identity. Cassie also placed herself within a particular group when she referred to herself as a "huge weather dork." Shawn would often watch the weather and recalled the experience of a particular thunderstorm that helped him focus upon who he was: "This is something I want to do." When the fit was right for them, it also felt right to them—consistent with their sense of identity. Tyler asserted that "getting into meteorology was just a natural thing," and Lisa's focus on warning coordination was "just a natural" for her. When it was natural, it was very meaningful. After describing how her job was a good fit for her, Janet said,

> I don't think we take into consideration . . . how much weather is affecting people financially. We just think about tornado outbreaks and when it's going to snow or when it's going to rain and it's so much *more* than that. It's *so* much more than that. And it's so *interesting*.[3,4]

Mike placed himself in a particular class of forecasters: he noticed early in his career that certain forecasters "had more of a blended research and operational mentality that I liked." Finding the place where the sense of identity fit opportunities was sometimes difficult. Jordan knew he did not want to pursue a master's at a certain school because the program emphasized research. "I just don't want to put the time into it," he said, before describing other options he was considering.

For those with the strongest interests as children, the sense of identity began during childhood, as discussed earlier. Dimensionality on the sense of identity included the extent to which their reception from others was congruent with their desire to be a forecaster (addressed within the category **affirmed by others**), how encompassing the sense of identity was, and the extent to which their identity was congruent with their current or desired state.

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[3] *Quotations were edited to remove extraneous phrases that might identify speech patterns of particular people. Words in brackets clarify referents or replace specific information that would identify someone.*
[4] *Emphases reflect how she spoke.*

Several participants had a strong, encompassing sense of identity. Cassie felt a thrill when watching weather. "I'm one of those," she laughed. Mike and Tyler had intense "passion" for weather. Both said they had been interested "for as long as [they] could remember." It was an interest Mike said "wouldn't go away." Lisa knew her interest went as far back as childhood, and of her adult life she said, "when it comes to warning coordination . . . that's me. I'm just that way. . . . I think it [warning coordination] was just a natural for me." Jordan expressed why extent of interest can be so important: "if it's something that really interests me, then I'll dig in until I can find the answer. But if it's not something that really intrigues me then I'm like, okay, whatever."

Others expressed their realization of a sense of identity that was not completely congruent with their current or desired state. Shawn thinks of himself as "more of a concept person" than one who thrives on the mathematics of the science of weather. Outside of work he said he prefers to engage in other pursuits, and tries to lead a well-rounded and balanced life.[5] Janet also has a somewhat mixed identity, as evidenced by a pattern of interest beyond the forecast itself; in adulthood her interest is focusing to the framing of weather impacts upon users. The last clear example is a conflicted identity in Travis, who is not doing things he defines that someone like him would do. He expresses partial interest, like Raymond, who is "not a winter person" and has trouble learning about it. "I've always been a convective person," Raymond said.

[5] All participants had outside interests; deliberate pursuit of balance was only articulated by Shawn.

Relating Categories to Each Other

> Just remember that doing qualitative analysis is an art as well as a science and that there is nowhere in the analysis where this is becomes as apparent as in the final integration. (Corbin & Strauss, 2008, p. 274)

The processes of grounded theory meant that several types of categories were identified despite my interests being focused in cognitive aspects of learning. All category types could not remain uncoded or ignored. The interview questions about learning yielded many categories that dealt with cognitive aspects of learning. They were found throughout the data. Affective aspects of learning were also found throughout the data and were integral to participants' formative and current learning, as well as to their career choices.

The presence of affective categories in this study helped raise several questions that may have been less apparent without them. First, do the findings of this particular line of inquiry require additional balance by studying the experiences of forecasters who were clearly capable, but felt unwelcome and left the profession for that reason? It may be challenging to identify potential participants in part because any individual has multiple reasons behind decisions, but finding such participants would help test that portion of the emerging theory. Second, every organization is comprised of a range of competence. Do less competent forecasters have more potential they could achieve if given better social support? To what extent can lower competence be attributed to a lack of affirmation from others that would have helped them learn how to think about forecasting, and to continually learn day-to-day as weather evolves? Affirmation plays a role in learning. During the earliest years affirmation was important for learning, even when initially absent. This line of questioning could drive an independent, related line of research. These categories also raise questions about the role of the affective when learning could ultimately—at the moment of learning—be considered a cognitive endeavor. Were these aspects of learning less apparent in other studies by how other researchers asked questions or approached their studies? If the questions asked in this study had been more tightly focused on a particular type of weather and the act of forecasting, would the stories have focused more on the cognition itself, without regard to the role of others in learning? To this second question I feel confident in saying the role of others would have been just as apparent, in most interviews. Ironically, the three forecasters that spoke of their learning as if it were a slightly more solo endeavor still had strong social aspects to their learning. They simply tended to speak of their accomplishments in a personal rather than a collective way. The social aspects were revealed through follow-up questions that probed their stories.

Working toward theory: the progression in understanding. In working toward identifying the emerging theory, I looked across forecasters' stories as I was considering what they were learning to do. Figure 2 shows a progression of understanding that is seen most clearly by looking across stories of those with differing time-in-service, but Raymond stated this general concept directly:

> Probably the most basic change would be in the early years,
> everything was based on analogs, and pattern recognition,

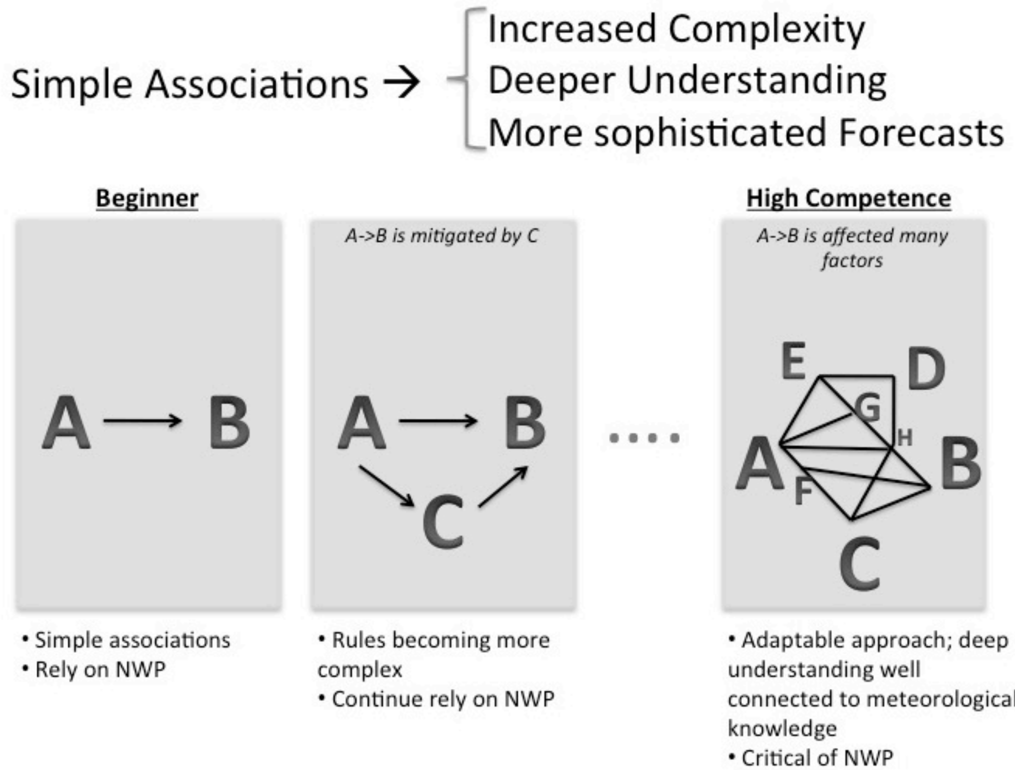

Figure 2. How forecasters described progression of their understanding

> because that's all I had. I didn't have the broader understanding. I have become a little more knowledgeable in the dynamic processes and I can apply that to a pattern and not always come up with what I might have come up with without the dynamic understanding.

Because the essence of this diagram was not explicitly sought in interviews, the underlying idea was confirmed with two forecasters who were not participants, who conveyed instances where they were able to increasingly connect knowledge of the science to their forecasts, thereby deepening their understanding of exactly why simple associations worked. That allowed them to move past a point where they had to rely on the association, but they continued to consider the association in a deepened understanding of the weather. They did not believe their thinking processes while forecasting had fundamentally changed from the associations they had first learned—but their forecasts had become far more sophisticated.

There are many simple associations beginning forecasters hear when they are first learning. An accessible example for readers of this study would be the saying: "Red sky at night, sailor's delight. Red sky in morning, sailor's warning." That simple association, that red at night (A) leads to sailor's delight (B), is based upon the general tendency for midlatitude weather systems to move from west to east. High moisture content in the air due to incoming storm systems can cause a red sky in the morning. In contrast, the dust and clouds of departing weather systems can cause a red sunset. This analogy fails rather dramatically, even at midlatitudes, if the storm system is a westward-moving hurricane. A non-participant forecaster confirmed this association–to–deepened understanding idea, and provided a forecasting example. He had learned that the magnitude of the pressure gradient at 850 mb was a good proxy for forecasting strong and gusty surface winds. The stronger the pressure gradient (A), the stronger and/or gustier the winds at the surface (B) would be. As he learned more, he began to understand why that association sometimes worked, as well as when it failed.

Every participant had at least one example of deepening understanding. Forest initially had large forecast errors in high temperature forecasts along a coastal area where marine fog events occurred. His errors became smaller as he learned some fundamental aspects of fog formation, but still had to learn and understand the nuances of how fog dissipates. In one example he mentioned that clouds did not clear completely, moderating the high temperature below what it would have been had the fog completely cleared. Cassie described beginning to learn the nuances of strong winds. As she was beginning to understand how to forecast them, she came across an instance where the winds were not going to be strong, despite the pattern seeming similar to her. Another forecaster explained the nuance to her to help her understand. All other participants had similar stories. Raymond and Shawn both missed forecasting severe events because of subtle changes in instability. Travis learned that instability had now become a nuance whereas in his first forecasting location essentially any instability led to severe weather. Henry and Mike both worked at better understanding subtleties in order to extend their ability to do their job. For younger forecasters, these subtleties were a significant challenge to learning: Lisa continued to look for subtle features after discovering some very meaningful ones.

Looking across participants' stories, there were differences in the extent to which participants relied on and trusted numerical weather prediction (often referred to as "models"). The young forecasters had an insufficient knowledge base to do much else, but quickly learned that models were prone to being incorrect, especially when it mattered most. While forecasters were first beginning to realize the exceptions or nuances of associations, they generally continued to rely upon the models until their understanding was sufficiently complex and deep for the models to become one of many pieces of information to consider and make sense of when forecasting. Raymond illustrated much of this when describing how a younger forecaster asked him what number he looked for in the models for a particular parameter. He told them he did not use any one number, which he described as baffling them. He explained that the value depended on the larger scale of weather that day, and was never a hard, fast number. But a young forecaster does not have the knowledge base from which to do what Raymond admitted was almost an art.

Entry to the profession. Diagramming for the emerging theory helped identify relationships between several categories through identifying a common experience for the five participants who had particularly strong interest during

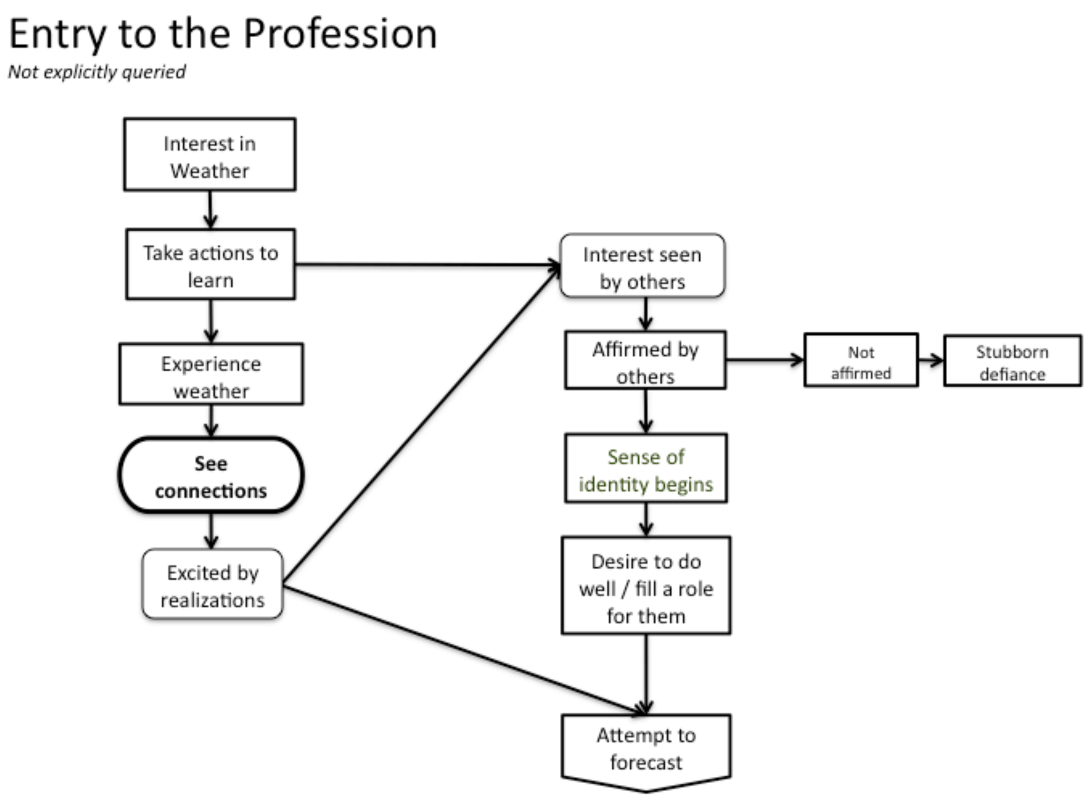

Figure 3. Five participants had similar childhood experiences with pursuing an interest in weather that others recognized and affirmed. Shapes are used similarly to a flow chart. Rectangles with sharp edges indicate a code. Rectangles with rounded edges indicate an explanation that connects boxes. The oval is a termination point: learning. The pentagon indicates that additional information comes into or out of this diagram at those points.

childhood. They pursued that interest in some way, as described earlier in the category "expression of interest." Those actions led to excitement when they experienced weather first-hand and realized the connections between what they had read and what they had experienced. Their interest was persistent and noticed by those around them (right column of boxes in Figure 3). Teachers, parents, and friends began calling them the weatherman or weathergirl and asking what the weather was going to be like. That affirmation by others began a **sense of identity** they were pleased with. Tyler's kindergarten teacher told his parents she thought he would be a meteorologist after he routinely cut the forecast from the paper and took it to class. He said, "I'm being honest here, for as long as I can remember, I've always loved the weather. So me getting into meteorology was just a natural thing." Mike said he had been interested in storms as long as he could remember, and, "It probably gave somebody a clue that I was always doing my science fair projects on tornadoes every year." I could still feel Cassie's and Lisa's excitement when they related some of their first experiences seeing connections between what they saw in the sky and what they had read about. Lisa thought she was around 9 or 10 when she saw a rare tornado for her area:

> I was always looking at clouds and telling myself that those types of clouds brought rain, this type of cloud formation was rain. And I knew, of course, what tornadoes and stuff looked like. I was always reading stuff about the weather, about tornadoes.... There was actually a tornado that touched down [nearby] back then.

> And I saw this. I was sitting there in my front yard and I climbed up the tree and saw the great big supercell out there, and you could actually see this thing rotating. You could see the rotation and everything in it, and I said, there's got to be a tornado close by! ... And sure enough, they had put out a tornado [warning]...

These five participants developed a deep sense of identity related to their profession during their childhood. Cassie's sense of identity was partly expressed in how she gave prelude to her actions with what they meant to her: "Well, you know, me being a huge weather dork, when we'd have pretty bad weather I'd go outside and I'd look at the clouds."

Others around these five asked them to fill a role for them, even as children. Mike and Forest both said they began forecasting because classmates started asking them what the next day's weather would be. Mike and Forest had nearly identical statements, with Mike saying, "Well, if I'm going to answer questions like this, I better actually try to figure out how to forecast!" Tyler got a high school job with a local science center and began forecasting. His boss noted his interest and skill and let him update the center's web site forecasts. With Cassie, interest was more than helping her friend. For Cassie, her role became a deep and meaningful part of a friendship:

> ". . . my friend was *so* scared. That I just took it upon me to try to calm her fears . . . I felt a strong urge to comfort her in whatever way I could. . . . I guess that kind of fueled my interest . . . in something I wanted to learn more about [anyway]."

Cassie continues in this role today: "Even into our young adult lives, she's still looking for answers from me. It's kind of fun."

Affirmation was not always received. Off to the side of this diagram there are boxes that describe how someone with a strong identity might persist despite not being affirmed by others. Mike had always done his science fair projects on tornadoes: "Until the year they told me to change topics. And so I went to hurricanes." Later, in college, he aspired to go into research, but struggled with mathematics. He persisted through his degree and graduated. This may echo a progression of learning events for some participants during their professional years as well, as described later.

The Emerging Theory

> *Lisa:* I'd probably say 30%, yea, a third. I'll go with a third of the pie chart is probably coursework. And then, half the pie chart is actual experience. And then that other little sliver that's left would probably be about the modules, and other types of coursework, things like that, whether they're online.
>
> *I: The continuing development, rather than the initial?*
>
> *Lisa:* Right. Correct. Right. So yea, I guess that is about a third of it got me started. And then a good, at least half of it, I would think is just the constant interaction, the real time seeing things that pieces it together for me.

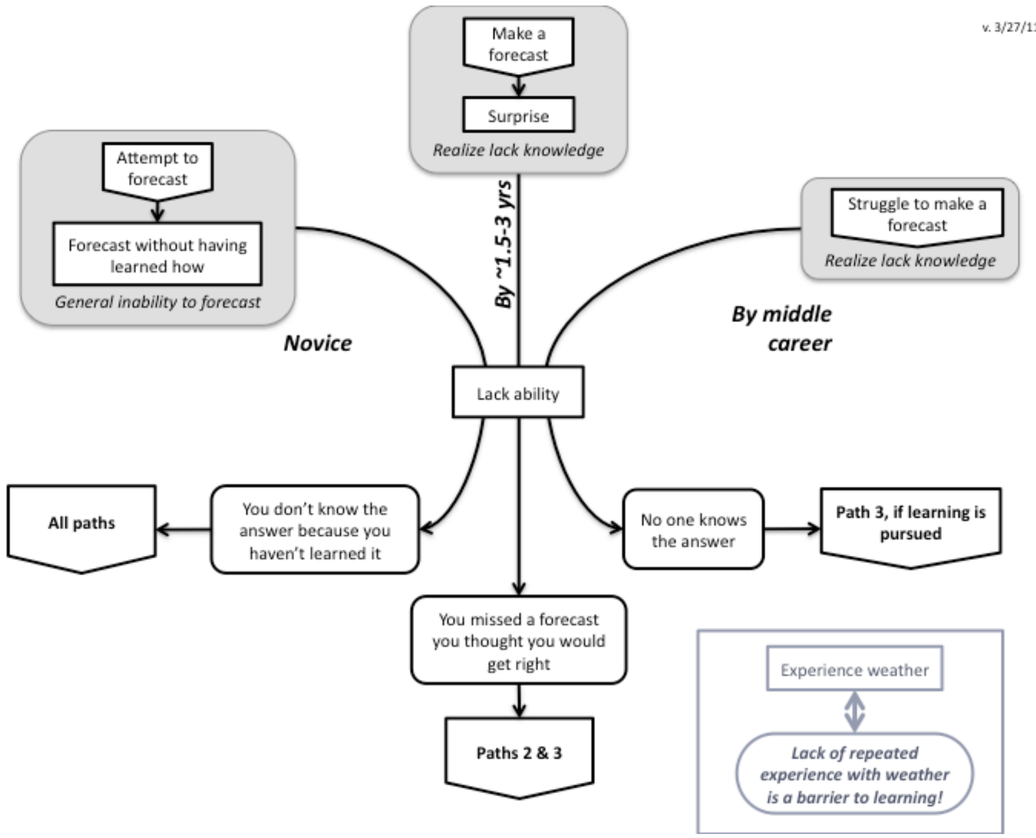

Figure 4. Common triggers for learning at various stages of a forecaster's career. Shapes are used similarly to Figure 3. Shaded gray boxes help distinguish three starting points to this diagram.

Triggers for Learning at Different Career Stages. Figure 4 is a prelude to the emerging theory. It illustrates characteristic ways that learning cycles begin at different stages of a forecaster's career. The diagram is simplified in that when someone first begins forecasting a new phenomenon they become something of a novice.

Novice forecasters began on the upper left of the diagram and looped through the left side: they nearly all found themselves attempting to forecast without having learned how. Lisa felt her schooling left her ill-prepared to forecast. She "met all the qualifications [to be a forecaster]," but, she explained, her school did not "have people instruct you and show you the different features and have people instruct and show you the different things that are happening that you've learned [about]." Cassie and Lisa both reported that their public sector offices were short staffed, leaving little time to work through training resources for forecasters. Their duties did not initially involve forecasting, but Forest's private sector employer had no training program. Jordan, Janet and Tyler were fortunate to work for companies that provided formal training, or focused mentoring, during their first weeks on the job. Travis was the only young participant to feel somewhat prepared for the job, explaining that his college was oriented toward forecasting and had integrated forecasting exercises into several courses.

Learning tended to be triggered differently for those with 1.5–3 years experience, and followed a path straight down through the center of Figure 4. Once participants gained competence on common processes and weather types, their learning instances shifted to times when something unexpected happened. For example, Forest said that by the third year he could recognize precursors to several phenomena that had major impacts on the weather in areas he forecasted. His learning then shifted to be caused by surprise when a forecast went wrong. For example, through his own learning, and a tool a senior forecaster had created, he could forecast marine fog reasonably well. He said, however,

> Nine out of ten times its gonna verify. There's that one out of ten times when it doesn't. . . . That's when you have to go back and look at all the data and try to figure out what happened. That's when you learn and improve as a forecaster.

Lisa was interviewed at four years experience, and had entered this phase. She mainly learned from surprises, and regretted missing discussions that took place immediately after events she had forecasted, after her shift ended. Jordan's interview centered around a period of his forecasting life when he had about four years experience with one type of forecast, and had shifted to a new one. The new type was a shorter-term, more time critical forecast. Still, he believed he gained most of the competence needed after six months. One of those months was spent working directly with an experienced forecaster, and afterward he worked with a mix of experienced and inexperienced forecasters. Jordan did not cite the need for exposure to the full set of seasons that most forecasters did, but he was only a partial novice at that point in his career.

Forecasters can find themselves at a novice stage for a new phenomenon they have never heard of and do not understand. Lisa described that she was still occasionally learning major constructs that were not taught in school, such as Q-vectors.[6] Some forecasters had begun to use the parameter, but she was still learning about them. This may be similar to Shawn, a middle career forecaster, who reported not knowing about a midlatitude instability concept after having worked in a tropical location for many years. These two examples put a forecaster partially into a novice learning mode because the knowledge was relatively common and could be somewhat easily obtained. It differed markedly from the middle career forecaster

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[6] Q-vectors are a mathematical, rather than meteorological construct. The divergence of this parameter indicates synoptic scale vertical motion.

who encountered difficulty forecasting something for which an understanding was either uncommon or did not exist.

By middle career forecasters were not surprised very often at how the weather unfolded after making a forecast, and stories tended to focus on instances where they struggled to make or implement a good forecast. In other words, instances where they were dissatisfied with the state-of-art. Henry spoke about collaborative efforts to improve the data and tools that helped him forecast. Raymond and Mike each told of cases where their offices consistently did a poor job at forecasting something. For Raymond, it was forecasting an event type that was unusual in his area: "It's pretty rare that we anticipate a tornado day. We're just not seeing the signals. They're pretty subtle. I'm hoping I'm getting a handle on it now." Mike told of acting on two types of problems:

> "What usually guides studying a type of event. . . [is that] I don't want to make the same mistake again. . . . And so it's almost always a specific [event] . . . but [I have also studied] a persistent forecast bias."

These data suggest not all forecasters became *strivers,* advancing the state of art. And the extent to which they engaged in such activities might be dependent upon the collusion between a strong sense of identity with social affirmation, as will be discussed later.

Whatever stage they were at, the realization that they lacked ability usually caused forecasters to review an event to try to figure out why the weather evolved differently than they had forecasted. The extent to which they engaged in such investigation varied primarily by how much time they had and how difficult it was to figure out what went wrong. Time was a challenge to learning for every participant. Experience with weather was also critical to forecasters' learning. No two weather events were exactly alike. If any particular type of weather was rare or infrequent, the forecaster did not have opportunity to learn.

Learning Processes: The Emerging Theory. One of the greatest challenges of researchers employing grounded theory is to decide upon the focus of the emerging theory. For this study, a total of 101 stories were identified as having sufficient detail to identify how and why learning occurred. Of those, 95 grouped well and were chosen as the focus of the emerging theory. The remaining are addressed in the next section. These 95 stories described learning with moderate to high degree of complexity, and are the basis for the emerging theory (Figure 5). There are three paths, clarified in Figure 6. All paths begin at the upper left, with the variety of triggers noted in the preliminary diagram that showed how learning cycles begin (Figure 4). In this figure there is no dependence on time in service; the three entry points there are generalized to 1) a general inability to forecast, and 2) the realization something is not known. Stories that traced a path through the leftmost boxes to the ending oval Build Knowledge represented situations where learning happened relatively quickly. The right two paths took longer to trace, and sometimes ended without learning (bottom right). Forecasters with some experience could encounter a general inability if they started to forecast a new type of weather or moved to a new geographical location with new local effects driving the weather there. Figure 6 is a simplified version of Figure 5 to make clearer that participants described three basic learning processes. Young forecasters began with a general inability to forecast, as did more experienced forecasters who were now dealing with phenomena they had not forecasted before. The realization they did not know something could trigger learning, no matter their time-in-service or experience with a phenomenon.

Path 1: Being taught: strong support from experienced forecasters. Forecasters benefitted a great deal when experienced forecasters chose to help them learn the job. This path describes learning when the forecaster was not prepared to

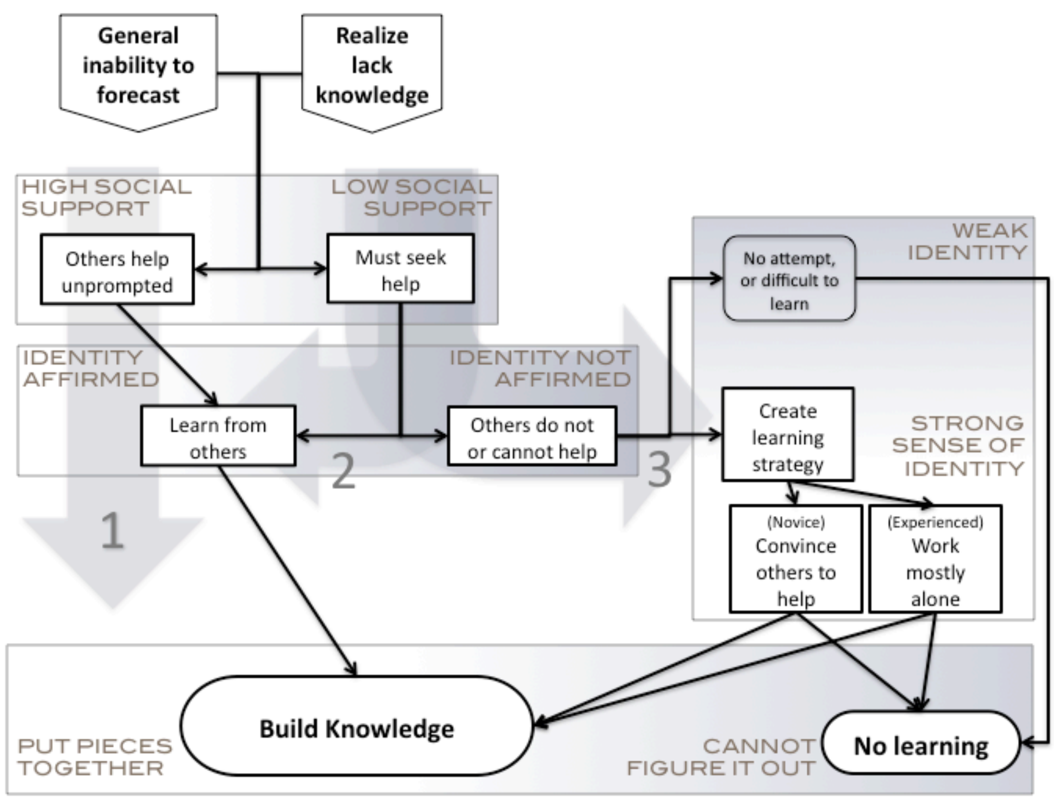

Figure 5. The elements and relationships representing a preliminary theory of how meteorologists learn to forecast. Shapes are as in Figure 3. Gray boxes indicate codes with variation built into the theory.

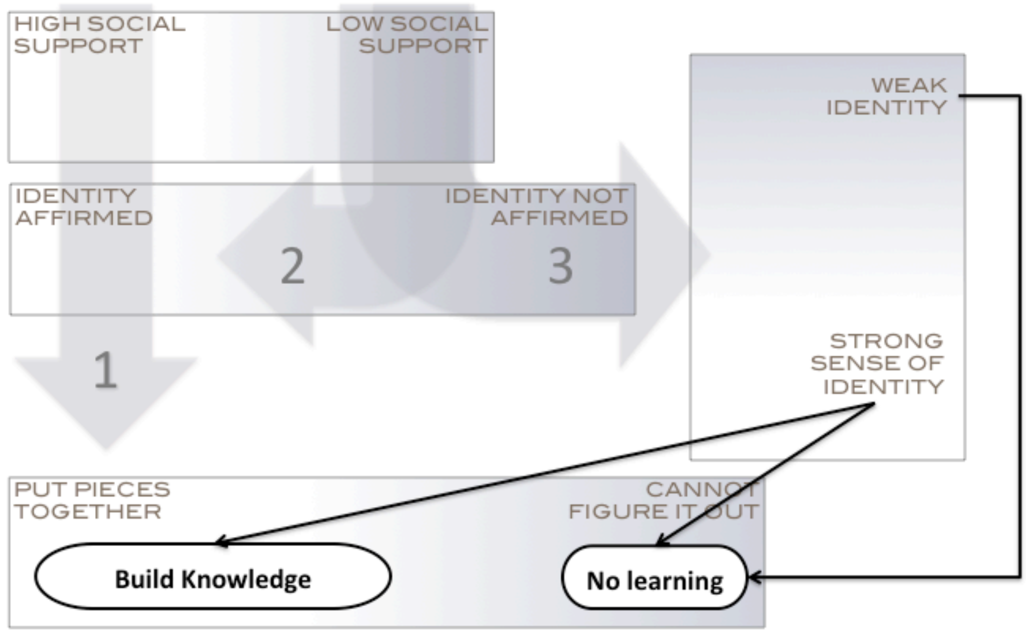

Figure 6. Simplified diagram to clarify common learning processes. Compare with Figure 5.

do the job, or an aspect of the job, and others initiated the learning interaction. This path ends in a useful knowledge structure of weather and the appropriate processes to access and use that knowledge effectively if the experienced forecasters themselves have useful knowledge structures. This path *can* end there, because others could—and did—help them learn.

All but one participant described mentoring interactions that fall on this path. In Janet's first job other weather observers were retired forecasters. They taught her how the observations they made were related to upcoming weather. Raymond initially was assistant to the forecaster in his first job, and learned his initial forecasting techniques from him. Then Raymond emulated his boss when he first took over the forecasting duties. Tyler described a similar interaction, though with more deliberation: he was hired to replace someone who was retiring, and that person focused most of his attention during his last few months on helping Tyler learn the job. Henry and Lisa reported learning how to think about the data and the forecast from several veteran forecasters in their first offices. They implied or specifically spoke of multiple mentors. Shawn and Forest both spoke of particular mentors who helped them develop a deep understanding of marine meteorology by telling them stories and explaining nuances. Unlike the four just mentioned, Cassie experienced only minimal mentoring in her first job location, but then enjoyed a mentor frequently initiating interactions in her second one. Jordan had a particular mentor for a few weeks when his company won a contract to begin a new type of forecasting; like Tyler, the job transition was structured that way and the experienced forecaster shared readily. Mike focused most of his stories on recent (mid-career) learning, but described a lasting impression from an early interaction with an experienced forecaster he had long admired.

Participants were keenly aware of how valuable these interactions were: This learning both resulted in a deeper conceptual understanding of weather processes and ability to more quickly focus upon the most important data and processes for the particular situation. Janet said that despite her degree in meteorology, in her time as an observer she "actually learned about cloud types and how they had to do with airmasses, and how they had to do with fronts." She reported that her mentors helped her get "used to looking up at the clouds and . . . [figuring] out what the weather was going to be like from there." Raymond spent his first year learning what forecast elements mattered for the day from discussions with his mentor and by and listening to the mentor's weather briefings. Tyler and Raymond both had a smooth transition to their first forecast job because of their mentors, quickly moving into Path 3 strategies (discussed later) to develop their abilities further. Jordan's mentor taught him how to think about impacts of weather on the client, and showed him ways to build weather maps that would help him quickly answer the client's questions. Henry and Lisa described learning a lot about processes from veteran forecasters around them as they first started out. Cassie is now learning quickly. She said, " I can expect—every time I'm on shift with this person—that I'm gonna learn a whole bunch of new things. And it's awesome!" Forest explained why these interactions are so valuable: "the older forecasters. . . . know things, they have seen things, they recognize things a lot quicker than you do." Shawn illustrated both knowing and seeing in describing how his mentor explained, then told him to observe interactions between wind-generated waves and swells. In part by learning how to carefully observe, Shawn quickly learned and better understood the resulting impact on marine activities from surfing to boating. Finally, part of why a particular veteran forecaster had such a lasting impression on Mike was that he found out that this person, whom he had long admired, was from the same area he was, and as Mike put it, they "clicked right away." It was a very affirming interaction.

This learning path is relatively fast. Forest said most of his mentoring on marine meteorology took place over a three to four month period, whereas when he learned on his own he needed at least a full year to begin to recognize repeating weather patterns. Tyler also stated that seeing repeated weather patterns was important in his relatively isolated position. Now that Tyler's mentor is retired, Tyler is learning in a less efficient way (discussed in Path 3). But he and Raymond both had a smooth transition to taking over a boss's duties because they were mentored directly into the job. Jordan reported a similar time frame as Forest after mentoring, gaining most of his competence within five months. Cassie found that instead of being confused and requiring some time to figure out the nuances causing strong winds at certain locations in her second forecast area, an experienced forecaster explained a subtle phenomenon. Lisa also quickly overcame a forecast challenge when someone explained a local phenomenon models did not capture. Henry simply asserted that "a lot of veteran forecasters" were "really helpful," so that he could "learn a lot faster" how to overcome problems, and learn forecasting techniques in general. Path 1 may describe interactions long past the early stages of one's career, when forecasters routinely share their complementary knowledge bases. Henry is at a middle career stage now, as is Mike, who spoke of an effective synergy in his office: "We talk about events often at work, especially those of us who've been there for at least 10–15 years, and know each other really well, and know each others' interests."

Lisa and Forest, at three to four years in their current location, found it meaningful that they had become the mentor. Lisa said, "To me it's just important to pass it on . . . of mentoring someone else. But it's something I learned the same way." For Lisa it was a certain subtle weather feather that affected forecasts in her area. "Otherwise you don't pick it up, you don't see it," she explained. For Forest it was his new knowledge of marine meteorology. Forest reflected,

> Now I know, it's kind of strange, because I've been here for four, or, what, three years, almost four, and now we have newer forecasters in our office that are young that don't know marine meteorology. We've had three new people come in since I started. And [the experienced forecaster I learned from is] gone. And now I am telling people the same thing he did. And so it's kind of weird how it moves along.

Everyone learning through this first path is being affirmed, but it was not clear whether that was as notable to them as it was for stories that are described by Path 2. For two forecasters, there was a clear lack of opportunities to learn in Path 1 that helped illuminate the underlying lack of affirmation. As she was first starting, Cassie sought to develop her forecasting techniques. Without mentors, however, her approach was to shadow "as many forecasters" as she could. She was distressed to note in their body language that they were often unwelcoming. The affirmation from others in her second job was in stark contrast to her first, which had been incongruent with her own sense of who she was and how fast she desired to gain competence. Travis also reported indiscriminately shadowing all the forecasters in his office. Both expressed a sort of desperation to learn all they could as quickly as possible, and neither reported having a mentor in the office where they were using that strategy. Cassie later had better mentoring, but Travis did not describe being mentored after leaving school. That does not necessarily mean he did not experience mentoring; it was not part of the stories he told.

Path 2: Seeking help: the benefit of social interaction. Path 2 is similar to Path 1, but describes learning where the forecaster sought help from others. In many cases, it was a general inability; in a few, it was a specific gap in their knowledge of forecasting. Unlike Path 1, they did not find themselves being mentored. They had to seek help. In all but one case the forecaster was affirmed in these interactions.

Sometimes forecasters knew they had a general inability or were still developing their forecasting ability. This realization led them to seek help and ask questions. Cassie explained that the marine aspects of their forecasts were particularly difficult for her: "I don't have the experience of living by the ocean to really understand how it affects the area. And so I constantly have to ask." Cassie did not feel affirmed in these interactions, but all the others did. Raymond benefitted a great deal by his reception in a National Weather Service forecast office collocated with the lab in which he worked. Recall that he had initially begun forecasting by emulating his predecessor. As he learned more, he said, "I looked at more." He began to visit that forecast office routinely. He said, "I would actually walk around and talk to talk to [them] when I was putting together my forecast for the day." He learned a lot through those interactions. Janet also found help from others readily available. "There's always somebody that can help," she said when describing how she would ask questions of fellow forecasters. Forest said he had sought help at his first NWS office and emphasized how to learn from experienced forecasters: "You just ask." Travis did this as well, before having to work as a warning forecaster. He first had other duties, but would watch what the warning forecasters were looking at and ask them why they issued the warnings they did.

Afterward he would monitor which forecasts verified. Jordan was specifically paired with a veteran forecaster. "He knew where I was coming from . . . that I didn't know anything about what they did and I wanted to see their systems," he said, and that helped how his questions were received. Tyler also learned generally about weather from others, but in one of his stories it was while still in high school. The interactions were through an Internet discussion board. He said, "I started [learning how to forecast] by reading weather service discussions and by reading one newsgroup in particular. I was just reading what people had to say." He explained how this was so effective, as well as that it had an affective component to him: "It was reading from people who knew what they were doing and having the desire to be able to do that myself."

Participants also had specific instances that led them down this path. Those learning events did not necessarily take long, but the path involved more steps than in Path 1. Of the story below, Lisa said, "It took all of, what, 10–15 minutes at the most." It was a learning opportunity, but also an affirmation. The older forecaster reportedly said, "You're seeing something, you're picking it up but you're not exactly clear on what it is. Let me elaborate a little bit and tell you what is causing this," thereby affirming her. Lisa was describing how she had noticed a cloud line on the satellite image, curious what was going on. By the end of this story she had explained that no one coming into their office forecasted precipitation correctly in this type of instance because it was a local effect of the geography. She learned through direct interaction with the older forecaster:

> He said, let's take a look, let's take a look at some things. And we were looking at dewpoints, temperature. We looked at the upper air observations and everything, and went ahead and did just a real quick analysis, looked at the streamlines that we drew, vs. what the model streamlines were showing on AWIPS. And, ah, yea, we just took a look at it and he says there's a 700 mb trough here, and he said, that's just something really important to look at. Just pay attention to features like this, especially when we do have an upper level feature that's moving through, we can have these little troughs that can linger back here.

For Shawn, it was realizing he did not understand a specific way of thinking about midlatitude instability. The particular construct had not been covered in his coursework, and he had recently worked in a more tropical environment where it was not a factor in forecasting the weather. After seeing the construct in a few forecast discussions, he wanted to stop "pretending" that he knew something about it, and "[asked] somebody who might actually know about it." The other forecaster complemented him for asking and explained it in a way that made sense to Shawn.

When middle career forecasters sought help, Path 3 usually described their stories because they tended to be learning to stretch the state of art. One example clearly falls here, however, because help was readily available once requested. Mike would sometimes seek detailed information on a particular type of weather. He would "email [someone][7] or talk to [those] who've done work in that area" to ask them where he could find more information. He concluded, "And then once they tell me, I can find it and read it. We help each other out that way. And that's good."

Path 3: Need to learn, but help not readily available. This is the longest path and captures what participants described as their most significant learning events. Initially others did not or could not help, and the forecaster was conscious of creating a strategy to learn. Younger forecasters created strategies to learn how to link the science to the forecast and to do the job, while experienced forecasters created strategies to extend the science or build upon their ability to do their job. About half of Path 3 incidents involved others, regardless of time-in-service. The remaining involved the forecasters' own resourcefulness in an apparently solo effort. Tyler was the only young forecaster engaging in solo efforts. All but one forecaster described some of their learning efforts as if they had created the learning strategy themselves. For five of the participants, Path 3 led them to increasing their own knowledge and ability to do the job. For four others, the story involved stretching the science or their ability to do their job well. Tyler described doing both simultaneously. Two forecasters had no stories coded here. These efforts sometimes resulted in no learning.

In the first set, where a forecaster needed to expand their own knowledge and ability, stories ranged from how they dealt with general inability to how they created a better way to do the job with existing science. Cassie's story below illustrated the former when she wanted to learn more about marine meteorology in

[7] Names removed to protect anonymity.

her first office. Others in her office apparently had a different expectation of what it took to learn:

> I knew I learn best if I can apply my knowledge . . . [Our marine focal point said, go through these modules and they should help you a lot. I [said] well, it’s not necessarily going to help me. [So I said] if I do these modules and then if we sit down and talk about it . . . and show me . . . I’ll learn a lot better and I’ll be satisfied. And so we did that. And I feel a lot more comfortable with . . . the marine side of the forecast now.

The marine focal point was referring to training modules developed by the NWS. Another common way of learning in NWS offices is by practicing forecast or warning situations in displaced real time. Lisa, however, was still questioning many things and had not yet developed an ability to quickly discriminate what to focus on in given weather situations. Of those practice sessions she said, "I don't like to do that. If I'm going to go back and review something I want to do it at a little bit slower pace and be able to ask a lot of questions as I go through." She explained, "Because there's things that I see on there. . . . I might see [little features] . . . or some detail I'll pick up." She needed time to clarify what to focus on, and to "cement" concepts. Forest had even greater learning needs than Lisa or Cassie in his first job, which was in the private sector. He was shown his desk and told to start forecasting. When questioned about that he reiterated, "I had no formal training there. They just, boom. They said, go ahead." Forest's strategy was to go out of his way—on his own time—to learn all he could about forecasting from publicly available training and library subscriptions to books and journals that dealt with weather in a practical way.

In this path, learning also involved improving one's ability to do the job. Shawn told of creating a new way to visualize instability after failing to correctly forecast a severe weather outbreak. Jordan's company was sometimes asked for a non-routine forecast for which they had no models or data prepared in advance. He and his colleagues searched the Internet and Jordan was one of several who led the creation of a collection of links and resources for data and model output that they might need again.

Tyler had to both create his own strategies and extend the science because of the unique type of forecasting he does: seasonal climate applied to agriculture. Because the ability to verify forecasts is delayed by several months, he has had to create strategies to learn:

> One thing I think I've done . . . a good job at . . . is making sure that I save and document work that I do. So, the next year, when . . . the forecast comes around again, I'm not starting over from zero. I'm starting where I left off. And hopefully I will have . . . made a good forecast to begin with, but if I didn't . . . hopefully I will be able to learn from my mistakes and figure out, maybe there were some flaws in my original reasoning.

There are a few other meteorologists in his company he talks with as well. At another point in the interview he pointed out that there is much yet to learn about seasonal forecasts. He knew the larger scientific community was also interested in this type of forecasting, and looked forward to the state of the science advancing.

Middle career forecasters were advancing the science or their ability to do their job better through their learning in Path 3. The three middle career participants had slightly different manifestations of the path. Mike actively stretched the state of the science through research that he published. Mike's interview centered on his investigations of a particular severe weather event that deeply intrigued him. He was eventually able to answer many of his questions about what had happened and why, but only after digging deeply into several topics, and collaborating with others on aspects of his investigation. By the end of the interview, he had related three learning stories that used this same strategy. Two of his stories were triggered by particular events that bothered him. The third story was an ongoing irritation with poor forecasts that eventually motivated him to "just go in there" to figure it out. Unlike in those stories, he explained that it is usually easy to figure out what went wrong with a forecast.

Henry's focus for learning in this path was building upon his ability to do his job by better understanding his particular, local forecasting challenges. "When you get out into the field," he said, "you can see the lay of the land and all, just how water comes off particular hills, how it goes and drains down toward a particular city." Complementing that, he also built relationships with the emergency managers and other people in the local communities. This was one of a few strategies that helped him understand the nuances of flooding, and the only one that clearly fell here.

Raymond told two stories in this path. He was interested severe weather, a particularly difficult forecast challenge for his region due in part to poor data. Forecasting severe weather in his area was also difficult because low population density may, as he was discovering, mask the occurrence of tornadoes. Although much of the effort was his own, he had spoken with forestry officials to learn about instances of tree damage. He was in the process of figuring out how to better forecast and identify tornado occurrences in his area. In a second story, he related that his strategy of actively reviewing paper submissions to scientific journals sometimes led to new forecast strategies to try. Through that involvement in the leading edge of the science of meteorology he was improving his own understanding and ability.

Mike and Henry—the middle career forecasters—had examples where they could not figure something out, but were not expecting to do the work themselves. Mike was particularly keen on his own strengths and how those complemented others. With one particular mystery he had identified, he said:

> So I started thinking something was going on in the boundary layer. I'm no expert...but something is going on there. So we [put our observations out there]...in hopes that someone would grab ahold of that and . . . try to figure it out. . . . That's an example of a case where I didn't do that project myself because I didn't have that in my area of expertise. . . . And that happens fairly often.

Mike's strategy in cases like the above is to carefully delineate what he is seeing and why he thinks it is a mystery, then leave the work to someone else. He will go so far as to publish this type of research that delineates problems, thereby participating in the larger scientific world from a forecasting perspective. Recall Mike had once aspired to be a researcher, but was discouraged by his poor performance in mathematics courses while pursuing his undergraduate degree in meteorology. In another example, Henry had to figure out how to solve a problem that one collaborator was uninterested in helping with:

> There can be a particular city where the hydrology is so complicated within this area that, say the US Geological Survey won't put any gages in there just due to the complex nature of the hydrology because they have certain criteria where they locate their gages.

Henry had to rely on others and a different strategy to solve that problem.

It was particularly challenging to young forecasters when others could not or did not help them learn. The knowledge needed to forecast the weather is extensive and complicated. It is difficult to learn without someone helping you learn how to think through complex processes. Sometimes the challenge was the situation the forecaster was in, such as the private company with high turnover. Forest said, "So I'd be following up from the day person. The problem is, the day person only had about, I think he had eight months experience on me." Other times it was simply the overwhelming nature of having gigabytes of data in front of you with little idea how to sort out what was important. Lisa said, "I was looking at everything with one of the forecasters that retired. . . . We were looking at everything and he started pointing out some of the things in the satellite observations." Cassie put it this way:

> And there's one person here in particular who does that [initiates mentoring] a lot and I *love* it! [laughter] Because I don't always have to seek out what's, you know, what I'm not doing correct. And, 'cause, half the time I don't know.

To this I had responded, "Well, yea! You don't know what you don't know sometimes!" I paused at that point, then added, "A lot of the time, you know?" To which Cassie gave an emphatic and exasperated, "Right!" She seemed relieved that someone finally understood how she had been feeling. Most participants described struggling with connecting their formal schooling to the application of forecasting. In this first set of participants, Tyler may have been the only exception, crediting his extensive efforts to learn before school as laying a context in which to connect the formal knowledge more easily.

As just shown, forecasters with the strongest senses of identity not only persisted through these challenges, but created an apparently effective learning strategy.[8] In that strategy they eventually needed to rely on others to some degree to learn. Sometimes they had to almost force someone else to help them to figure it out, see connections, and learn.

Returning to the proposition that identity plays a strong role here, Raymond, Janet, and Travis's cases support this notion. Raymond had a strong sense of identity for forecasting severe weather, but then self-identified as being poor and uninterested in two others types of forecasting. This appeared to inhibit his learning. He pointed out that a meteorologist's schooling does not include background

[8] Note that quality of their learning was not independently assessed.

knowledge relevant to one of the tasks. On the other, however, he had a strategy in mind. He said,

> I do not do as well as other people in the office on wintertime snow events. But we have one or two people that are quite good. I would love for them to teach WES cases[9] about how they forecast snow so I could learn from them.

Similarly, Janet is clearly engaged in her work. It was surprising not to find learning in this path. The topics she brought up that might fit here, however, did not contain sufficient how/why. Those topics included her realization of natural talent to mitigate risk and related career goal to add a business degree to her weather knowledge. Her professional identity has solidified to something she hopes to become engaged in soon.

Finally, Travis's conflicted identity raises questions about how one's sense of professional identity interacts with social support for learning that may not be well captured in this model. Travis did not speak of having a mentor, and the Science Officer in his current office was initially unavailable. He described asking questions of older forecasters, but not of them initiating explanations. None of his stories described particularly complex learning events or of deep engagement in thinking about weather processes. Recall he felt his schooling had prepared him reasonably well, but it is not clear that it was actually the case. Perhaps he desired this for

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[9] "WES cases" are weather events presented as a simulation on the Weather Event Simulator workstation. Forecasters work through these cases under guidance of another forecaster that is acting in a teaching role.

himself, but was unsure how to proceed with what might actually be a weak foundation.

Returning to the diagram for one last item, note that the far right bottom corner of the diagram illustrates that efforts sometimes ended with no learning. As already shown above, Mike always collaborates with others on projects, but despite this usually effective strategy, is sometimes unable to figure things out. Cassie and Forest each had a story of an event that someone else in their office missed and the office failed to figure out why. Raymond was still working on strategies to become more proficient at winter weather forecasting. All forecasters in this study, regardless of how strongly they identified as a forecaster were bothered by these occurrences. Those with the strongest identities took the most extensive actions to learn.

What the theory does not address. Participants only briefly acknowledged learning that was triggered externally, such as by altered biases in numerical weather prediction models or new software updates. They instead chose to focus on a more significant topic, the one I had raised when inviting them to participate: learning how to forecast the weather.

The majority of incidents involved social interaction, and this realization during the process of collecting data led to asking for examples of learning that were completely asocial. To this question even Mike, a resourceful forecaster with a very deep and complex knowledge structure who actively reads scientific literature and strives to push the limits of his ability to forecast, said,

> It's hard to think of any specific examples right now. Almost every [learning incident] . . . has involved, maybe the initial spark curiosity was [something] I noticed and wondered what is that, and I better go check it out. . . . That's probably as close as an asocial experience as I've had with something like that. But in the process of doing so I start getting with people and seeing what they have seen, and you know, asking [my friend], and asking others, . . . have you seen this before, what do you make of this, I don't understand it completely. So, in the end, if it doesn't involve some sort of social interaction right away, at some point it will before long.

There were five incidents omitted from the emerging theory. They represented a scattering of items that did not naturally group with the others. Those writing about grounded theory point out that the complexity of life results in this circumstance, and to report on it so the reader can assess the researcher's decision to omit them (Corbin & Strauss, 2008). These five incidents were mixed between childhood and job, and involved much simpler learning than the challenge of learning to forecast. The two stories from childhood were Cassie's early interest in watching weather videos and reading weather books, and Lisa calling the NWS public telephone line to hear the forecast. In adulthood the omitted stories included Travis looking up a forgotten term, Tyler being honest with himself about why he missed a forecast, and Forest's "ah ha" moment of finally making a connection between his experience and something he was learning. These were included in coding and preliminary diagrams, so may be familiar to readers. Stories often had multiple aspects of learning, so other aspects of some of the stories were included in the emerging theory.

Next steps

The immediate task was to compare this emerging theory with prior research into learning. Several constructs had been identified at the outset of this research (see Chapter 2) that were intriguing and could now be seen in a new light. Other concepts were identified that merited investigation in the literature to see what other researchers have learned. These include professional identity and the role of affirmation from others.

Summary

Analysis began on two of the first four participants, selected because they varied on pre-conceived ways that the forecasting task might vary: type of forecast, environment being forecast, and time-in-service. Two coding approaches yielded similarities but also pointed to stark differences in learning for the two forecasters, one early and one middle career. Data collection progressed to a total of eleven forecasters, and a new approach to analysis yielded a broad set of categories that touched into both cognitive and affective domains. In the end, complementary insights were gained from the variety of analytical tools employed.

A central, repeating theme about a strong sense of identity with their professional role as a forecaster was consistently important to how the participants engaged in learning, particularly when they were poorly supported and had to create strategies to learn. A second, strong theme emerged: learning was faster, forecasters were happier, and their resulting knowledge was better connected and more thorough if participants had good social support. Building useful knowledge structures was greatly helped by hearing how other forecasters were thinking about the weather and how they used data in different situations.

The emerging theory explains that forecasters built useful knowledge structures faster when their internal sense of identity as a forecaster was affirmed by others. Forecasters were more likely to persist through adverse work conditions and poor social support if they had a strong sense of identity, going so far as to create their own strategies to learn. In nearly all cases, those strategies involved essentially forcing others to help them learn.

This primary set of data led to a preliminary set of elements and relationships characteristic of a theory about how meteorologists learn to forecast the weather. Chapter 5 will discuss the result of comparing this emerging theory with existing literature. The original constructs included in this work will be reexamined and additional literature will be sought that better addresses the notion of one's identity and how that impacts learning. Questions that arose during this analysis, and additional questions raised through the comparison with literature suggest directions to take this work.

Chapter Five

Introduction to Triangulation

To increase confidence in the research findings, this chapter discusses how this study was triangulated. First, comparison was made with the experiences and observations of forecaster learning by four managers responsible for training forecasters. Quality of the study was then judged by its consistency with literature about forecasters. Empirical studies and published reflections were both used. Finally, results of this study are compared and contrasted with a look across the landscape of literature in adult education and related fields. Similarities and differences with these sources of information about forecaster learning are discussed, as is what this study adds beyond what is already in literature.

Comparison with Training Officer Reflections About Learning to Forecast

Quality of the data and findings were triangulated against information from discussion with four individuals involved in forecaster learning on the job. The results of this study were not shared. Instead, these individuals were asked about what they saw taking place. Interviews bring out what is most prominent on the interviewee's mind, and may not reflect the totality of their views (Patton, 2002). Three were Science and Operations Officers, hereafter referred to as simply Science Officers, for the National Weather Service. This is the position responsible for training the staff in each of the local forecast offices, regional centers, and national centers. Science Officers are to spend at least one third of their time developing, delivering, and facilitating staff training not already offered through the three training branches of the NWS and through COMET. Science Officers are responsible for honing forecasters' abilities. One Science Officer served in that role for a national forecasting center; the other three for local forecast offices. Two of the Science Offices had worked at some point with one or more of the participants in this study, but this was not revealed to them. One private sector manager was also queried; he did not have contact with any of the private sector participants.

Each person emphasized different things about learning. Some of their perspective was driven by their context. The first two Science Officers worked in similar positions in local NWS forecast offices, but the third worked in a national center that nearly always hired experienced forecasters from within the NWS. The private sector manager spoke about aspects of aviation forecasting that the NWS does not do.

The first Science Officer emphasized that much of forecaster learning was from mentors, and that most learning was informal. Although experience was a wonderful teacher, it was an inefficient one. And if experience was the only teacher, people were going to get hurt as a result of bad forecasts or missed warnings. Thus others' experiences helped younger forecasters learn faster. He had identified two of his senior forecasters as being the best in his office, and had asked one, in particular, to mentor new interns.

He also spoke of encouraging all forecasters to fulfill a role within the office, drawing the analogy of a softball team. He provided opportunities for differing specialties to develop, and facilitated each forecaster's growth into a role. He said that expertise was to be grown, managed, and seen as a resource. Each expertise would eventually be needed at some critical moment when confidence was necessary to make a bold forecast. He noted that his best forecasters were service oriented, and focused on the impact of weather. They had good appreciation of the science in three and four dimensions, and could think in different time scales. They expended their energy on important things rather than on tenure. The poorer forecasters thought more linearly and simplistically.

The second Science Officer emphasized that while there was a lot of training available, what forecasters really needed to learn was abstract thinking and how to deal with conflicting information. As he expanded upon that topic, he pointed out that young forecasters absorbed what they saw in older forecasters. Included were idiosyncratic (not empirical) strong beliefs, and unproductive and unscientific forecast techniques. He speculated that I had probably seen a mix of old and new in my interviews: The NWS forecaster's role was changing as forecasters moved increasingly toward decision support to core partners (National Weather Service, 2010). Forecasters were increasingly attending to activities they did not do in the past, such as providing decision support to emergency mangers that had come to understand and value weather information when handling any type of incident.

The Science Officer for a national center was responsible for training the forecasters that had been selected for transfer from a competitive applicant pool. One of the difficult things for them to learn was how to change their mindset when expecting one type of weather but another occurred. Because he knew that was particularly important for their role in the NWS, he deliberately chose cases for training that forced forecasters to work through that type of situation.

He had a few additional observations about learning. He had personally experienced that the same weather could come together in what seemed an infinite number of ways. He said this after, and in spite of, a long and overwhelmingly successful career. He apparently felt that each forecaster in his office was successful, because he saw their differing approaches to forecasting as an asset during training. He valued that they learned from each other during training simulations. He also mentioned that regardless of how a forecaster considered data, there were times they had to return to—or discover—an empirical basis for the weather in a particular region or at a particular time of day. He had led some of these studies himself, motivated by a deep desire to improve the state of art.

Finally, a private sector manager emphasized that it was difficult to create and maintain an aviation forecaster training program because his company had little turnover. They were also challenged to accommodate learning on the job because they maintained limited staffing. The Federal Aviation Administration had strict regulations that affected training and forecaster behaviors. For example, continuing education was required for all forecasters, and there were regulations regarding what information pilots may use to make flight path decisions. Unfortunately, this conversation did not become any more specific than as described.

The observations and experiences of these individuals are largely consistent with this study. My study verified the observation that on-the-job experience was an important means for learning, but insufficient by itself. Certain types of weather were infrequent at any one location, and if a forecaster was not aware of the underlying phenomenon he or she continued to miss forecasts when that phenomenon drove the weather. Thus, forecasters needed to learn from others. The vast majority of learning stories collected for this study involved others, and forecasters did not apparently know how to discern whether that learning was of quality. My study also verified the notion that the NWS forecaster's role is changing, though it was not central to their stories so outside the scope of the emerging theory. Younger forecasters mentioned differences between younger and older forecasters. While they learned meteorology and forecasting processes from them, they also knew to rely on their younger peers for certain other aspects of learning the job, such as help with new software tools. The observation that forecasters needed to learn how to change their mindset when expecting one type of weather and another occurred was also verified. There were stories of events where the forecaster or someone else in their office did not recognize a changed weather outcome, nor adequately respond. Alternately, there was one story of successful reaction to surprise. It is an important skill to learn. My study suggests that one way to learn this skill is to miss events and desire not to miss another.

Regarding the idea that forecasters who used the most complex thinking were also service-oriented, this study detected differences in both what forecasters were learning and how they spoke about it. That information is suggestive of the quality and depth of their learning. Public sector forecasters talked foremost about dynamics of the weather itself, and secondarily about the impact of weather. Although I draw that distinction, recall that public sector forecasters were keenly aware of the impact of weather on their users, and had a deep desire to fill their role with outside partners. Public sector forecasts are not aimed at a specific user or user group, but must be applicable to anyone. The three private sector forecasters that had a single specific user's need to focus upon were close enough to that user to see, in an ongoing basis, what that user needed. The fourth private sector forecaster did not know how utility companies made decisions based on his forecasts, as that was tightly guarded information.

The experiences and observations triangulated against this study differed mainly in areas that this study could not capture well. Participants did not include any stories where they later realized something someone taught them was incorrect or unproductive. Some participants may not have been in a good position to evaluate the quality of learning from more experienced forecasters. Negative emotion regarding this type of realization could also affect participants' readiness to share such stories without me directly asking about bad learning.

Another difference with training officer reflections was in regard to NWS offices struggling with morale. One had thought such offices had lost their sense of group identity. The impact of lost group identity and poor morale could help explain Cassie's experiences in her first office: no one appeared to take much initiative to help her learn. On the other hand, Travis had been at two offices and appeared to have a generally supportive environment in both, yet he was not learning deeply. There may not be a direct correlation between learning and office morale or office identity, though one likely confounds the other.

My study added information to the observation that the most service-oriented forecasters were also the most complex thinkers. Because this study directly caught a service-orientation across sectors it was able to show how filling a role for external users was a strong motivator for learning: young forecasters quickly learned weather and the mechanics of the forecast if they could focus upon the user.

In summary, this study is consistent with the observations and experiences of those involved in training forecasters: the vast majority of learning is informal and from others, young forecasters may be unable to discern the quality of their learning, the role of the public sector forecaster is changing, and it is difficult to alter expectations when weather begins to evolve differently than expected.

This study differed in regard to the hoped-for impact of encouraging forecasters to fill a role in the office would help them grow and develop into those roles. While this study provided evidence that differing roles may provide middle-career forecasters with strong motivation to learn and grow, it did not provide evidence of such an impact on those still working to achieve competence. When younger forecasters spoke of helping others learn, it was regarding the same items they had had to learn when first moving to the current office rather than teaching something they had taken further initiative to develop.

This study also added information. One Science Officer observed that some forecasters appeared to think more simplistically, but could not explain why. This study provides evidence that those forecasters had a shallower engagement due in part to a weaker identity and poor social support to learn complex thinking. This study also added information, mainly from the private sector, regarding how strong mentoring and focus upon users may impact learning to make it far more efficient and focused.

Comparison with Literature About Forecasters

It remains that no studies have directly addressed how forecasters learn to forecast the weather, though a few additional studies beyond the three described in Chapter 2 were located that touch into what forecasters do. Some of those studies of forecasters discussed below were general, while some were specifically done using the construct of expertise. One was an ethnographic study of a particular forecast office not long after endemic problems led to a spectacular failure during a high-end tornado event; the office likely had a wide mix of competence.

Forecasting, or the "practice of futurework," as Fine called it (Fine, 2007, p. 126), is a challenge both because of the uncertainty involved, and the ill-structured nature of it: forecasters must themselves identify the problem of the day (Curtis, 1998; Pliske, et al., 1997; Targett, 1994); some forecasters identified that problem before going to work (Hahn, et al., 2003). The ones exhibiting behaviors of experts then formed preliminary mental models of the expected weather (Joslyn & Jones, 2008; Pliske, et al., 1997). Forecasters took either an intuitive (pattern recognition) or dynamic (logical analysis)[10] approach to their forecast decision (Curtis, 1998; Doswell, 2004; Joslyn & Jones, 2008). Doswell (2004) added a nuance from his

[10] Joslyn & Jones also identified two broad strategies, but identified the second as an analytic error-estimation strategy. Her research team observed two of the four forecasters carefully identifying model errors and then using those to adjust model output, assuming the magnitude of the error would not change.

many years of reflection upon forecasting and review of heuristics literature that forecasters fell along a spectrum between those two types. He also cited work to promote the idea that the first forecasters used a wholly intuitive process. When Stuart, Schultz and Klein (2007) noted that the human forecaster added value when complex heuristics—intuitive methods—came to a different (and correct) solution than model guidance. Klein Associates researchers (Pliske, et al., 1997) had previously identified five types of forecasters among the widely divergent group they studied, with the intuitive scientist being the ideal; however, only two of 40 military forecasters studied fit that description. Fine's (2007) unique sociological lens complements Klein Associates's. He suggested that the development of intuition is key: forecasters needed (accurate) gut feelings more than Ph.D.-type knowledge for what they do.

Many researchers initially presumed that forecasting expertise followed the 10-year experience rule-of-thumb. Most realized in the course of their research that forecasting does not follow that rule (e.g., Hahn, et al., 2003; Hoffman, et al., 2006; Pliske, et al., 1997; see further discussion in Chap. 2), but it is not clear if all did (e.g., Trickett, Trafton, & Schunn, 2009). The following qualities are from those studies that identified forecasting expertise; citations include consistent findings from the remaining studies. These studies included a range of types of forecasting, including general forecasts, short-term weather warnings, terminal forecasts for aviation, and synoptic scale heavy precipitation forecasts. The forecasters were either military or NWS. Some of the studies used a naturalistic decision making approach, meaning the researchers studied the forecasters in real operations (Joslyn

& Jones, 2008; Morss & Ralph, 2007). These studies found that expert forecasters were cognizant of the public impact of weather (Fine, 2007; Hahn, et al., 2003; Morss & Ralph, 2007), and their work contained a strong social component within the office as frequent conversations took place while formulating their forecast (Daipha, 2007; Hahn, et al., 2003; Morss & Ralph, 2007). Expert forecasters identified the main challenge of the day (Daipha, 2007; Joslyn & Jones, 2008; Pliske, et al., 1997), and thought deeply about the tools, information, and data coming at them (Daipha, 2007; Hahn, et al., 2003; Joslyn & Jones, 2008; Morss & Ralph, 2007). Forecasters often incorporated others' knowledge, experience, and interpretations into their forecasts (Daipha, 2007; Fine, 2007; Hahn, et al., 2003; Morss & Ralph, 2007), which Fine further articulated as enriching professional memory and allowing the testing of ideas. Forecasters at times added their own senses as well (Daipha, 2007; Pliske, et al., 1997), to build a mental model that was then checked and rechecked frequently as the weather evolved (Hahn, et al., 2003). Their understanding could be easily adapted to any request for information (Joslyn & Jones, 2008; Pliske, et al., 1997). They built their experience base from individual weather events (Daipha, 2007; Hahn, et al., 2003; Morss & Ralph, 2007). It was important to gain direct, immediate feedback from people as they were impacted, and to conduct postmortems to relate data and information available to the resulting weather (Daipha, 2007; Hahn, et al., 2003).

To all the above, and likely representative of the range of competence in forecasters he studied, Fine (2007) added a social and interpersonal context not directly evident in most studies. He asserted that forecasters relied on a set of knowledge claims based on their experience, intuition, subcultural wisdom, and scientific claims. When these conflicted, their authentic experience tended to prevail. As something of an aside, although scientific knowledge brought legitimacy to forecasting, Fine said it posed a status challenge to the role of the forecaster. And because theories were generated outside the forecast office they must be "invited" into the forecaster's world (p. 101).

Other researchers have alternate explanations or findings in regard to some of Fine's assertions. For example, Daipha (2007) noted a contrast with Fine's work, that nearly all forecasters in the NWS office she studied were involved in research, and further that their involvement was "intimately connected with the professional identity of the NWS forecaster" (p. 53). She also interpreted the competition between forecasters and computer models as not between theory and practice, but as reflecting of forecasters' deep desire to "produce the most accurate NWS forecast possible" (p. 79). And for that, forecasters exploited what models offered while attempting to improve upon them. Roebber and Bosart (1996) showed that experience had a greater effect on forecast skill than knowledge of the underlying science. If so, forecasters would be wise, rather than feeling threatened, to use experience before knowledge of the underlying science when those are in conflict. In context of that threat posed, Fine said forecasters nearly always altered any solution provided by models to assert their role. Morss and Ralph's (2007) data provide an alternative explanation: forecasters always tweaked numerical model output to add detail, such as with known effects of topography, that they knew models did not adequately capture. Note that Baars and Mass's (2010) study found that forecaster changes do not consistently improve upon models, which touches into the importance for this general line of research on forecaster learning, actions, and decision-making to advance to where it includes measures or independent perspective on the quality of learning. It also does not negate the broader importance of better understanding and facilitating human learning in complex domains.

Some studies distinguished non-expert forecasters. Non-experts relied on computer models, used a fixed set of procedures, relied on rules of thumb, had a narrow focus, failed to consider larger scale weather features, and often ended up reactive to the (unexpected) weather that evolved (Bosart, 2003; Hahn, et al., 2003; Joslyn & Jones, 2008; Pliske et al., 1997). Although Daipha (2007) did not address expertise, she noted that forecasters appeared overwhelmed with the task of working with the gridded forecast database to create their forecasts, something younger forecasters in my study expressed frustration with. Note that several researchers found that years of experience in forecasting did not necessarily correspond to expertise (Hahn, et al., 2003; Hoffman, et al., 2006; Pliske, et al., 1997).

Targett (1994), a forecaster with the Bureau of Meteorology in Australia, pointed out that several conditions led to individuals' unique approaches to forecasting: their understanding of the atmosphere, local knowledge, past experiences, and individual weaknesses in applying that knowledge to their forecast. Targett's observation makes sense in terms of how memories and knowledge are created. Few forecasters have identical experiences. Daipha's (2007) participants believed forecasting was idiosyncratic; she asserted, however, that this simplification neglected the thoroughly collaborative nature of forecasting in the NWS.

To complete this section, two writers have promoted visions for better education. Lamos (1997), in writing a concept paper for how professional development of forecasters should be designed, promoted focused training that was directly tied to what forecasters did. Forecasters must first be taught how to apply understanding of key atmospheric factors to the forecast, then to synthesize a large amount of information using tools provided. Lamos asserted that scientific understanding was necessary to evaluate models and other tools; forecaster education needed to help forecasters build a complex understanding so they could visualize atmospheric processes.

Doswell (2003) also provided a vision for improving forecaster education. He proposed a creative method for learning, suggesting forecasters would quickly gain a much deeper understanding of both atmospheric dynamics and model limitations if they could repeatedly change the input to locally-run models and see the resulting outcomes. In a different writing, Doswell (2004) promoted his own ideal about the duties and characteristics of what it takes to be a good forecaster. One of four primary duties was that all forecasters be mentors to incoming forecasters. Meteorological education would include learning how to mentor effectively. Among the characteristics he promoted were high-level visualization and conceptualization skills, a passion for the subject, and continuous learning.

This work is consistent with the findings of others in many ways. Young forecasters without dedicated training found the ill-structured nature of forecasting, along with the inherent uncertainty, amount of data, and complexity of tools overwhelming. Those exhibiting expert qualities were deeply engaged in the forecast, relating ongoing weather and their forecasts to mental models. They kept up with the state of art, and some of them pushed that state by doing research. They were cognizant of the impacts of weather. Those who had opportunity for social interaction generally took good advantage of it, though it was clear that not all around them were people they wished to learn from. They learned a great deal by experiencing weather and by reviewing bad forecasts. When particular types of weather either did not exist or were rare, they had trouble learning to forecast it well. Their own senses may also be at play, with two forecasters stating it was much harder to learn marine meteorology because they had never lived by the water and thus did not have any intuitive sense for it.

I did not collect detailed data on what forecasters do so cannot compare well with other aspects of researcher's studies. Forecasters in this study did not appear to be threatened by theory, as one researcher found. Neither did forecasters express opposition to or distance from theory. Most embraced it fully, and many actively read conference proceedings and journal articles. The forecaster on the forefront of seasonal climate prediction was in fact anxious for others interested in seasonal forecasting to help him advance his understanding of how to predict it.

My work differs from other research in identifying the interplay of the affective element of professional identity and whatever affirmation they received from others. A positive convergence of these constructs manifested as expert behaviors: those with the strongest senses of professional identity and good social support clearly had a passion for the subject, had developed deep, critical thinking skills. They continued to learn through their careers, including both after the occasional surprise of missing a forecast and a nagging dissatisfaction with the state of the art. Some of those with poor social support had trouble learning, but persisted if they had a strong sense of professional identity. Those with weak or partial professional identity were less invested and appeared to be learning a more simplistic approach to forecasting.

This work may not have captured the fluid nature of forecaster decision-making Curtis (1998) described. New information was constantly coming in to the forecaster's workstation, but participants did not appear to address this challenge outright. It is unclear whether learning to become a fluid thinker was embedded within their stories. Forest even stated that outside information did not alter one forecast when it should have: the cold temperatures at a televised NFL football game that made him aware—but he did not connect this to his forecast—that models were not capturing the strength of the cold air.

My research suggests the primary influences on forecasters' learning are the more experienced forecasters in their office, and sometimes a particular mentor. Formal continuing education has a role, but it appeared to be more important when social support was absent. Most of my participants reported that their formal science knowledge was organized for application to forecasting. The exceptions are Tyler, who was forecasting before he learned the science, and Mike, who had a challenging advanced forecast course that forced him to make connections. Travis also thought his schooling was relevant, but displayed simple, linear thinking approaches in his learning stories. For all others, the day-to-day learning from experiencing weather and keeping up with the ongoing live and displaced interactions through forecast products.

One of the greatest challenges to a forecaster is moving from a simplified understanding to a deeper one that allows them to grapple with nuances in how weather evolves. Forest, Cassie, Lisa, and others would likely take good advantage of an opportunity like Doswell (2004) envisioned of altering inputs to locally run numerical weather models. Likewise, Lamos's vision of providing the most "parsimonious" education was what Janet experienced in her training program, to her great relief and joy. In her dynamics course as an undergraduate meteorology student it was difficult to see the practical application, but of her training program she said, "it wasn't the fact that I knew how to derive something in that formula, but that I actually saw where the practical application fit in."

Comparison With Literature About How Adults Learn

At the outset of this study several literatures were examined that provided overlapping, yet distinct lenses. Few of those addressed affective dimensions of learning in much detail, yet that was dominant in the stories forecasters told for this study, resulting in a return to seek out new literature. Following are sections first briefly addressing the adult learning and expertise literatures considered in Chapter 2. The section closes with two new constructs: non-western ways of knowing and professional identity.

Expertise. Forecasting appears to be an area of expertise, though it also appears that with the crutch of numerical weather prediction even incompetent forecasters can appear somewhat skilled. Experienced forecasters in this study appeared to exhibit expertise. It is not clear from expertise literature how to identify potential for expertise.

Studies like Smith's (1990) seminal work comparing genetic counselors to faculty experts showed that characteristics of experts could not necessarily be defined by faculty behaviors. Fortunately, outside researchers did not attempt to do that with forecasters, but instead studied forecasters themselves to define the characteristics of an expert forecaster. Comparisons of forecaster expert performance with this study were discussed in the previous section comparing this study to literature about forecasters. As will be seen below, one model to explain development of expertise has stood some testing and remains intriguing.

Learning to become expert. Two topics are here: what determines conditions that lead to expertise and partial models to explain how one gains it. First, there was significant debate in the literature regarding whether deliberate practice or innate ability accounted for expertise. This study did not measure or address innate ability, but does capture aspects of deliberate practice. Though small in number, these participants made rapid gains through the convergence of strong professional identity and strong social support and affirmation from others. It is not clear in this work what role innate ability might have, though all participants successfully completed a difficult undergraduate degree.

Second, I had reviewed two partial models that attempt to explain development of expertise. This study supports Alexander's Model of Domain Learning (Alexander, 2003), perhaps more so in light of later studies where she and others distinguished situational interest (interest in the tantalizing, but necessarily core information for a domain) from individual interest (deeper, longer standing interest in the general domain; Alexander, Kulikowich, & Schulze, 1994) and show how those correlate with domain knowledge as people move from acclimation to competency or proficiency (Lawless & Kulikowich, 2006). In the Model of Domain Learning knowledge, strategic processing, and interest all interplay as people move from acclimation to competence (and sometimes expertise) in a domain (Alexander, et al., 1994). Learners begin with surface-level learning strategies and a tendency to be most interested in the tantalizing, just as forecasters began with simple associations and focus upon what they perceive as most pressing or important. Later, learners use deep-processing to think in more critical, analytical ways, just as most of these forecasters had begun doing. When learners were interested, they took advantage of events and surroundings, just as most of these forecasters did. Later, learners began to take a more strategic approach to learning to meet their professional goals, just as three of the four most experienced forecasters had begun to focus their learning on areas of their own or the field's incompetence.

The Model of Domain Learning states that situational interest was initially important. It assured persistence through the early stages of domain knowledge acquisition. Following this, Lawless and Kulikowich (2000) found a positive correlation between domain knowledge and interest that increased as students moved to graduate work and then specialized. Learners had difficulty in early stages of learning in discerning what information was important. If students achieved expertise, their knowledge developed into a broad, deep base from which they pushed the boundaries of their knowledge through problem finding. At that stage their interest was high, and they stayed engaged over time.

This study differs from the description of those studies reviewed thus far regarding Model of Domain Learning in two key ways. First, both types of interest appear present simultaneously, even early in domain learning for forecasting. It is not clear that forecasters' situational interest always precedes individual (broad) interest. Participants with a childhood interest did state attraction to the tantalizing aspects of weather, but also exhibited the day-to-day domain interest that these researchers state comes later. This study also differs in regard to the importance of social affirmation. The Model of Domain Learning does not address social affirmation. It was initially developed within the context of K–12 education, where social affirmation from teachers may have been present and presumed. Forecasters are learning the bulk of their forecaster knowledge without the support structure inherent in formal education. This model remains intriguing. Alexander (personal communication, April 27, 2011) said that empirical research on Model of Domain Learning has recently been extended from school age children to adult experts, so additional studies underway may expand upon how the model applies to adults and to situations outside formal education.

The other partial model involved intellectual ability, metacognitive skills, and learning (Prins, et al., 2006). This study was not designed to capture intellectual ability, so cannot be compared.

I do see strong evidence for the need to scaffold learning, something implied by both models of development of expertise. In considering studies of scaffolding, my results suggest that van Merriënboer and colleague's (van Merriënboer, et al., 2003) partial and whole task practice approach is desirable, though with a caveat. Janet and Jordan spoke of applied training where concepts were practiced in parts, then a phase of their jobs where they began to forecast under supervision. Participants learned most of their forecasting knowledge on the job, through their own and others' experiences, rather than through training sessions. The caveat is that whole task practice may need to progress at the learner's pace for a novice learner (as opposed to in a displaced real time). Lisa saw a lot of detail in data during real-time weather simulations and did not have sufficient time to ask the questions that would help her learn how to discriminate what was important in data.

Reflective practice. Reflective practice was considered both as a means for individual learning and within the context of the larger organization. First, three studies were reviewed that had tested the efficacy of reflective practice in education and nursing. The studies found that reflective practice was valued, but not characteristic of all adults. One study found it did not clearly correlate with expert educators (Ferry & Ross-Gordon, 1998), but the others merely found that some were hesitant to reflect due to fear of reprisal or dislike of remembering negative situations.

Nearly all participants mentioned reviewing events they had missed in order to understand why; the others may have done so but did not mention it. They used reflection to increase the complexity of how they thought about weather. Reflection served younger forecasters to expand the types of data they considered and helped prevent them from repeating mistakes. Reflection served older forecasters by providing nagging dissatisfaction with the state of art. They sometimes then took action to advance the science.

Second, the context of professionals as sometimes confined to a larger organizational setting had been considered. Researchers had found that reflective practice could instigate organizational change. In one case, the researchers were unprepared to deal with the consequences and abandoned their study (Jones & Stubbe, 2004). In the other, researchers identified that nurses in a particular study were too constrained by their physician partners and managers to effectively learn and change through reflection; the others severely devalued nursing knowledge generated from practice (Mantzoukas & Jasper, 2004). These two studies showed how some professionals do not or cannot simply reflectively practice, and sometimes navigation of sociopolitical relationships was necessary. Consistent with those, a nursing researcher suggested in a position paper that nurses expand how they framed problems to include their context in order to effectively resolve problems they were reflecting upon (Heath, 1998).

The learning that these forecasters described rarely appeared to push organizational boundaries. There appeared only two exceptions: Mike told of an instance where his manager prevented him from publishing an investigation he had done, and Jordan said that while his company nominally encouraged innovation, it was difficult to gain programmer's time to build his ideas into their systems. Nearly all learning stories were ones that were accomplished. In discussing barriers, time was by far the most dominant. Weather does not stop to allow a forecaster to research what happened yesterday.

Coaching was described by participants to some extent, and generally as Schön (1987) had envisioned it. In Schön's vision, a less experienced person actively questioned a more experienced person's ideas as the less experienced person worked through problems. The experienced person would help the less experienced to see flaws in reasoning, and helped them take their thoughts further until they could see implications and complexity. Participants generally described exchanges as ones that would qualify as coaching. For example, Lisa had seen a feature in satellite imagery that had made her curious, and asked an experienced forecaster about it. His approach was to answer her question with, "Let's take a look. Let's take a look at some things." He coached her through doing a quick analysis of streamlines and showed what other data would help answer her question. Few of the potential coaching exchanges were described with sufficient detail to ascertain whether they fit this type of exchange, however. In many cases the potential coaching had taken place too long ago for the participant to recall details clearly.

Self-directed learning. Educators have described self-directed learning as both 1) a goal or set of skills critical to a professional, and 2) a process describing how professionals engage in learning. Two definitions of self-directed learning were considered, that of Knowles (1975) and Hammond and Collins (1991). They both involve a learner taking the initiative, with or without others' help, to determine learning needs. From there both definitions include forming goals, as well as the resources and strategies to achieve those, followed by assessment of the outcomes. Hammond and Collins expanded upon Knowles's definition to describe the diagnosis as increasing self and social awareness, to analyze and reflect upon the learner's situation, to specifically identify competencies, and as the formulation of goals as being ones that are both socially and personally relevant.

Interactive models are most likely to apply, as they describe informal learning (Merriam, et al., 2007). These models generally include the following, in various degrees. They simplify to consider context of the learner, with that sometimes providing fortuitous encounters. Learners also choose to learn, and are able to self-manage that learning. Such presumes the learning builds off existing skills and knowledge. One model in particular emphasizes metacognitive ability to monitor learning.

The ability of my participants to self-direct was mixed. Many were able to create their own learning strategies in the absence of help from others, but a few seemed unable to. The lack of skill in self-direction often appeared to be caused by lack of interest and motivation. It was sometimes a manifestation of how their professional identity was either elsewhere (Raymond, who self-identified as an expert in severe weather) or conflicted (Travis, who was not doing things he explained someone like him would do). The middle career forecasters that were pushing the state-of-art exemplified effective self-directed learning skills. Raymond's description of his ability to effectively self-direct in one area but not another suggested that he needed help identifying what he needed to learn for the second area. No forecaster answered that they learned differently for different types of weather, so I have no evidence to suggest that self-directing skills would be specific to weather type.

The initiation of self-directed learning did not generally involve a self-initiated assessment or diagnosis of learning needs beyond the instantaneous recognition and acceptance of a forecast failure. Self-initiated learning was triggered by 1) general inability when first beginning, 2) surprise at a missed forecast, or 3) a nagging dissatisfaction with the state-of-art. None chose to tell a story where someone else took initiative to point out a learning need; absence of such stories did not mean such instances did not occur. Neither did many stories involve a need for others to form the learning strategy. The only such cases were where a younger forecaster followed a post-event investigation that someone else in their office led.

Moving onward through the parallel definitions, however, these participants tended to choose their learning strategies and self-evaluate the outcomes. This is consistent with Candy's (1991) assertion that when given opportunity, learners will choose strategies that work well for them. In a broader perspective, Kegan (1994) pointed out that it was unrealistic to expect adults to consistently self-direct given the demands on us in these modern times. The nature of this study did not assess learning needs, so did not identify needs that remained unmet.

Several studies were reviewed that showed self-directed learning to be a primary or major mode of professional learning. These studies found self-directed learning to be productive, though note that they relied on self-reporting. The instruments and studies on self-directed learning may be useful to assess whether forecasters have skills and are ready to self-direct, though it is not clear that how well they apply to the very complex domain of forecasting the weather. Physicians are not expected to self-direct their learning of how to become a physician, for example, but only to self-direct much of their choices for formal continuing education, and their ongoing day-to-day learning. Meteorologists do not learn much about forecasting in their formal education, instead learning the broad, underlying knowledge of the discipline.

This study found that forecasters floundered without good social support. For example, Forest appeared better able to self-direct than Cassie, but he was aware there was no support in his first job. In contrast, she was expecting to go through a training program. Their reactions to those two situations may not correlate to their fundamental ability to self-direct. One participant expected to be responsible for the bulk of his ongoing learning: Tyler made the point several times in his interview that learning how to learn was one of the key skills he had gained in college. He felt confident he could continue his learning now that his intense mentoring period was complete.

The last aspect of self-directed learning addressed in Chapter 2 was whether professionals could be expected to effectively self-direct. Kruger and Dunning (1999) had published a landmark study showing that those performing in the top and bottom quartiles on several tests could not accurately self-assess their competence, significantly under and over-estimating it, respectively. Studies in medicine have confirmed that some physicians are unable to accurately self-assess (e.g., Fox & Miner, 1999; Violato & Lockyer, 2006).

Many forecasters nominally have an advantage over those groups, as they generally have some type of verification available to them on a daily basis. Some private companies base promotions on whether forecasters outperform models. Meaningful forecast verification, however, is not captured by simplistic values of, for example, temperature. For feedback to be truly useful, it would need to include information that helped forecasters qualitatively assess their thinking processes.

Career stage. As Houle (1980) had suggested when he expanded the classic model of professional education, a jungle gym is a reasonable analogy to describe the phases of learning for the participants in this study. When forecasters moved to a new geographic location, began a new type of forecasting, or changed sectors their learning needs returned somewhat to a novice level—perhaps a downward-sideways movement on the jungle gym. The classic upward progression was visible, too, as the triggers for their learning shifted from a general inability to being surprised at missed forecasts as they gained competence. Some competent forecasters then used nagging dissatisfaction with the state-of-art to initiate research projects.

Two studies had been located from nursing and medicine that addressed how learning changed over time and as career evolved. In the first, Ramming (1992) found that younger and less experienced nurses usually (45%) or occasionally (49%) consulting with another nurse. In contrast, nurses with the highest degrees tended to use nursing educators as resources. My findings are consistent with hers. Younger forecasters strongly preferred learning from other forecasters, and this study included data to know why: they needed to learn how to think about the forecast and the ability to distinguish which resources were most effective in creating one. The most experienced forecasters had a tendency to consult literature and experts.

The second study was Fox, Mazmanian and Putnam's (1989) seminal study of how and why physicians changed their practice. Of ten forces that drove change, the desire for competence or excellence was the largest. Further, the researchers suspected it was a driving motivation behind all changes. My study initially identified a strong desire to fill a role, a very similar notion that more concretely recognizes the professional's relationship to others. That construct evolved to focus on the forecaster's sense of professional identity as the driving force behind their learning.

Fox, Mazmanian and Putnam found that physicians, particularly in early stages of their careers, tended to use experiential learning when solving specific problems. Young physicians were reconciling the complexity of practice with what was learned and practiced during formal schooling. Overall, experiential learning accounted for just over half of all changes, particularly if the driving force was professional. The authors explained this made logical sense because medicine is an applied science.

Forecasting is also an applied science, and my study also found that schooling did not prepare the participants for the realities of practice. The authors identified that mid-career physicians tended to make major changes to their practice. Such changes were not evident in forecasters in my study, though that could be an artifact of who was interviewed. These forecasters tended to make changes early in their careers before settling into an office they then worked at for many years.

Illeris's two processes and three dimensions of learning. As addressed more fully below, many learning theories focus only upon individuals' cognitive processes. Illeris's (2003) work captured a more comprehensive understanding of human learning. It included two processes: the external interaction between the learner and his or her environment, and the internal process of knowledge acquisition. Illeris's model depicted the learner's environment as the basis for their learning. Environment interacted with the individual's dual processes of dealing with learning content and the incentive or motivation needed for learning. Illeris emphasized that all three dimensions were present in all learning, even if one appeared dominant. Learning outcomes in a chemistry lesson were used to illustrate how variations in balance and interaction between the dimensions lead to radically differing learning outcomes for each individual present.

My study supports Illeris's more comprehensive attempt at theory, particularly that forecasters were always learning from some particular environment and always had interaction evident between affective and cognitive aspects of themselves. My emerging theory, however, focuses more on the process pathways as the dimensions interact through a particular learning transaction. Illeris's model does not include a core, unchanging sense of identity other than how it manifests in the mental energy to learn. He did address four types of learning, and that the most extensive—transformative learning—involves changes to one's identity. My study did not capture anyone undergoing transformative learning other than the steep learning curve of building initial competence in the domain.

Indigenous and non-western ways of knowing. Cajete (2000, 2011) has studied indigenous learning from several Native American traditions. Indigenous learning is completely holistic, including that the learner him or herself is intimately integrated into what is being learned. To become a person of knowledge is to take a journey through learning and education. The pathway is both toward knowledge and toward yourself. As you take the journey of knowledge, you find your *face*. Finding face is to discover who you are—your true identity. In order to find your face, you must also find your *heart*—what drives you. Finding your heart is finding your affective self. Then you must find your *foundation*—your location. What is the work that fits you?

This description of indigenous science learning is much like my study's central category and its interaction with other categories to explain forecaster learning. Cajete's words were not in their vocabulary, but were in their stories. Those participants who felt right found convergence between their interests—which were deep, and part of their identity—with positive affirmation from others. When convergence between those elements was not in place, they felt angst and imbalance.

Merriam, Caffarella, and Baumgartner (2007) recently identified four common themes within five non-western ways of knowing that differed markedly from western conceptions of learning in adulthood. Western ways of thinking tend to focus upon cognition, and on individual learners, but non-western perspectives present a fundamentally different conception. First, interdependence is emphasized, where one's identity, self-concept and self-esteem are developed within the social context. Second, learning is communal rather than having a social hierarchical structure of teachers embodying the knowledge and expertise. Third, learning is holistic, encompassing the total person. Finally, learning is a natural part of daily life, with much of it informal.

My study supports the first two rather directly: most forecasters worked in a small group, their ongoing learning was communal. The third, of learning holistically, touches into the core findings of this study. I was less certain where daily, informal learning allows for learning a large body of research and consensus of knowledge in disciplines within a reasonable period of time, though current western hierarchical approaches to structuring knowledge in formal education do not necessarily allow for easy application in many domains. It is my hope that western educators can continue to better understand indigenous ways of knowing and consider how they add valuable perspective.

Professional identity. Literature on identity is extensive. Identity is broken into constructs of self-identity, group identity, identity affirmation, identity achievement, work identity, identity play, and more. There are many strands of research, such as identity interactions with organizational change, female pursuit of STEM professorships and careers, minority student achievement in higher education, minority achievement into scientific fields, and much more. Without awareness of the extent of this research, my study revealed that the forecasters' sense of professional identity was important in explaining how and why learning occurred. Given the extent of the literature, the following is a cursory comparison of recent works with my study.

One strand I was familiar with, but did not emerge in the data, is that of identity threat, also referred to as stereotype threat, affects achievement. Researchers have now turned to more nuanced investigations that vary from being quantitative and manipulated within experiments (Derks, van Laar, & Ellemers, 2009; Ghavami, Fingerhut, Paplau, Grant, & Wittig, 2011) to qualitative exploration and theory building efforts (Ibarra, 1999; Pratt, Rockmann, & Kaufmann, 2006). These are addressed briefly.

Researchers looking at identity achievement (exploring and understanding your identity) and identity affirmation (a strong feeling of belonging to the group) found that the affective identity affirmation mediated whether achieving an identity led to well-being (Ghavami, et al., 2011). This could be important in understanding why my study participants had greater well-being when affirmed by other forecasters. Ibarra (1999) identified how role transitions resulted in exploration of identity by observing potential role models, then experimenting with and evaluating provisional selves. Such exploration may explain the disjoint Travis exhibited between who he thought he was and what he actions he actually took. Another study linked differing outcomes of achievement depending on the sense of identity that was affirmed. Personal identity can be distinguished from social identity (Derks, et al., 2009). Participants in a previous study by the authors had greater motivation to improve themselves when they felt strong association with the same group that affirmed their social identity. Derks, et al.'s newer study extended those results to show that the motivation included interest to improve the entire group. However, those same participants lost motivation to improve their group if given opportunity to affirm their personal identity.

The context of these studies was persons in minority groups, but they may be meaningful to professional identity. Professionals are seen to be of a high-status group where one speaks of *who one is* rather than *what one does* (Pratt, et al., 2006). The studies may also provide a different lens on understanding dynamics within NWS forecast offices. One Science Officer had noted that when a forecast office struggling with morale it had lost its group identity. Those offices were poorer performers, just as participants in the studies cited here performed more poorly when their identity was threatened or unacknowledged. Ibarra and Petriglieri (2010) expanded on Ibarra's previous work to distinguish *identity play* as experimentation with selves in ways that are not organizationally imposed. Ibarra's previous work was with managers in role transitions where they altered identities in accordance to demands placed upon them. There is an extent to which forecasters have latitude in what type of role they will fill, and this may be a place where identity play comes in for the forecaster. Not all forecasters engage in an optional activity of doing research, for example. Ibarra and Petriglieri are careful to point out that play is only possible in a safe environment. An NWS office that has lost its identity may no longer be a safe place for identity play.

One study linked learning cycles with identity development. In studying physicians during their residency, Pratt, Rockmann, and Kaufmann (2006) constructed a model of interplaying work and identity learning cycles. Medical students have strong notions of professional identity before pursuing their degree. The researchers studied how residents' identities changed and interacted with learning of their work. When their residency work was congruent with their preconceived identity, their residency *enriched* and deepened their identity of being a physician. Primary care residents tended to find their identity enriched. Surgical residents, however, found incongruence between their preconceived identity and their experiences during residency. This led the surgical residents to *patch* their identity, meaning they found themselves patching together their notions of a general physician with their notions of what a surgeon did. Later in residency their identities became enriched as they identified their specialty as the "most complete doctor" (p. 247). Finally, radiology residents found their identities incongruent and had to initially *splint* disjointed identities of being a student together with that of a radiologist: early in residency their experience was more like formal training with additional reading, study and technical conferences. Only when entering their third year of residency did they begin to shadow radiologists and begin practicing their specialty. The learning and identity cycles interacted at the point where learning the work of being a physician did not match their preconceived identity of what that work would entail, and that disjoint led at times to serious identity work. The researchers did not appear to have participants who did not learn the work, and did not comment on alternate scenarios to a successful residency experience.

The above studies add to previously reviewed research. Some of them addressed how identity affirmation assisted in a sense of well-being. When basic needs are met, adults have greater capacity to learn (Merriam, et al., 2007). When forecasters were not affirmed in my study they experienced distress and feelings of being unwelcome. That distracted them from learning and doing their job. A strong sense of professional identity seemed to mitigate this challenge to some extent. For example, Cassie and Forest pushed through negative emotions because they had strong sense of professional identity. However, both found that situation unsatisfactory. They each moved to a new work location, after which they learned much faster and more effectively. In the new setting they were affirmed.

The above studies differ and add complexity beyond mine as well. They show nuance and depth to the sense of identity, suggesting that my study may fall short of fully capturing how identity impacts learning to forecast. Forecasters may, in fact, have two senses of identity: that of belonging to the group in which they work, and that of their own personal identification with the work.

Summary

Confidence in the model was increased by triangulating the data, method and results of this study in several ways. First, the experience and observation of how meteorologists learn from three Science and Operations Officers and one private sector manager provided observations of learning that were consistent with this study: on the job experience was the most common mechanism for learning, learning was dependent on weather occurring, forecasters may not be cognizant of the quality of their learning, and learning to react to surprise was an important skill to learn. They differed in that participants did not relate any stories of later realizing and unlearning bad techniques. They also differed because this study did not capture information about the sense of group identity in the offices where forecasters struggled to learn. This study added explanation in regard to the best forecasters possessing a service-orientation. This study showed that those forecasters in closest contact with users of their forecasts were strongly motivated to learn so they could focus upon that user's needs. Their learning was also better if they possessed a strong profession identity and good social support.

Confidence in the research findings was also increased through triangulation with empirical studies and published reflections of military and NWS forecasters. That literature builds a picture of the nature of forecasting and touched into learning to forecast that is consistent with these findings in many ways. Beginning forecasters in the NWS found the ill-structured nature of forecasting difficult to learn, some forecasters in both employment sectors exhibited characteristics of expert forecasters, and all forecasters made good use of social interactions. Working frequently through weather events and reviewing forecast failures were primary means for learning. Lack of those experiences, and if they had never personally experienced types of weather made those types more difficult to learn. This work differed from the literature on forecasters first by studying forecaster learning directly. It also differed by identifying a critical interplay between professional identity and affirmation from others that explained the paths through which they learned.

Finally, increase in the confidence of the results of this study resulted from a return to the landscape of literature in adult education and related fields. Much of that literature provides incomplete conceptual lenses. There exist two models of learning that are similar to these findings: Alexander's Model of Domain Learning and Illeris's theory of adult learning. In Model of Domain Learning, knowledge, strategic processing, and interest all interplay throughout the development of expertise. Surface-level strategies are initially used before learners transition to deep-processing. Model of Domain Learning is similar with exception that it identifies two types of interest that progress in a way not seen in this study. It is not clear if the construct of interest in Model of Domain Learning is conceptually similar to professional identity identified in this study. Illeris's model was also similar, though it addressed interacting elements rather than pathways taken to learn. Two processes—the external interaction between the learner and his or her environment and the internal process of knowledge acquisition—interacted with the learner's environment. The environmental dimension is the basis for learning. Inside the individual there is both the acquisition of knowledge and motivational dimensions. Illeris emphasized that all three dimensions were present in all learning, but variations in balance and interaction between the dimensions could lead to different learning outcomes for each individual.

The notion of finding face, heart and foundation in native science learning, and the interdependence that helps one develop their identity, self-concept and self-esteem was strikingly similar to what emerged as important in forecaster's interactions with other forecasters. Complex learning is—at least in practice—strongly a communal activity.

Chapter Six

Introduction to the Discussion

The work closes with a discussion of where this work might next go, and how it could be extended. Just like any other qualitative study, the data collected for this work is thick and rich. Some leads were not followed because the purpose of this study was to better understand forecaster learning across type of weather, employment sectors, and time-in-service. The surprising emergence of the centrality of the affective constructs professional identity and affirmation from others led to a few questions. A few more were raised through reflection on how the triangulation done in Chapter 5 provided confirmation of the quality of this work.

The similarity of this emerging theory with Alexander's Model of Domain Learning and Illeris's comprehensive theory of adult learning is encouraging. Neither included professional identity, though both highlighted the importance of affective constructs. As such, this model merits confirmation of the ideas within it. Two phases are proposed for that testing, given the immaturity of understanding of forecaster learning. First, identification and delineation of a common learning event would provide a tool for identifying that learning has occurred. Three hypotheses that form the key aspects of this theory could then be tested.

Final thoughts are in regard to the role this study might play in a larger body of research on forecaster learning and learning more generally in complex domains. This study is but a first foray into understanding forecaster learning through empirical research focused directly upon professional learning of weather forecasters. Readers from the domain of meteorology are accustomed to a science where generalizations can lead to laws, and then to prediction. Social science generalizations, however, lose important detail of individuals, leaving generalizations such as this one underdetermined. In the social sciences, it is a preponderance of evidence from many studies employing a variety of methods that advances the science.

Outstanding Questions

As with any qualitative study, there are many leads that were not followed. This study had a relatively tight, yet also broad focus on learning how to forecast across type of weather, employment sectors and time-in-service. Continued effort to maintain the scope leads to the following questions.

The centrality of the interaction between a strong professional identity and affirmation by others was not anticipated at the outset of this study, and made prominent the role of the affective when learning could ultimately—at the moment of learning—be considered a cognitive endeavor. Are there forecasters who were clearly capable, and possessed a strong sense of identity as a forecaster, but did not learn well in this complex domain due to poor social support? If the interaction between the two core categories was identified correctly, such persons exist. Forecasters learned how to think about forecasting through their interactions with others as they worked and watched weather day-to-day. During the earliest years affirmation was particularly important for learning. Forecaster quality or capability was not assessed in this study, as discussed in the Limitations section in Chapter 3.

Along the same general thread, and assuming good social affirmation and support, is a particularly strong sense of professional identity the causal factor in why some experienced forecasters became *strivers*, actively pushing the state of art? The three experienced forecasters who frequently and actively extended their ability to do their job also had considered or worked in careers that used research skills. Did they instead merely gain skills to undertake and successfully complete such research projects? Or did those experiences lead to a professional identity that included being a researcher? To what extent are all forecasters interested in research? The routine review of missed forecasts is a form of research, though does not necessarily become an extensive endeavor.

The outcome of triangulation with reflections of those involved in training forecasters raised additional questions. The learning issues most salient to forecaster trainers sensitized me to issues not fully addressed in my data. First, when—and how—do forecasters realize they have learned something incorrectly? Participants in this study likely learned both good and bad things about forecasting from others. They spoke of discarding techniques that did not work after trying those techniques, but did not speak of learning something, then later correcting that learning. Participants also spoke about adding nuances and complexity to their understanding, but not fundamentally correcting an initially flawed understanding.

Second, could effective forecaster training be more structured, yet still help forecasters build an applied knowledge structure? Forecasters learned the majority of their knowledge informally by working and watching weather day-to-day.

Learning was therefore tied to the particular experienced forecasters that a young forecaster interacted with, and to the weather they experienced.

Third, are some forecasters able to think in complex ways and develop deep, rich knowledge structures while also being more or less oblivious to how the weather impacts users of their forecasts? A Science Officer observed that the most complex thinkers in his office were also the most service-oriented. This study found that the four forecasters most closely connected to their users learned faster than the remaining seven. Also, that all forecasters exhibiting complex thinking were strongly aware of their role to users of their forecasts.

This emerging model is distinct from literature on forecasters, none of which had explicitly studied how forecasters learned. Morss and Ralph (2007) had included a paragraph about forecaster learning, but had gleaned that information from observations of what forecasters did and talked about, and from their own knowledge of forecaster education, rather than explicitly seeking that information in their study (R. Morss, personal communication, May 10, 2011). Although the studies are not directly comparable with this one, they do help raise some questions.

First, are expert and non-expert forecasters learning in fundamentally different ways? Alexander's Model of Domain Learning and other literature on learning do not suggest this would be expected. In Model of Domain Learning, for example, knowledge, strategic processing, and interest all interplay throughout the development of expertise. Surface-level strategies are initially used before learners transition to deep-processing. The majority of forecaster learning, however, is done on the job, and because of that, forecaster learning is highly contextual to the people around them and to the weather experienced. To what extent does the development of forecasting expertise depend upon being in a context with expert forecasters? When a young forecaster is learning from expert forecasters they are likely learning deep-processing from the start. Perhaps only their own efforts would use surface-level strategies, and do so because they would be unclear on where to focus their thinking.

Second, one Science Officer specifically trained on the need for fluid decision making. This observation was echoed by literature (Bosart, 2003; Curtis, 1998; Hahn, et al., 2003). New data can signal a need to change expectations and forecasts. One participant's story involved realization of his failure to incorporate new data and change his forecast. It was a similar situation to the weather event with which this work was introduced in Chapter 1. How can forecasters best learn to incorporate the constant influx of data? In other words, learn a fluid decision-making ability?

This emerging model appears more holistic than many existing models, but not necessarily more so than Alexander's Model of Domain Learning (just addressed) and Illeris's more comprehensive theory of learning. Illeris's theory includes two processes: the external interaction between the learner and his or her environment, and the internal process of knowledge acquisition. The learner's environment is the basis for their learning, and it interacts with the individual's dual processes of dealing with learning content and the incentive or motivation needed for learning. All three dimensions were present in all learning, even if one appeared dominant.

Those two models did not use the construct of identity, but had constructs that are likely similar: interest (Alexander) and mental energy (Illeris), that provide incentive to learn. This emerging model also appears to naturally incorporate a perspective reflective of indigenous learning, though no participants were known to have Native American ancestry or strong awareness of Native thinking.

How long does it take to develop expertise in forecasting? No studies have established this; some determined that the 10-year rule of thumb did not apply. Does it still take 10 years to become an expert forecaster? Was the confound experienced by other researchers simply that you cannot assume expertise is reached after 10 years? Numerical weather prediction complicates assessing forecaster learning using performance, as it can mask depth of knowledge of the domain. Participants in the four to 10 years experience level felt they gained preliminary competence by three to four years experience. They continued to learn fairly frequently, however, when surprised at a weather outcome. Further sampling the range of experience from three to ten years could be fruitful in determining when learning plateaus.

Finally, one researcher had specific, but incomplete evidence that women may have unique difficulties in this primarily male domain (Daipha, 2007). In the course of her data collection, Diapha was told about episodes of strife between younger women and certain older males. She found that both groups believed there was an inherent tension between a traditionally male and more contemporary feminine culture. She also interpreted having seen an ongoing culture change; her presence was welcome. She cautioned that her "vocally feminist views" (p. 47) could have altered how forecasters presented themselves to her. However, she understood her participants to portray that retention of women in the profession involved female forecasters working harder to be accepted as forecasters, and tolerating an increased consciousness of their presence because they were different. How does the quality and type of learning opportunities afforded to young women vary from that of young males? In this study, lack of opportunities for mentoring was seen in both sexes, and changed by transferring to another employment location.

If further theoretical sampling were to occur to seek variation and better understand implications of this study, it would follow leads suggested above. Colleagues may be able to help me identify capable forecasters who began and struggled to learn in offices known to be poorer performers, but then moved to a higher quality office where they then realized their capability. It would also be interesting to seek and probe corrective learning. It may be the case that questions directed that way would have yielded information on corrective learning from these participants. Third, forecasters who learned well without good social support, or who learned well despite a weak professional identity would help probe the interaction between those factors and their impact on learning. Adding participants in both the 1–3 and 3–10 year ranges would further saturate how learning occurs in those years and how it transitions from general inability to learning after being surprised at a bad forecast.

Thoughts On Confirmation Through Testing

The model that emerged in this work contains a mix of constructs. The key items are whether help is received unprompted, the resulting degree to which one's identity has been affirmed, and whether the forecaster can then create a successful strategy to build whatever bit of knowledge is being learned at that moment.

Several hypotheses can be gleaned from the emerging theory:

- Forecasters learn faster when there is high social support.
- Others affirm the presence of the forecaster when they provide effective help.
- When others do not (or cannot) help, forecasters learn when they have a strong professional identity.

The first challenge would be to identify learning moments and test whether learning occurred. Some researchers have created and tested instruments to determine domain learning for other domains (e.g., Alexander, Jetton, & Kulikowich, 1995). Two issues arise. First, training modules teach underlying knowledge, and some modules propose processes or techniques. Participants in this study, however, stated that forecasting was idiosyncratic. Learning stories revealed that there were multiple ways to forecast the same thing. Second, it could be much more difficult to identify common knowledge gaps and design knowledge tests outside formal education, where the progression of subject-matter learning is nearly uniform across a set of potential participants. The mobility of forecasters, dominance of different types of weather in different places, and disparity in forecast aims across employers might require a focus and initial testing effort that includes only one employment sector and region of the country in order to identity areas of learning that have not likely yet taken place. Information resulting from first testing Figure 2, the progression of understanding for any given forecast, could help identify common learning needs and become the basis for a knowledge test.

The progression of learning from simple associations and reliance on numerical weather prediction models could be tested using a knowledge elicitation exercise (Hoffman, et al., 2006). Beginning with an experienced forecaster, ask him or her to identify a common aspect of weather that they had learned how to forecast. Coach them through creation of two concept maps: one that describes their initial understanding of how to forecast that item, and one that describes how they forecast that item now. If I am correct as indicated in the rightmost box in Figure 2 that forecasting becomes adaptable, full of nuance, and critically uses numerical weather prediction information, then the second map could take an hour or more to create. Repeating this exercise with several others would confirm whether the post-learning forecast technique is common among forecasters. Consultation with a set of domain experts could help identify whether differences in techniques are insignificant (e.g., that all forecasters used a measure of midlevel instability at about the same point), or whether the forecasting technique was fundamentally idiosyncratic (e.g., forecasters use a non-intersecting set of processes to forecast the same thing).

A second challenge to verifying the emerging theory is to identify methods with which to determine the strength of one's professional identity and whether one perceives affirmation by others for that identity. There appear to be existing instruments for at least ethnic identity achievement and identity affirmation (e.g., Ghavami, et al., 2011). If an appropriate non-ethnic instrument cannot be found, one could be created modeling after those. These types of instruments tend to use a series of statements that participants rate on a Likert scale.

Results could then be used in a cluster analysis (as Alexander, et al., 1995 employed) or through careful testing of how those two constructs interact (through a form of ANOVA), and provide predictive power to learning. Tests of interactions and dependence between variables would include:

- if time-in-service were included in data and a sufficient sample size could be achieved, the first hypothesis could be tested, namely, that forecasters learn faster given good social support
- given good social support, is perceived affirmation positively correlated with learning
- given poor social support, is a strong identity positively correlated with learning

Nomothetic and Idiographic Considerations

Lincoln and Guba (1985) provide a cautionary tale with which to close this chapter. Many of the readers of this study will be from the domain of meteorology. In the natural sciences generalizations are designed to produce law so that prediction is possible. In the social sciences, however, the particular of individual cases is critically important. When generalizing from particular situations, detail is lost. This study is "inductively underdetermined" (p. 117), and subject to the time and contexts in which it was done. Generalizations in the social sciences become idiographic, applied similarly to the way case law is built upon the precedents that have come before, and account the particulars of situations. This single study in itself represents an inadequate basis of evidence to understand forecaster learning, no matter how correct it may seem.

Summary

The work closed with a discussion of where this work about how forecasters learn across type of weather, employment sector, and time-in-service might next go, and how it could be extended. The data collected provided thick, rich descriptions that could lead in many directions. The core data provided the surprising centrality of two affective constructs: professional identity and affirmation from others. Triangulation with reflections and observations of forecaster trainers, along with the literatures about weather forecasters, adult learning, non-western and indigenous ways of knowing, and professional identity provided confirmation of several elements.

Several questions remain outstanding at the close of this work. This study did not capture unlearning or corrective learning, could not confirm whether the interaction of professional identity with affirmation from others was causal or could be caused by a third factor, did not provide data to know whether forecasters could build complex knowledge structures if essentially oblivious to how someone used their forecasts, and did not clearly identify the stage at which expertise appeared to be gained. If further theoretical sampling were done it would pursue these questions while also adding participants in the one to 10 years experience range to identify which forecasters developed expertise.

Despite those questions, this model merits confirmation of the ideas within it. Two phases were proposed due to the immaturity of understanding of forecaster learning. First, to confirm the general progression from use of simple associations to complex, nuanced understanding. If common learning events can be identified and delineated, they would allow determination that learning has occurred. Three hypotheses that form the key aspects of this theory could then be tested.

The title of this work promises much, but is appropriate for a first foray into a new area of study. Advancements in the social sciences occur after a preponderance of evidence from many studies employing a variety of methods. The choice of grounded theory for this study provided exploratory power that cannot be gained through presupposing that work in other domains will apply. It allowed for discovery of concepts unimagined within the biases of the current state-of-art.

Epilogue

All doctoral students progress through a series of emotions as they venture through an experience of being solely responsible for their learning. I was no exception, and had two main foci of emotions with which to struggle.

First, this work was done at a point in time where weather forecasters were increasingly outperformed by numerical weather prediction. This, despite that the latter—not one but a *set* of models... and worse, *ensembles* of *each* of those models, containing up to 50 members—do not provide a single clear answer for all forecast situations. For more than a decade, many have been forecasting the demise of the profession. This, combined with the increasing communication and collaboration with core partners such as emergency management, has led the National Weather Service (2010) to re-envision the role of the forecaster as moving toward decision support. While the National Weather Service ponders moving forecasters away from actual forecasting duties, some businesses and industries are just realizing the value of weather information and actively hiring forecasters (e.g., apparel: Barbaro, 2007; and energy: J. Duncan, personal communication, January 23, 2011).

Whether forecaster learning is about to become a thing of the past, many still live the need to learn in this complex domain. Graham (2011) was perhaps the clearest and most poignant among a room full of NWS Science Officers on the front lines, who see the need for forecaster learning as much as ever. When reflecting on his experience leading NWS support for other federal agencies during the coordinated U.S. response to the Deepwater Horizon well blowout in the Gulf of

Mexico he described having to frequently think on his feet, providing custom information to other agencies. Of his experience he said, "Decision support is a massive scientific challenge: you never know what they're going to ask for next." He absolutely needed a deep, thorough, complex, and adaptable understanding of the science behind weather and the ability to create and evaluate new forecasts (Graham, personal communication, February 23, 2011). In the coming era, forecaster learning may be more important than it has ever been.

The second focus of emotion may not be entirely unique to the doctoral process, but it was magnified by my complete ignorance of the method chosen for this study: the emotions inherent in learning while in the midst of doing. While I studied how meteorologists learn to non-linearly apply their knowledge of meteorology to any given forecast problem, I, myself, was engaging in a similar kind of learning: I was learning how to non-linearly apply knowledge about a set of analytical techniques to form a coherent whole that represented my data. Just as my participants were telling me they had difficulty learn how to forecast from books, and forecasting techniques are changing over time, I discovered I had not actually learned an inherently non-linear process from Strauss & Corbin's 1998 work. I later learned that grounded theory was itself an evolving way of thinking about how to use analytical techniques (Corbin & Strauss, 2008; Morse et al., 2009). And so while my participants tried and made many poor forecasts, I tried and initially felt that I conducted a relatively poor analysis. At least two of the younger participants, who were at points in their career with poor social support, conveyed that they read anything they could get their hands on that conveyed forecaster thinking. I did likewise with grounded theory, returning to explanations and examples of grounded theory many times as I struggled to figure out what I was supposed to *do*.

There is contradicting evidence in the literature on grounded theory as to whether the researchers who developed grounded theory begin with one or more interviews. Corbin's new edition of *Basics* (2008) includes an example of reading, reflecting, and speculating on codes and categories with the incidents in one interview before collecting a second interview to continue to develop the initial thinking with a second participant that diverges on a concept that appears to be central and important. None of her initial codes appeared to be very well developed until after subsequent interviews. But other, and much older resources such as Glaser's seminal article on the constant comparative method (1965), speak of having a wealth of qualitative data, from which an analyst chooses some portion with which to begin. What makes sense to me now, after I have tried both, is that either method will bring you to essentially the same place. It may prove to be more efficient, at least when aiming at finding common, underlying experiences in a dataset with known variation, to begin at the outset with a dataset that embodies some of that variation.

I needed more courage early on to trust that the fog of confusion and uncertainty would clear. I also needed to allow myself to play, but frankly, I did not understand just what that meant. Many writers on grounded theory use the term and it sounds great. But when you have never played, you are not quite certain what that means.

> Just remember that doing qualitative analysis is an art as well as a science and that there is nowhere in the analysis where this is becomes as apparent as in the final integration. (Corbin & Strauss, 2008, p. 274)

The above quotation proved true. The task of relating categories to each other was far harder than I ever imagined. But it resulted in a set of processes that generalized to strongly incorporate these participants' experiences with learning to forecast the weather.

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Appendix A: Interview Guide (Pilot Phase)

Daphne LaDue
Study: How meteorologists learn to forecast

This study follows grounded theory methodology. The following questions are likely to be used in initial, pilot interviews, and interview questions will evolve as the theory develops.

Background questions:

When did you first start forecasting?

> *potential follow-ups:*
> Did you learn before formal schooling in meteorology?

Where did you earn your meteorology degree(s)?
How long have you been forecasting for your job?

Essence of the interview, big open question about how forecasters go about learning to forecast with whatever follow-ups are appropriate to what the interviewee says. Some guesses of follow-ups are included:

Tell me about some forecasts you have done in the past year or so that were challenging or difficult.

> *potential follow-ups:*
> How did you deal with that forecast?
> What did you have to learn in order to deal with that forecast?
> What did you change afterward?
> How did that change come about?
> Can you think of another challenging or difficult forecast?
> (repeat)
>
> Do you learn differently to forecast different kinds of weather?
>
> Do you learn differently to forecast for different places?

How does your work situation help or hinder your learning to forecast?

Are there any factors that prevent you from learning?

How do you prefer to learn at this point in your career?
e.g. informal, experiences, social, formal

Appendix B: Interview Guide (Study Phase)

Interview Guide

v.3, 11/15/07

Daphne LaDue

Study: **How meteorologists learn to forecast**

This study follows grounded theory methodology, thus this is a topic-based interview and the specific sub-questions will evolve as the theory develops.

I. Initiators of learning

a. When did you first start forecasting?
b. Did you learn before formal schooling in meteorology?
c. Where did you earn your meteorology degree(s)?
d. How long have you been forecasting for your job?

II. Reasons for learning

a. What has been on your mind in the past year?
b. Why? Can you describe how that come to be a focus of your thinking?
c. Can you describe why that topic stuck when others didn't?

III. How resources and strategies are chosen

a. What kinds of things have you done to learn / improve / grow that skill or knowledge?
b. When you've learned about things in the past, how were your actions the same?
    i. ... How were they different?
c. What is your favorite way to learn now?
    i. ... How has that changed over time?

IV. Role of social interaction

a. What role have others played:
    i. ... in focusing this on your mind?
    ii. ... in helping the topic stick?
    iii. ... in helping you learn / improve?

V. Role of context

a. Would this effort have taken place if you were working in another setting? Why or why not?
b. Does the kind of weather you are learning about tend to make a difference in how you learn?
c. Do you learn differently for different places?
d. Do you encounter barriers or obstacles that make learning more difficult or impossible?
    i. ... related to resources?
    ii. ... related to time?
    iii. ... related to opportunities?
    iv. ... related to the system you work in?