EVALUATING APPROACHES TO DEVELOPING FORECASTERS IN THE CLASSROOM

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The undersigned, appointed by the dean of the Graduate School, have examined the dissertation entitled

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and hereby certify that, in their opinion, it is worthy of acceptance.

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"Nothing worthwhile was ever accomplished without the will to start, the enthusiasm to continue and, regardless of temporary obstacles, the persistence to complete."

– Waite Phillips

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Abstract

A core class in the meteorological education series is Synoptic Meteorology which consists of two courses over the course of a year. Traditionally, this upper-level class focuses on developing skills related to synoptic meteorology content and teaching students how to forecast using a variety of different educational approaches. The series culminates to two assignments that require students to synthesize and deliver weather information using the forecast skills they developed over the two courses. Two years of both Synoptic Meteorology classes were followed to evaluate student forecast growth using surveys, grades, and observations for different elements of the class. The second-year group of students were offered an internship experience to further develop these skills. Students were also required to participate in the forecast game and forecast results were also used in the analysis. There was no statistical difference in students grades overall and forecast discussions between the two groups. There was a difference between in written Area Forecast Discussions and in some elements of the forecast game, especially for precipitation forecasts. Students who participated in the internship also felt more confident, prepared, and grew their skills greater than the group that did not participate. Interviews from the internship highlight the positive impacts that the dedicated time to forecast and apply knowledge had on their development. The results show a way to develop forecasters using the various tools at an instructors disposal with dedicated time and effort.

Chapter 1 Background, Motivation, and Objectives

With the reliance on forecasting for many of the nation's needs, there are meteorologists at all levels that exist to assist with this task, from private companies to universities to the National Weather Service. These people are experts and achieved this level of skill over time through honing their skills and practice. Every year, about 1000 students graduate with a degree in meteorology in the United States with hopes of getting a job, many with forecasting as a job component (Hoffman et al. 2017). However, despite this situation, there are many graduating students that feel unprepared for their employment because of perceived weak forecasting skills (Hoffman et al. 2017). This lack of confidence may be due to lack of exposure to the complexities of what goes into a forecast or how to apply concepts learned in class. Through a hands-on approach broaching many different pedagogical approaches, the project proposed here aims to help students become better forecasters by the end of the year by increasing student confidence and moving students to a more expert level decision-making hierarchy.

To better engage students, there are many different approaches that can be used to instruct students in the classroom. Most of these techniques have been applied in other fields with success, yet the application of these methods to meteorological education has only recently become a focus. There have been many approaches to meteorological educational teaching, but no consistent approach or technique has been identified as the best for forecasting (National Research Council 2012; Quardokus et al. 2012; Dolan et al. 2017). Education in the classroom for meteorology does have support, as noted by the American Meteorological Society Annual Meeting conducting yearly symposiums on education, but work is normally done at one university focusing on tools available to them and sometimes only for one term or semester. Long term studies are also lacking.

Objective: The goal of this research is to test various teaching techniques to identify appreciable differences in student forecasting confidence growth and assess student understanding in a forecasting-based classroom. By focusing on easily accessible options, these approaches can hopefully be utilized more broadly.

Goal 1: Increase student forecasting skills through a multi-pedagogical approach allowing for a variety of learning experiences for the student. Only recently has education become an issue for developing future meteorologists. Studies have indicated that forecasting is one thing most students are interested in learning, but they are limited to large lecture hall, introductory classrooms making it hard to teach this material (Yarger et al. 2000; Morss and Zhang 2008; National Research Council 2012). Since these classrooms are full of students that are taking the course for a general education requirement, these students are not the target demographic, and more effort needs to be placed on training future students in the discipline with these skills. By engaging students on many fronts, students will have a more authentic learning experience. By assessing students learning through labs, real-world problem solving, authentic field experience, and the use of technologies, the students will be exposed to a variety of different approaches to enhance their learning. This comprehensive approach hopes to give students a deeper understanding of the forecast.

Goal 2: Using case studies and daily practice, students will be exposed to a variety of weather forecast tools and understand the application of topics established in the classroom. Case studies are frequently used in the medical field and are a hallmark of training in the medical field (Crowe et al. 2011). Normally case studies in meteorology are often used to assess what happened during a meteorological event of note, whereas here, the case study will be used similar to the medical approach (Market et al. 2007; Market 2016). Students will be guided and walked through events that will test knowledge obtained in the classroom during the time period of this research. When comparing expert student forecasters to more novice forecasters, both groups tend to suffer when dealing with more difficult atmospheric processes (Suess et al. 2013). By training students to deal with more complicated atmospheric processes, students will be more confident in their forecasting skills, hopefully leading to better forecasts. The use of case studies will be a key component in this development for students.

Goal 3: Through less instructor guidance and support, more demand will be placed on students that will increase student confidence and expertise with a culmination of these skills shown in student forecast writing and semester forecast discussion. An increased skill in forecast approach and understanding will hopefully be noted. Student forecasting skills have shown improvement in the first 6 weeks with only slight improvement afterwards (Roebber and Bosart 1996). By continuing to give feedback and putting students in the position to forecast constantly, students should continue to improve as they apply new techniques and refine their skills. By communicating effectively through written area forecast discussions, students tend to forecast better when significant inclement weather is occurring (Market 2006). Since significant inclement weather of note does not occur all the time, students need to continue the same level of effort and expertise in communicating their forecast.

The evaluation of the students was based on both objective and subjective approaches. Students were given various pre- and post- tests to gauge their cognitive development and understanding. Classroom observations were taken noting how students pose questions, respond to concepts, and discussion amongst groups.

Chapter 2 Literature Review

To complete the objectives of this research, a thorough literature review was performed. Since the research conducted is a blend of two fields, an educational and meteorological approach was used. The components of the literature review are broken down into a few different sections. The first section focuses on the novice to expert continuum and how learners grow through experience, training, and time.

The second section combines the concepts of education and meteorology together. The educational approaches used in the research are described with relevant meteorological examples.

The National Research Council (2012) notes the geosciences field of education research is less developed compared to other sciences fields like chemistry, physics, and biology which are more established. In addition, geoscience research tends to be combined with geology, oceanography, geophysics, atmospheric science/meteorology, astronomy, and geography. Educational research has the most support and research focused in geology. While meteorological education is published, the frequency is sporadic and across many different publications. To complete this literature review, other fields were researched to address topics and provide support as needed.

2.1 Novice to Expert Continuum

2.1.1 Benner and the Novice to Expert Continuum Origins

Learning and the application of this knowledge is a continuum of how a person comprehends and starts to apply growth to the tasks. Benner (1982) was one of the first to document growth and the changes often made as the learner progressed along the continuum in the field of nursing. Benner (1982) identified five main levels that a person moves along this continuum: Novice, Advanced Beginner, Competent, Proficient, and Expert. Progressing to the next level is a combination of moving from abstract principles to relying more on experience along with being able to draw out the complexity of the situation and make correct choices. However, transitioning between levels is blurred and may seem to suddenly appear, but there are certain observable characteristics. These classifications were further elaborated in Benner (1984) and Benner (2004).

For a novice, the learner has no experience with the situation and often has to be taught the key foundational aspect (Benner 1982; Benner 1984; Benner 2004). The learner is often taught these rules without context and knows that they simply must follow the procedure that exists and are not able not able to make judgment calls to determine which steps may be necessary. Benner (1982) discussed how a nursing student will go through an entire procedure such as taking weight or blood pressure of a patient. Specific features and attributes of the task needing to be completed are often pointed out by the educator as the learner is unable to focus on other tasks and often follow the procedure as outline (Benner 2004). At the novice stage, the beginner needs support to achieve the task and gain that experience necessary and establish patterns (Benner 1984). Nurses at the novice level are often new on the job or still in nursing school and their skills are basic and need to be developed. Benner (2004) suggests that idealized cases and contextual examples be used.

For an advanced beginner, the learner has a “marginally acceptable performance” and will often have limited experience with the task (Benner 1982). At the advanced beginner stage, a mentor or instructor is still present but due to gaining experience, the learner is starting to gain an “aspect” of the situation. An aspect is defined as global characteristics that require prior experience in a situation. While the learner may now have experience, they may not have all the patterns or behavior down to fully complete the task on their own, but the learner is starting to recognize patterns, develop their own approach to the situation, and set up priorities (Benner 1984). A mentor is still around and provides guidance on what to look for on some of the more nuanced aspects. While at the advanced beginner stage, the learner is not emotionally involved in choosing the necessary action because they still lack that experience. Benner (1982) uses an example of nursing student assessing a patient's readiness to learn about at home treatment for therapy or surgery.

At the advanced beginner stage, the nurse starts to feel some sort of responsibility (Benner 2004). The sense of responsibility can lead to anxiety and fatigue as they realize the complexity of the situation. While they may have experience, they may not have enough to feel comfortable with the situation, especially if the situation deviates from learned procedures and necessary actions for the situation (Benner 1984). Those at the advanced beginner level may have to self-motivate through pep talks and taking things "one step at a time" (Benner 2004). Students at the advanced beginner level may still rely on textbook examples and have difficulty assessing severity due to lack of experience and for this reason, may ask questions related to basic concepts. Career wise, the person may be considered a new graduate and have additional responsibilities they previously only had training on (Benner 2004).

The competent level is considered the standard level and one that people may stay at long term as it seen as satisfactory and ideal by supervisors (Benner 1982) and is a level that many achieve (Benner 1984). At this level, the learner often has two to three years of experience and often has a greater vision of the future (Benner 1982). They may have started to establish and envision long term goals and plans and know how to achieve these outcomes. In their position/job, they feel confident and feel as though they have mastered and learned to handle or manage the demands of the job. People at the competent level may still be anxious, but the general anxiety has decreased and now is more situation specific, showing growth and command of a situation (Benner 2004). While the person may feel this way, Benner (1982) commented that nurses at these levels still lack the speed and flexibility of nurses at the next level: proficient. While these nurses may be good nurses, they may not be as efficient as possible but have an established routine with success.

Part of the reason that the competent learner is satisfactory for supervisors is that the learner is becoming emotionally involved in the decisions being made compared to the prior two levels on the continuum. A competent learner often has years of experience and has an established record and may take pride in their job. Regarding the emotional aspect, Benner (1984) found that the trainee needs to stay emotionally involved and accept success and failures to fully continue developing and growing, and avoid stagnation, boredom, and regression.

Those at the proficient level have more experience and practice than those at the previous level. With more experience, those at this level can see a situation as a whole. Learners at the proficient level respond well to case studies as it allows them to draw upon their knowledge. Nurses at this level may see plans that "present themselves" as decision making is now less intense, meaning that the person can make decisions, with confidence, and is able to identify possible approaches to solve problems by modifying as necessary (Benner 1982). While they can identify an issue, or when something out of the ordinary exists, they may need help with the approach.

The proficient stage is often seen as a transition level to expert. One reason for the transitional consideration is that the person can perform and is guided by maxims. A maxim is only obtained through experience and a deep understanding of the situation (Benner 1982). The important aspects in a situation are easily identifiable to a person at the proficient stage, but not to those at a lower stage on the continuum. These are the nuances that exist and guide the person. The practical skills start to manifest themselves and the person can draw upon their experience and see potential outcomes (Benner 2004). Self-reflection from Benner (2004) indicated increased confidence as well. Benner (1982) noted that in a high stress situation like removing a breathing tube from a patient, the nurse was able to focus on the important aspect to aid the patient in returning to normal breathing and they can identify when/how they may get into trouble and can anticipate issues. The biggest change in the continuum is often seen going from competent to proficient because of this skill level (Benner 2004).

The final level on the continuum is the expert stage. A person at this stage no longer relies on rules or principles due to their vast experience and knowledge to draw upon. Due to this achievement, an expert can determine plans without effort and wasting situations that may delay the desired or needed outcome. Performance and task execution at the expert stage is holistic as compared to lower stages on the continuum where decisions are fractured, procedural, and based on incremental steps. The issues as noted by Benner (1982) with expert stage are hard to classify and show that someone has reached expert status. However, at the expert stage, the person often feels and exhibits confidence in both the way they handle the problem or situation and the outcomes. In addition, they often feel confident that a solution exists knowing that in their experience, they can solve hard problems. Lastly, these people often serve as examples to those lower on the continuum as an example of where expertise is best observed (Benner 2004).

Evolving and moving along the continuum is mainly due to experience and time (Benner 1982; Benner 1984; Benner 2004). However, by seeking help, mentorship, and building a physical (books and references) and experiential resource library, people can move along this continuum slightly faster (Benner 2004). Self-reflection when encountering a new situation can help aid in refining decision making while adding to the knowledge bank. While the work by Benner (1982; 1984; 2004) outlines the continuum, the examples presented focus mainly on the nursing field and are dependent on clinical style teaching. The novice to expert continuum needs to be applied more broadly to other fields with further depth of application.

2.1.2 Dreyfus' Revised Model

The work by Benner (1984) was taken from the Dreyfus Model of Skill Acquisition as it related to military pilots (Dreyfus and Dreyfus 1980) which was updated and applied to a more general population (Dreyfus 2004). The initial work had six stages with the final stage being master, but the updated work adopted the structure from Benner (1982) to the current five stages. In the revision, Dreyfus (2004) focused on adding context to the continuum within four different skill areas: components, perspective, decision, and commitment. Components are defined as the aspects of the situation that the learner can perceive and can be either context free that relates to general skills and abilities or relate to the situation. Perspective is the component of the situation and is what the learner chooses to focus on. Decision is how the person acts and responds to a situation. The response can be either through analytic reasoning or intuitive, which is influenced by the situation and experience. The final skill component is commitment, which is how much involvement the learner has in the decision being made. Commitment in Dreyfus (2004) is a way of including the emotional aspect that Benner (1984) discussed.

In the revised model, Dreyfus (2004) explains that the novice is at the beginning stages and the instructor's task is to break down the task/situation and provide the situation free of context. The learner has no perspective as the task/situation is new to them. For this reason, the learner makes the decisions with no attachment and focuses simply on the analytical aspect.

For an advanced beginner, while they do have some experience, they still lack perspective as the number of components in any situation may be too much and overwhelming. Decisions are still made based on their analysis and evaluation of the situation; thus, the advanced beginner is still detached as an instructor or mentor may still be making the critical decisions. However, because the advanced beginner has some experience, they can perceive the situation context free ***and*** as a part of the situation. At the advanced beginner stage, the person most likely will not know all the components necessary to complete the task or situation but will be able to identify some of the components and use prior knowledge to aid in completing the task. Dreyfus (2004) uses the example of a person using a stick-shift vehicle. Learning when to shift in a car includes both various signals like engine noises and speed which has both a situational and non-situational component. Unlike Benner (1982), Dreyfus (2004) includes that at this stage in the development, the learner is able to start using maxim instead of at the proficient stage.

At the competent stage, the learner still makes decisions based on an analytical decision but has gained further experience. Due to this experience, they can start to recognize and respond to the potential issue. However, at this stage, the individual starts to become emotionally invested in the outcome as they know what the result should be but may become overwhelmed due to the complexity of the solution and lack of complete understanding. This feeling can lead to the anxiety mentioned by Benner (2004). With experience, they are able identify the important parts to a solution and ignore the unimportant parts. Through this approach, they are restricting their possible choices, making actionable plans, and easing the decision-making process. The learner may however still struggle as they feel the weight and responsibility of the role, leading to difficulty in decision making (Dreyfus 2004). The difficulty can lead to the person falling back on using manuals and schema, having achieved success, they know they can achieve it. Even though failure can and will happen, the resultant outcome, whether positive or negative, can compel the person to go further. Dreyfus (2004), along with Benner (1984), states that the competent level is the level a person may stay at long term. They can use some recall and seek support, but over time, they may settle into a pattern while learning from successes and failure. Progression to the next level is dependent upon how the person responds to these successes and failures.

Dreyfus (2004) stated that it is the response to these positive and negative experiences that develop the proficient learner; Benner (2004) also described this notion. When a person has their experience, they internalize what happened and through this process, they can strengthen good behaviors and skills and inhibit unsuccessful ones. After doing this exercise, the proficient learner has an involved understanding and can see the necessary actions to make, enact, and achieve a plan or are adaptable to different approaches. Regardless of this change, the proficient learner is able see the important aspects because of the more experienced perspective. They know the context and can see the goals but may not always be able to know how to achieve them. In addition, while they may have experience, they may not have been able to anticipate or react to the wide variety of potential outcomes. This is what causes an individual to hold back from taking the next step. While the person may know what needs to be done, the way forward or best choice needs to be considered.

Similar to Benner (1982), the expert is one who makes decisions through an intuitive nature (Dreyfus 2004). They know the nuances and subtle considerations necessary and for this reason, often have many plans at the ready. They have a vast experience ready to draw upon to achieve success knowing the potential and successful outcomes. This wealth of experience allows the person to cognitively determine what needs to be done and break down the necessary steps, allowing for what appears to be an intuitive response. Both Benner (1982) and Dreyfus (2004) use the example of chess and chess grandmasters to draw upon this model. Overall, the main takeaway is to focus on development through practice, experience, and feedback. The various stages only serve as benchmarks to indicate growth.

2.1.3 Geoscience and Expertise

When considering how students learn either a topic or even a course, one can view the current set up of topics of a class and how information is presented. Often, students are newly exposed to a topic or method and are then assessed. Content, however, is often broken into four to six main items for a day or lesson; this approach is known as chunking. Larkin et al. (1980) defined chunking as anything that has become familiar through repeated exposure and is recognizable as a single unit. Over the course of a semester, Larkin et al. (1980) hypothesized that a student may learn 10 things from a chapter and can learn up to 300 pieces of information. Larkin et al. (1980) also used chess pieces to describe how this is done when relating to equations one may learn in a class. For example, describing and demonstrating how the rook or knight moved before having the person who learned it practice this movement in a match is an example of learning and assessment.

In a study with a think aloud, Larkin et al. (1980) had novices and experts answer kinematic questions to determine their various approaches. In the study, the expert had strong mathematical skills and extensive experience in problem solving compared to the novice who had just been exposed to the chapter but had a fair level of skill in algebra (a prerequisite for the physics course). In their study, they found that the experience and skill of the expert had a large impact as they were able to complete the problem in one-fourth of the time. The expert in the talk aloud was able to document the equations they were using to solve the problem, and their solutions appeared automatic and appeared to come easily. This matches with what Benner (1982; 1984) and Dreyfus (2004) identified as what an expert would be able to do. They were using a forward reasoning strategy while the novice was using a backwards reasoning strategy. In a backwards reasoning strategy, the novice started from the unknown variables and worked to the given variables, while the expert worked from the given variables to the unknown variables.

The problem sets used in Larkin et al. (1980) are similar to what many students may encounter in prerequisite atmospheric science classes or within major related classes. Larkin et al. (1980) theorized that expert development should move beyond the explicit examples given in textbooks or the classroom and that students should apply the newly obtained knowledge through worked examples or applications. While knowledge is necessary and prerequisite to developing expertise in a skill, moving beyond facts and identifying familiar patterns to guide experts and connect relevant knowledge to appropriate actions and strategies is how students can gain these necessary skills (Larkin et al. 1980). The recognition of patterns and learning how to approach problems has been stressed previously (Benner 1984; Dreyfus 2004). By giving students experience and examples relevant to their field, students may progress along the continuum. Using this approach lessens the demand on students' cognitive load, allowing for information to be stored in the long-term memory and allowing for deeper understanding of the problems (Larkin et al. 1980).

In the field of geosciences, which includes atmospheric sciences, only recently has work begun to look at developing expertise in the field, much less geoscience education. Some fields such as biology and physics have had this research focus area for many years (National Research Council 2012). Much of the work thus far on this continuum has been focused on the geology field and despite the focus here, temporal and spatial scale applications can be applied to meteorology.

Petcovic and Libarkin (2007) note that geologists often must figure out the past based on data they have available and make many inferences to determine how or why something happened to achieve the current status. Their research focused on a metaanalysis of the field to assess what skills are possessed by an expert. They determined there were five characteristics that experts had. They were:

1. Mental/conceptual models of complex process
2. Domain specific content knowledge organized around big ideas
3. Spatial thinking
4. Ability to visualize and represent sets of data in mental, physical, and computation models
5. Able to conceptualize spatial and temporal differences

These results are applied to the various maps and diagrams that geologists often have to consider. Meteorologists are frequently working with forecast maps which may be incomplete or have missing data, and they have to mentally fill in the blanks. As such, these characteristics could be applied to meteorology, as some are noted in later sections.

In addition to the characteristics discussed, Petcovic and Libarkin (2007) also determined how experts in geology solve problems. Their results mirrored what Larkin et al. (1980) found. When given a problem to solve, the expert uses an initial qualitative assessment of the problem to determine possible solutions. Throughout this process, experts go back to rules of thumbs to progress forward while continually evaluating their answers and plausibility. Experts think more deeply about their approach. Novices tended to focus on the surface features and would search for appropriate equations needed to solve the answer, like the backward-thinking approach found by Larkin et al. (1980). However, Petcovic and Libarkin (2007) note that instructors can approach this problem suggested by Larkin et al. (1980) with explicit teaching. In an explicit teaching approach, Petcovic and Libarkin (2007) suggest teaching expert strategies to solve problems, use real world problems, and use collaborative group approaches and group discussions to encourage metacognition aspects.

The approach of explicit instruction has proven successful as shown in Davenport (2019) which used worked examples and group work in a Dynamic Meteorology course. In this study, students were given a problem set, and if necessary, with applicable images to aid in learning and understanding. The inclusion of the images was to aid in the development of critical thinking with directive prompts to help guide student thinking, as suggested by Larkin et al. (1980). The results of Davenport (2019) were compared to semesters that did not have a worked problem approach. Students in the worked approach managed to achieve 6-7 points higher on the final grade compared to the control group. In addition, student feedback indicated receptiveness to this approach. While this may not apply to moving students directly along the continuum, students were instructed on problem solving approaches, thus moving addressing a forward-thinking approach.

In addition, Petcovic and Libarkin (2007) felt that something important for their field was that students needed to be instructed on mental models. An important aspect of success they noted was that students recognize patterns and the potential impacts. Identifying patterns is a part of the process of moving along the continuum and it is the ability to recognize and respond to these that can determine the stage of the person (Benner 1984; Dreyfus 2004). In meteorology, pattern identification can easily be applied to winter forecasting and the origin of lows and snow ratios (Harms 1970). While this does not always occur, patterns can serve as guidelines. Finally, Petcovic and Libarkin (2007) propose that future instructors try to identify what type of instruction can help novices move toward expertise in their reasoning and thinking. The research presented here attempts to answer as it relates to the meteorological classroom.

Two recent pieces of research focused on the difference between experts and novices, but also addressed how instruction can improve student's skill and provide requisite knowledge to move students along the continuum. Kastens et al. (2016) used eye tracking software and bathometry and topography imaging to determine:

1. How and where do novices versus experts focus their attention in imagery?
2. How do experts and novices describe and interpret the data visualized?
3. What instructional strategies can be used to guide novices based on reported strategies from experts?

Their research used 45 students from a psychology participant pool with 26 reporting never having taken any sort of earth science coursework. The 14 experts used all had at least 10 years of experience. In the experiment, each person was given 20 seconds of uninterrupted and unguided time to assess the images shown on screen before being asked questions and responding aloud and having their response rated for correctness. Kastens et al. (2016) found that the experts performed much better than the students, however, they also found that students who had previous experience with an earth science class performed better than those who did not have any experience. Kastens et al. (2016) did not determine if prior experience would have these students potentially at a higher novice stage compared to those who did not have any experience. While scores were better overall for experts, both novices and experts managed to focus on the same features/focus areas for about the same amount of time, such as ridge or valley in the images, before looking at other features. However, when asked to describe the features and identify what the features represented, experts outperformed novices. In addition, experts would look at various components of the map such as other features, the latitude and longitude, and glance at the color bar. For novices, outside of the main features, they spent much more of their time looking at the color bar or looking back at the main feature of interest using it as a reference point. Novices also lacked description of quantitative aspects when describing the figure.

One hypothesis from Kastens et al. (2016) was that when students look at information, they look for the most important information which helps them make broad qualitative statements about the features they saw before focusing on smaller, potentially unfamiliar features. Data on maps can be messy, busy, and hard to interpret for novices, yet the information is realistic with what they would experience in the real world. Gould et al. (2014) showed that it is possible for students to make meaning of messy data as it encourages them to look and consider the data more deeply.

Kastens et al. (2016) asked how experts would instruct novices if they were teaching them features and the responses all matched the concept of perceptual learning. Gold and Watanabe (2010) state that perceptual learning is, through experience and the use of one's senses, how one can be taught to better make sense of what they are experiencing. These changes can be in either spatial or temporal patterns or both, and it is through this experience that the perception is altered, and one can provide more complex, differentiated, and abstract descriptions. In addition, this change in perception works in adults and is a skill learnable and retained throughout life. One of the experts in Kastens et al. (2016) reported this, describing that they just naturally "saw" the feature and that the feature was obvious and "jutted out" at them.

Kellman and Massey (2013) found that one way to increase success in perceptual learning was to provide multiple instances of the phenomenon with many similar features but also that there is enough variation between the images that the range of possible outcomes and variations are covered. Kellman and Massey (2013) also showed that feedback, regardless of correctness, can aid in perceptual learning. Kastens et al. (2016) and the experts in their study, suggested that if perceptual learning was used, pointing out main features, providing feedback, having students articulate their decision, and providing context should be used when instructing to help students make sense of data. This approach of instruction suggested by the experts is similar to guiding students using pattern recognition as suggested by Petcovic and Libarkin (2007).

Nosofsky and McDaniel (2019) used the idea of pattern recognition and applied it to a geology class. Using clearly defined categories of geological rocks, the authors trained students in how to identify the various samples. The authors were careful to make sure there was no overlap between the various methods used to test the rocks (i.e. Metamorphic vs Igneous) but that the categories had many different variations showing realistic aspects by not using clear cut examples. Through this approach, the authors were able to show the different features and nuances that existed in the same rock types and avoided instructing students to look for key features, which avoids any misleading aspects. Nosofsky and McDaniel (2019) were able to instruct students on category level features through this approach and with active learning where students were engaged aiding in knowledge retention. In the examples used, students also had subtle diagnostic features pointed out to them through feature highlighting. Finally, as suggested by the experts in Kastens et al. (2016), students were given feedback on their answers. The work of pattern recognition was applied to geology but could easily be applied to meteorology as well.

Much of the work mentioned here focuses on the geo- side of geoscience education. Meteorology has many patterns that repeat with a variety of nuances that occur between them. By instructing students to identify these features like radar indications of severe weather or midlatitude cyclone development, they can start to gain valuable experience and move along the continuum. Over time, students should be able to identify these on their own and estimate the potential impacts. Work for students and their growth as forecasters along the continuum needs much further documentation.

2.2 Meteorological Education

2.2.1 Basic Meteorological Components

When considering how a meteorological program should be structured, one of the major professional societies in meteorology that provide certification, the American Meteorological Society, issued a 2023 statement on what bachelor's degree programs should have. Section 2, sub-section d, states "course instruction in the program should employ best practices for effective undergraduate instruction and draw upon effective practices revealed by discipline-based research in higher education" (AMS 2023). In addition, section 3 describes the classes and requirements that should be included that a student does when achieving a bachelor's degree along with bullet points of what skills they should have. Section 4, sub-section b, has two primary skills listed: scientific computing and data analytics and oral, written, and multimedia communication. Additionally, in section 4, subsection c, one recommendation is that students can make a weather forecast that falls under the description of information vital to address societal needs. As tasked by the AMS, **programs are supposed to teach students to forecast and communicate this output**. However, the focus of meteorological education and forecasting has not been a priority thus far, as frequently noted by the National Research Council (2012).

According to a forum at the 2004 American Meteorological Society Annual Meeting, 18 specific characteristics were determined of what makes a good forecaster (Stuart et al. 2006). While some of these are soft-skill components, the technical skill side can easily be taught in a classroom to make better forecasters. The skills of note are that the proficient forecaster can "synthesize knowledge to useable information, learn from past events, possess good diagnosis and prognosis skills, and can assimilate and integrate a wide variety of data/information" (Stuart et al. 2006). This was echoed in Sills (2009) where forecasters needed to have a solid conceptual understanding of meteorology and various processes along with analytic and diagnostic skills. The most common tool used by a meteorologist is numerical weather prediction (NWP) and is a crux for forecasting. As a complex field, a variety of educational approaches are potentially needed to fully transfer knowledge and teaching forecasting. Weather forecasting itself falls into the higher contexts of Blooms Taxonomy.

Work by Kahl (2008) highlights a noted trend and problem justifying this research: primary meteorological education research previously focused on the introductory level course. Kahl (2008) found that while students at this course level are learning, and are learning the topics they want to learn, they are learning limited content. While this an important area to focus on, more work, especially at higher level courses, is needed to establish better and practical educational practices in meteorology. The

National Research Council (2012) frequently noted the lack of Discipline Based Education Research (DBER) in the geoscience fields. With educational practices established and used in other fields, meteorology instructors can use techniques as a part of instruction. Students will not just learn but become better scientists.

Both Roebber (2005) and Kahl (2008) focused on integrating more active learning into the classroom to not only help reinforce material, but address what students are most interested in such as severe weather and forecasting (Knox and Ackerman 2005). Roebber (2005) also suggests designing activities and lessons that appeal to as many learning styles as possible. Part of the issue, at least at one university, is that there is a disconnect between how instructors teach and how students learn (Roebber 2005). Some professors interviewed noted that they wanted to change their educational approach, but may lack the training, knowledge, or support to do so. These issues persist today (Kopacz et al. 2020). However, in some instances, some people interviewed did not see the need to change their teaching strategy and noted that a blend of theory and practice is uneven at all levels (Kopacz et al. 2020). Charlevoix (2008) noted meteorology is just beginning to enter the realm of scholarship of teaching and learning as a sub discipline. While more work needs to be done, there are trends that exist using established pedagogical approaches and the impact on students.

One common way for knowledge transfer is with scaffolding. Scaffolding is a learning process that is designed to promote deeper and fuller learning by using a variety of different support and tools and slowly taking them away to allow for student independent thinking and learning (Vygotsky 1986). By allowing students to learn on their own, they can move up Bloom’s taxonomy by applying what they have learned and allows them to synthesize the knowledge. In meteorology classes, due to the complex nature topics covered, scaffolding is needed to fully engage students in the short time span (Quardokus et al. 2012).

By establishing the overall goals of what a student in meteorology needs to learn and noting the roles of future student endeavors, the work now turns to the primary focus of this research: forecasting and education.

2.2.2 Forecasting and Education

As highlighted by Stuart et al. (2006) and the AMS, forecasting is a major component of the degree, and yet, training may not occur in the academic classroom. While there have been various studies that document student forecasters and skills over time, how forecasting is taught and what effective approaches are, it is important to move students along the novice to expert continuum.

To engage students, an authentic research approach can be used to impart scaffolding techniques. By encouraging students in a lab setting where they can put their skills and knowledge to use, students feel more successful and achieve a sense of satisfaction by being able to make sense of what is learned in the classroom (Quardokus et al. 2012). A lab-based classroom approach that focuses on this can impart the same experience as long as the necessary equipment is available to counteract any potential limitation. Due to various limitations and options available to students and teachers, integrating this type of learning requires instructors to work and consider all instances of teaching and the available tools. Universities have access to the necessary data and computer programs where students can learn to forecast. Even without access to meteorology data at a university, with the internet there are ample adequate websites to address important topics and convey information without the necessary technology.

Another way to improve along the continuum is to increase the perception skill through reasoning and knowledge. Experts can determine patterns based on past cases and use that as guidance for handling similar, current situations (Klein et al. 2006). The use of analogues now aids forecasters in reaching these conclusions faster for those with less experience. In addition to this experience, expert forecasters can make adjustments as the situation evolves rapidly and create an appropriate plan of action (Klein 1993). In meteorology, especially during severe weather, things change rapidly, and forecasters need to be able to handle these situations with speed and ease. Hoffman et al. (2017) developed a chart that shows what skills and thought processes go into proficiencies based on forecasting strategies, knowledge, pattern recognition skill, and causal reasoning and mental modeling. A less proficient forecaster mainly used guidance with little analytical or critical reasoning other than what they learned in class, whereas the most proficient forecasters compared multiple models to understand the problem and are able to think past basic information.

One concern in meteorology by some is that the role of the forecaster is diminishing, and models are the way of the future (Doswell 2004). While models are a useful tool, the forecaster needs to be able to discriminate between them and their performance versus what really happened. This is where the ability to analyze data and learn from past events is vital. Kocin et al. (1995) and Uccellini et al. (1995) documented forecasters as they used the model to forecast and noted how they responded to their experience versus the model. An experienced forecaster is better able to discriminate better between model runs and determine the feasibility between them (Kocin et al. 1995). While under observation, the forecaster worked with a more inexperienced forecaster and worked through the issues they were seeing and how to handle the output (Uccellini et al. 1995). Their observations noted a deeper understanding of concepts that an expert used to forecast versus what the note.

Ladue (2011) used observations similar to Kocin et al. (1995) and Uccellini et al. (1995) to further the understanding between knowledge transfer from expert to novice. A pilot study by Ladue (2011) found that most learning is accomplished on the job and begins with the general inability to forecast. While inexperienced forecasters do improve their skills quickly while working with someone more experienced, their overall experience is dependent on how they persist and create strategies to learn (Ladue 2011). One way is to ask the forecaster to provide feedback and to critically evaluate their own performance. In addition, working with someone who has more experience in the field is helpful. By assessing their performance, Josslyn and Jones (2008) found that less experienced weather forecasters often used one model, had issues with pattern recognition, and focused on not making mistakes. However, all this work has focused on those who have already received degrees and have employment as a forecaster. The impact of instructing those still in school may yield similar results or could lessen time for on-the-job training.

One of the most common ways to assess student growth is with some sort of forecasting contest or comparison. Research focused on forecast games over the years have led to a lack of consensus overall on the impact of the forecast game other than students show some growth, whether as degree seeking or non-degree seeking students.

One of the first studies to determine forecasting and skill for students in a comparison was Roebber and Bosart (1996). They used nine semesters of forecast contest data from the State University of New York at Albany which included temperature and precipitation data and compared the forecast results with those who had high experience to those who had low experience. In addition, they compared faculty to undergraduate students. Roebber and Bosart (1996) found a rapid growth in the low experience forecasters in the first five to ten forecast periods compared to high-experience forecasters. The authors felt this was part of an adjustment period as the results after this time were less sporadic for a low-experience forecaster. Errors persisted for the remaining 70-100 forecast periods for the low experience forecaster, but this was believed to be mainly due to learning the climatology and nuances of the region they were forecasting. These errors were picked up much sooner in the high experience forecaster and was not noticeable by the end of the 30-day forecast period. As such, there were significant differences between the low- and high-experience forecaster for maximum temperature, minimum temperature, and 12-hour precipitation at the 95% t-test. There was no significant difference between the faculty and undergraduates. Experience rather than education level correlates better with skills. While day to day there may be slight differences, real skill is apparent during extreme events when the ability to adjust mental models is needed and the meteorological conditions deviated from established "forecast rules." Roebber and Bosart (1996) concluded that the high experience users were able to make better use of mental models which came from experience and the ability to adjust better mentally. This ability to adjust may have stemmed from forecasting daily and/or experience. In addition, experience, rather than education level correlates better with skills. While day to day there may be slight difference, the real skills are apparent during extreme events when the ability to adjust mental models is needed and deviate from "forecast rules." Experts can draw from cases allowing them to recognize patterns, and act appropriately. The growth of the low-experience forecaster and the rapid progress they had shown them moving through definable stages reflects their increased ability to implement basic forecasting strategies. How they gained their strategies whether it be from class, own research, or guidance, was not documented.

Yarger et al. (2000) used an online web-based activity for a large introductory course at Iowa State University. They reported similar trends to Roebber and Bosart (1996) for forecasting skill with rapid improvement followed by a leveling off. However, Yarger et al. (2000) only used the 25 best scores in their analysis. An outcome of this research for students is that they asked more questions about the “why” of the atmosphere allowing for additional topics to be covered as students help guide the course narrative for the day. This was especially evident during the portion of weather briefings led by the instructor. Even at an introductory level, there were forecasting gains and application of concepts.

The web-based activity was again used in a follow-up study by Cervato et al. (2009) where they implemented the contest as a part of the student grades to determine performance for the same large introductory class. They found that it does have a direct impact: students who do well on the forecast challenge do well in the class as is reflected in the final grade. This may be because the forecasting challenge is 25% of the grade, but when adjusting for this factor, these positive results persisted. However, this outcome could have meant that students who forecasted sooner and were more diligent about it, were more engaged in the material and class, and thus did better. This is further supported by the fact that seniors enrolled in the class did better when relating forecast performance and test scores as more experienced students may have better test taking ability. Regardless, ~92% of students found the assignment somewhat useful indicating that this helped with learning and applying content material (Cervato et al. 2009).

Hilliker (2008) also conducted a forecast contest, but it was carried out over a multi-class approach in three different introductory meteorology courses: a general education course, a degree major course, and graduate student course. For both the general education and major course, there was a direct relationship between those who did well in the forecast contest and their performance in the course. In addition, Hilliker (2008) found that not only did students improve, but they also started to outperform numerical models. This could possibly show the value that even those learning to forecast have, helping quell the concerns in Doswell (2004).

Bond and Mass (2009) used a 10-week senior level forecasting lab that emulated a real-world situation from a 10-year period. As the class was offered in the spring and was typically comprised of seniors, the research assessed the forecasting capability of students after years of classwork. They are the only ones to do student research as it relates to forecast ability, real world emulation, and using upper-level degree seeking students only. Bond and Mass (2009) found that it takes 6 weeks or 25 forecasts to gain proficiency where, after this time period, it leveled off. However, students in the class were forecasting for nine different parameters at four locations. As such, students had to learn the patterns, nature, and nuances of the location they are forecasting for, which may have been a challenge for the students. If students focused on only forecasting in one area, maybe the time window could have been reduced. These results were compared to the first author to see how experience mattered. They found that the students who did best matched well with the “expert forecaster” they were competing against. When comparing forecast scores to the test grades and performance in the class, they were only moderately correlated (0.4) and may be due to the diverse nature of students and their goals and career ambitions. Bond and Mass (2009) noted that scores in the beginning tended to match NWP output, indicating students were relying too much on the model to forecast and not correcting these outputs. Experience with the model and how the model handles a forecast appeared to be why the students’ scores improved. This daily practice is what Roebber (2005) stresses in bridging the theory to practice gap.

The forecast assignment at Iowa State University was used again by Suess et al. (2013) except this time they compared the forecasting results of the introductory class to those of expert and more experience undergraduate students. However, compared to Bond and Mass (2009), they found that the improvement was restricted to the first 10-15 forecast periods before leveling off. On average, student forecast scores were about one point better than persistence but were not as good as the “expert” undergraduate forecasters. In addition, the students in the course did much worse than the experts when active weather was occurring, but they also struggled. Active weather is a challenge and is where student forecasters may struggle. Instructions to lessen this addition to the forecast score is something that research future may focus on.

Schultz et al. (2013) also conducted a forecast game for third year students in a newly developed course for two terms with 40 and 44 students in each term respectively.

However, as there is no meteorology program at the university, these students had little meteorological background. These students completed a forecast for only a ten-day period. Overall, similar to Hilliker (2008) and Bond and Mass (2009), those who did not forecast well did not do well in the class. However, since there was a bonus assigned to the final grade, Schultz et al. (2013) found that three of the four students in the first term and three of the six in the second term that managed to obtain the bonus point had some of the lowest scores in the class. For this reason, it was hypothesized that the bonus points motivated students who were doing poorly to perform better in the forecast challenge to make up for the lost point, that it allowed for students to excel in other ways, or that the students with higher grades were not as motivated. No exact reason was determined. However, Schultz et al. (2013) did include weather discussions in their class, but it was conducted by the instructor. This was done to help students with no experience to understand the forecast process and the complexity associated with it to help move students along the various stages of Bloom's taxonomy. Student feedback also indicated this growth. Since this was done with non-meteorology degree seeking students, the growth could potentially be greater for them, especially with multiple periods to practice forecasting.

Not only does forecasting increase student skill when forecasting, but so does the application of writing a forecast, known as the Area Forecast Discussion (AFD). The AFD is a product that describes the scientific reasoning behind the forecast made and is both issued and amended frequently at National Weather Service offices. How this impacts student forecasters has little research conducted about it, but work by Market (2006) shows that students who do write an AFD tend to outperform students who have not written an AFD for a forecast period when there is significant weather to occur. All 20 students in the sample agreed that writing an AFD helped organize their thoughts about the forecast. With all the maps and data available, it may be hard to communicate, but through the practice of communicating the weather, students can learn to put their thoughts together. The study did not mention how students learned to write AFDs, which is something further research can do to compare how this can aid in developing forecasters further. AFD writing and learning has little published research as it relates to students.

Athar and Sara (2014) used Columbia, MO to evaluate student forecasters over the course of the fall and spring semester. They found that students were able to outperform various NWP models, thus providing support to the skill of the human forecaster compared to the model. When comparing the point total between the two semesters and despite students issuing four more forecasts in the winter than in the fall semester, the error averages of the student forecasters actually decreased for minimum temperature and precipitation by 31 and 30 points respectively in the winter semester. There was an increase of 20 points for maximum temperature. Do the findings of Athar and Sara (2014) indicate students' gaining expertise? While their findings do not delve deeper into this topic, this may indeed indicate some gain.

The cross-collaborative nature and learning from someone more experienced can also aid in developing forecasters. Cohen et al. (2018) created a joint class with the Storm Prediction Center (SPC) and the University of Oklahoma School of Meteorology to teach severe weather forecasting to advanced students and graduate students. The opportunity to work hands on with guidance from so many experts in the field is a unique one to this university. It does, however, highlight the use of educational techniques discussed later, specifically, experiential learning. Cohen et al. (2018) noted that both instructors and students learned to forecast and severe weather forecasting skills, however, the lack of quantifiable data makes determining how forecasters grew hard to draw conclusions about the nature of this learning.

The lack of forecasting skill with recent college graduates is something that is troubling, as the weather significantly affects the economic output, the gross domestic product, and can destroy infrastructure and towns (National Research Council 2003). There are roughly 100 atmospheric science programs (in the United States) and the amount of expertise at each place varies along with the structure of the department and class offerings. Not all departments have a lab or forecasting component to them, which may limit the job prospects of graduating students (Hoffman et al. 2017). Due to this lack of resources, there may be time spent on the job training people up to a required level to handle their responsibilities (Jim Sieveking personal communication). By focusing on making better forecasters by the time they leave college, time in a new job can be better spent acclimatizing them to the new role or training in weather for that specific area.

2.2.3 Expertise and Mental Models

The National Research Council (2012) concluded that insufficient spatial skills may impede issues in problem solving. In order to have a handle on meteorology, a 3D understanding is critical as often maps are only provided in slices or layers of the atmosphere and students have to interpret from a level aloft to the surface for an area. There is point data, such as station observations and Skew-*T* diagrams, but information from these points is applied over some distance. This creates a temporal and spatial strain on forecasters, especially those new to the process. Recent work, however, has focused on how various groups assess mental models. Sills (2009) found that they wanted forecasters to be able to understand and develop temporal and spatial data cognitive models like a plan-view composite. This is doable in university meteorological programs. As a part of the “geo”-sciences, meteorological maps can be thought of as similar to the maps a geologist would use and look at. Maps in meteorology are often constructed as contour maps with relief and important features (McNeal et al. 2019). Atit et al. (2016) focused on best practices to instruct novices how to read topographical maps. They found that the use of pointing and tracing the features along with gestures, in addition to specific vocabulary, helped students better interpret the maps correctly. Overcoming various spatial limitations will allow students to be able to make meaning of maps and forecast information.

Hawkins et al. (2010) looked at introductory level undergraduate students and their understanding of 2D and 3D atmospheric features with maps. Since these students lacked the depth of knowledge that a more experienced meteorologist has, identifying and testing misconceptions was also conducted on the map. Males outperformed females when it came to 3D maps and assessing features while females managed to outperform males in 2D maps. Students overall struggled with assessment of features, hypothesized by the authors as due to lack of training. However, the results do indicate that both a 2D and 3D approach be used to instruct as it can serve all learners and help make connections (Hawkins et al. 2010).

Expert forecasters often have mental models that they can draw upon. Forecasting is often an iterative process, especially considering the amount of quantitative and qualitative data the meteorologist has at their disposal. This iterative process was tracked by Trafton et al. (2000) where military forecasters of various levels of expertise discussed how they made mental models during a forecast. They found that the forecaster would look at data sources 40 times, 58 different data sources, and the AFD they were writing 30 times. When building their mental model, forecasters looked at data in a goal directed way and integrated information from other sources to track data and build this model. They also did not take all the information and only focused on their specific task. They generally extracted qualitative information, like amount of mixing at a level, and used this to develop quantitative information, but never explicitly stated. Forecasters spent most of the time focusing on the qualitative aspects instead of the quantitative aspects. The researchers theorized that it was because these images can help in the mental aspect and forecasters can edit this mental image and allow for a developed visualization, especially in a 3D space.

Trafton et al. (2000) found that forecasters in this situation will look at a complex field, like a mean sea level pressure map with a 984-mb low over the central plains, build a mental model for their forecast, and use that to generate more general information to the end user by saying “there is a low over the Central Plains”. These forecasters did build a mental model with spatial and temporal components, but Trafton et al. (2000) found they determined that the forecaster was generalizing information and may be missing out on important details and nuances in the final product. To solve this problem, Trafton et al. (2000) suggested integrating data and overlaying it to complete a more holistic picture. Part of the issue with the research here is that forecasters in the armed services often have a large area to forecast for, have a time limit to achieve a forecast, and only use basic data. This trend continued in the work by Joslyn and Jones (2008) where novices did not generate mental models in their forecast and relied on the computer models and forecast products. Further analysis of experts and students needed to be conducted.

McNeal et al. (2018) analyzed the various techniques that meteorologists use to look at imagery within spatial thinking between undergraduates, graduate students, and experts. By identifying the most common approach, instructors can attempt to train students on this approach. Participants in the study were given various meteorological images like surface maps, satellite imagery, and radar, and asked to answer questions and how they managed to answer the question. They found that up to six different spatial skills were needed, but the three most common skills used were mental animation (74.6%), disembedding (72.4%) and perspective taking (71.6%). Disembedding is the ability to identify something embedded or obscured by “noise”. In meteorology for example, McNeal et al. (2018) included disembedding by identifying fronts, gradients, and other features from a busy or clustered map. This is something meteorologists commonly encounter.

The usage between students and experts, however, reveals that the experts have a better understanding of meteorology and had more experiences to draw upon. This difference depended on the images they were looking at however. For example, students (88% undergraduate, 75% graduate) mentally animated the radar image compared to experts (42.8%). When asked if students used mental animation for the surface map, 70.2% of students did not but 67.9% of professionals did. In addition, only 56.8% of students used disembedding for the surface charts while 82.1% of professionals did.

The work by McNeal et al. (2018) was further explored in McNeal et al. (2019) where they focused on spatial cognition and meteorological instruction between students and professionals. In their results, they found that domain knowledge and disembedding were the most important and were related. Regardless of skill, as participants stated they used more disembedding, their meteorological domain score increased. McNeal et al. (2019) from these results suggested that training students to interpret maps and identify map features is associated with student success in the classroom, similar to many previous studies (Roebber and Bosart 1996; Hilliker 2008; Bond and Mass 2009). The stressing of pattern recognition continues to align with how guide students in building expertise, as noted by Dreyfus (2004).

While these previous studies focused on meteorology and mental models with forecast maps, there are other components of meteorology where mental models are necessary. Kastens and Ishikawa (2006) identified three main cognitive tasks that can guide what experts do. These are: describe and interpret objects, comprehend spatial properties, and usage of spatial thinking. Within the "describe and interpret" task objects are applying rules of thumb, learning the terms and techniques, developing schema, and determining shapes and patterns from noisy backgrounds. The "comprehend spatial properties" task included being able to make and use maps and synthesizing 1D and 2D images to develop a 3D mental model. Finally, within the usage of spatial thinking tasks lays the idea of converting distance to time or stating how things "move" through the ocean such as temperature and salinity diagram. This is similar to how a meteorologist interprets a Skew-*T* diagram. Elements of the novice to expert continuum by Benner

(1982; 1984) and Dreyfus (2004) exist. Establishing a guideline as Kastens and Ishikawa (2006) shows the importance of mental models.

The ability to understand mental models seems to be correlated with stronger forecast ability as shown in Roebber and Bosart (1996). In addition, as shown by Stuart et al. (2006) and Ladue (2011), having a mental construction of various meteorological components can lead to grasping concepts better, connecting material, and potentially developing relevant skills. McNeal et al. (2018) and McNeal et al. (2019) showed the relationship between map analysis and the various approaches experts took over novices. Disembedding is one technique that instructors may want to focus on. By developing instruction, guiding learners in the analysis, and giving them experience, students in the classroom can gain these skills as well as it relates to analyzing forecast maps. The “how to instruct” is covered in the next section.

2.2.4 Pedagogical Approaches to Meteorological Learning

There is a wide array of approaches to teaching meteorology and some are covered here. A common approach, but broad in scoop, is active learning. Active learning is any learning that actively engages the students in the learning process (Fink 2013). Research has shown that students engaged in this type of learning have improved critical thinking skills, increased retention and transfer of new information, improved interpersonal skills, and increased success in courses (Prince 2004). In many of the sciences discussed in the National Research Council report (2012), active learning was highlighted as one of the successful approaches in the sciences. There are a variety of ways active learning has been implemented in the atmospheric sciences overall with a high degree of success. In addition, instructors and educators interested in improving their instruction often use this approach (Manduca et al. 2017)

A popular and well researched approach to develop students is experiential learning. Experiential learning engages the learner by doing and then reflecting on their experience. This instructional practice was put forth by Kolb (1984) and focuses on learning by a cycle in four stages. These stages are the person (1) has a concrete experience where they (2) observe and reflect upon the experience leading to (3) formulating concepts and generalizations that are (4) tested in a future situation, resulting in a new experience thus repeating the process. When implementing this cycle, three things need to be integrated. This includes: knowledge which includes concepts, facts, and information acquired through formal learning and past experiences; the activity itself in which there is an application of this knowledge to a real-world setting; and a reflection of this experience where one is able to analyze and synthesize this experience to create new knowledge (Kolb 1984).

Moore (2010) compiled a list of various experiential learning approaches. The different approaches include internships, service learning, cooperative education, research experiences for undergraduates (REU), study abroad, and community-based research. However, as noted in the process by Kolb (1984), any experience that emulates the real world could be considered a part of experiential learning. Fink (2013) ascribes to courses or activities that focus on “rich learning experiences” where students can experience multiple kinds of significant learning goals at the same time. Fink (2013) considers the list of experiential learning from Moore (2010) as outside of the classroom experiential learning. For in-class experiences, Fink (2013) includes debates, role playing, simulations, and dramatizations. As long as students are able to go through the learning cycle proposed by Kolb (1984), access to an authentic experience is relatively easy to incorporate in many classrooms.

In the meteorological classroom, there are ways to integrate experiential learning. Wade and Caricone (2019) simulated an end of year experience where students in an upper-level forecasting class were tasked to answer phone calls and respond to situations as a forecaster to someone pretending to be an end user of meteorological products such as an emergency manager. The simulation emulates an experience they might have in the real world. Integrated throughout the course are lessons and discussion on ways to respond and handle these situations with various associated forecasting examples. Students overall enjoyed this and appreciate that it was a true reflection of what they may face in the future. This is one way to simulate and train students integrated within the classroom. Croft and Ha (2014) conducted similar research with their field consulting classroom which was met with positive reception. The course, having gone through different iterations so no standard has been established, has students meeting the course objectives and developing the necessary professional skills. Cohen et al. (2018) also included professional development in their course to connect the theory of severe weather forecasting and the practical applications. In addition, as shown by Bond and Mass (2009), a classroom or lab component that emulates a real situation can work if the tools are available such as proper computer programs.

Another way to integrate active learning is through the case study approach. The case study approach is commonly used in the nursing field and combines two key principles: the case narrative and the discussion of the case. The case study approach is an active learning strategy that engages students to think critically (Popil 2010). Students are given information and must come to a conclusion and develop or apply newly learned skills, allowing a connection between theory and practice. In addition, depending on the design of the case, students may also work on refining other skills including communication, cooperative learning, and self-consciousness towards assumptions and conceptions (Popil 2010). Keen and Thatcher (2010) in an aviation weather course based in Australia given various case studies to learn how to avoid potential issues in aviation forecasting. They were given similar data to what they would have on the job for the actual event. Student feedback was highly receptive to the event, and the authors found that the students' awareness and understanding of severe weather phenomena improved. Both Rutledge et al. (1993) and Palmer et al. (2009) used various case studies with radar classes to train students where Palmer et al. (2009) also used field work to achieve an authentic experience. With data freely available and accessible, case studies in meteorology could play a crucial role in developing and practicing emergent skills for students learning to forecast. Many instructors may already include this format, but formal documentation in meteorology is lacking.

One of the most compelling ways to give students an experiential learning experience is with a field course. In these types of courses, students and an instructor(s) define some objective and head out to either do work for research, as a general course such as storm chasing, or both but all contained an element to develop forecasting skills.

If the experiential aspect is well designed, it can contain many different learning aspects. Mullendore and Tilly (2014) designed a combined forecasting internship and field campaign in conjunction with a course designed to cover topics related to the Deep

Convective Cloud and Chemistry (DC3) field campaigns. The course itself was taught over two spring semesters with five and six students respectively. Only the six in the second spring course participated in the field experience. In addition, students learned to forecast and were given a pre- and post-test throughout the course and students self-assessed their forecasting abilities. Questions asked included topics such as "ability to forecast longevity and deep convection," "ability to forecast in a 24-48 hr period," and a "nowcast" forecasting ability. There were gains in all aspects and while the instructors felt students may have assessed their skills too high, the authors agreed that students had demonstrated gains. For the internship components, students were providing a daily forecast for the campaign for two hours a day, seven days a week, for 6 weeks. They were focused on the 0-36 hour window for deep convection. The daily forecasting was favorably reviewed with high rankings in forecast paradigm, improvement of skill, and students felt value as a team member. However, students did not like the start time, teleconferencing to the field campaign group, and lack of self-verification. The instructor noted students were not prepared for the pressure/multitasking setting, but felt it gave a good exposure to the real-world aspect. For the field experience, students liked that they were finally able to put concepts into practice and see the results of their efforts. These results show how education and field work can be combined to develop students *and* meet research needs.

Both Barrett and Woods (2012) and Tanamachi et al. (2020) had success with field experience with a focus on storm chasing. Barrett and Woods (2012) designed a not-for-credit course for the United States Naval Academy with the learning objectives to understanding atmospheric processes and severe weather, how to obtain real time data, and provide real world experience. The course was completed over two springs and the students selected were all meteorology degree students and received training on related severe weather topics, storm spotter training, and compiled a forecasting guide based on published papers. Radar analysis was especially stressed as chasing was in-situ. In addition to chasing, students led forecast discussions, visited national centers, and met with other graduate students and researchers to explore future options. While chasing, students had to take notes about the days' forecast and observations as well which was one part of the assessment of the success of this course. Pre- and post-surveys, forecast sheets, a quiz, and an essay were also conducted. Results showed a content knowledge gain related to severe weather in both samples groups. Student worksheets indicated that the students got better at forecasting and were able to home in on the interest area better over time. The journals were infrequent and not really used and were mainly used to track details on long days and help with the final essay. The essay reiterated this forecast growth and confidence along with students liking the application of their skills, similar to other research. Synthesis of the results showed that they learned the science of convective weather and the tools and techniques to make a successful forecast.

Similar to Barrett and Woods (2012), Tanamachi et al. (2020) also conducted a chase course, but their work also included the use of instrumentation such as an X-band radar, a radiosonde, and precipitation stations. Their data came from 18 students over three years for a four-week chase course, with one week in the field. The other weeks were used to learn about the data collection, forecasting severe weather, conversations with graduate students and professors, and visits to local weather offices. Students were also required to journal, helping instill the theory by Kolb (1984). The course had a unique distribution of students with seven graduates, ten undergraduates, and one non-degree seeking student. In the four-week course, students showed growth and gains in their ability to forecast and even learned about the metacognitive process. Over the course of the class, on a 5-point scale, student pre- and post-test surveys showed a 1.2-point increase in students' self-assessment to forecast the weather and 1.5-point gain in an ability to present a weather briefing. This was one of the first to document with evidence how students perceived their ability to communicate the weather to future forecasters.

Work by Sherburn et al. (2019) had students at North Carolina State University working with the local NWS to provide radiosonde data for High Shear Low CAPE systems. Since the local office was over 100 km away, this not only gave students experience with a radiosonde system, but provided valuable meteorological information, establishing a partnership with the local office. Students were placed in charge of deciding if balloons were launched based on established forecast criteria. By analyzing the upcoming event, students could practice their forecasting skills. No specific measurables were gathered from this research. Students also had the autonomy to determine how long to keep launching. The lack of specific guidance allowed students to get an understanding of the processes necessary for intense observations periods (IOPs), something they may be a part of in graduate school. Also, exposure to instrumentation is important as there has been a decline from 1964 to 2000 with fewer than 20% of schools offering graduate level courses on instrumentation (Cohn et al. 2006).

Field campaigns also help students determine some career aspirations and work on non-technical skills as put forth by Stewart et al. (2006). The clarification of career aspirations was gained from the experiences from Mullendore and Tilly (2014) and Tanamachi et al. (2020). Rauber et al. (2007) combined field experience, research, and future careers aspirations. Research was conducted by aligning field projects with classroom exposure where 24 graduate students and nine undergraduates managed to conduct research, complete theses, and publish research. However, this level of activity, for some schools and professors, may be limited by staff, funding, and other goals. Rauber et al. (2007) showed potential productivity and positive outcomes. However, Shaprio et al. (2009) showed that even local measurement tools in an undergraduate classroom can be structured to have an authentic research approach to develop research skills.

These studies show there are plenty of ways to integrate an experiential learning component beyond the storm chasing class that can impact all students. The prospective student page at Northern Vermont University has this element as one of their features that entice students to attend. The website gives clear examples of how they integrate this approach into the classroom such as the use of a radiosonde system, forecasting applications in the classroom, and working with working with professors on their research projects. Student testimonials reflect that they gained valuable real work experience. With the bevy of opportunities available at many schools, as shown here, integration of a real-world learning experience helps solidify and connect concepts in the classroom and practice necessary skills. As discussed in Stuart et al. (2006), there is more to meteorology than just forecasting, and activities that target more of the mentioned skill set that need to be developed.

Chapter 3 Methods and Methodology

3.1 Overview

This chapter details the design used to conduct this research. The chapter is broken down into different sections describing the methodology used. The first section describes the participants in the research study and the classroom and content. The second section describes the different procedures and experiments used and the pedagogical considerations established in Chapter 2. The third and fourth sections address how the data was analyzed.

The design of the research fits into the DBER approach as it is "grounded in the science...discipline and addresses questions of teaching and learning in [said] discipline" (National Research Council 2012). In addition, the research attempts to answer the nature and development of expertise in the discipline, a long-term goal of DBER (National Research Council 2012). Charlevoix (2008) describes the need for more atmospheric science education research as scholarship of teaching and learning (SoTL). Charlevoix (2008) encourages atmospheric science educators to look in their classroom to further atmospheric education practices specifically, a tenent of DBER application. However, as proposed by St. John and McNeal (2017) there is an overlap between SoTL and DBER. While this research looks at forecasting in a classroom, almost all universities that have a meteorology or atmospheric science bachelor's degree program have a synoptic meteorology class. Such a course is a key part of the structure of an academic program as described by the AMS. As such, these results can potentially be applied to any academic program looking to develop student forecasters.

3.2 Design Overview

3.2.1 Participants and Setting

All the participants for the research were college age students in two four credit hour courses, ATM_SC 4710, Synoptic Meteorology I, and ATM_SC 4720, Synoptic Meteorology II. Both courses are cross-listed with graduate courses, ATM_SC 7710 and ATM_SC 7720 respectively allowing for both undergraduate and graduate participants in the study. As a 4000-level course, this is a junior/senior level course. In addition, the courses are treated almost as part I and part II with almost all of the students taking both in sequence in the same academic year allowing for roughly the same number of students between each semester. As such, ATM_SC 4710 is taught in the fall semester and ATM_SC 4720 is taught in the spring semester. If a student does not perform well in ATM_SC 4710, they may not go on to ATM_SC 4720 as successful completion is a prerequisite. In addition, to enroll in the class, students must have taken ATM_SC 1050, Introduction to Meteorology and Math 1700, Calculus II. The course also recommends that students have taken one physics course. The physics course is required for the bachelor's degree of Atmospheric Science at the University of Missouri and must be calculus based. As such PHYS 2750, Physics I, is the course that students are required to take. However, with approval from the instructor, students can enroll without having met all these requirements knowing that course may be difficult for them.

All students for this study had to sign an Institutional Review Board (IRB) form allowing for consent. This was project 2009131 and a copy of the letter is included in Appendix A. The study was included under the "exempt" title as there was little harm to the participants and collected data, when published, would be anonymous. It was heavily stressed at the initial recruitment period and throughout that students did not have to participate in this research, complete any survey, or have their data used at any time. Students were able to opt out if they wanted. In addition, students' grades were not tied to their participation. The IRB letter allowed usage of the students' grades and observational notes. The participants were from the 2017-2018 and 2018-2019 classes.

3.2.2 Classroom Content and Lab Setup

ATM_SC 4710/7710 for Fall of 2017 (FS17) was taught in a classroom/lab combination that can hold up to 25 students. The classroom is fitted with a computer, overhead projector, and two whiteboards. The Fall 2018 (FS18) version of the course was taught in a different classroom that was not used for lab. The classroom was fitted with an overhead projector, a whiteboard, and a computer. The FS18 version of the class also included audio recording through Panopto.

The course description for ATM_SC 4710/7710 focuses on instructing students in meteorological data along with basic techniques for meteorological analysis. The course covers the mathematical and physical underpinnings of forecasting, especially at a day 2–7-day scale, or the synoptic scale. Students learn how to analyze station maps, use them to forecast, study basic forecasting methods, learn isentropic analysis, cross-sections, time heights, snow forecasting, and basic satellite and radar analysis. An example Syllabus is included in Appendix B

ATM_SC 4720/7720 is treated as a continuation of the previous course, so students are expected to be familiar with and have recall of the prior material. The classroom used was the same as the SP18 class. The Spring 2019 (SP19) version also included Panpoto audio recording.

The course description of ATM_SC 4720/7720 includes graphical analysis and interpretation of atmospheric phenomena. As the continuation of the course sequence, students are assumed to have an understanding of the previous semester's material. Topics in the class include midlatitude cyclones, vorticity, the quasi-geostrophic χ and diagnostic ω equations and their various derivations, thunderstorm and severe weather forecasting, and jet streaks. This course is also the writing-intensive course for the department. An example Syllabus is included in Appendix C.

Both iterations of this class used class time and forecast time in the Weather and Visualization Lab (WAV Lab). This room is fitted with 15-16 computers installed with the LINUX operating system that allow for access to various meteorological programs. These programs include IDV, GARP, GEMPAK, the ntl suite (including NMAP2 and NSHARP), and AWIPS-II. The lab also has additional programs for research installed and is used in instruction for other classes.

Halfway through this research, GARP and GEMPAK ceased to work, and AWIPS-II became the primary program used. However, old case data still existed and worked with GEMPAK. GARP and GEMPAK were used in the meteorological enterprise. AWIPS-II is used by the National Weather Service and was used to emulate these real-world environment students may end up in. Universities are provided this system through Unidata, a community with a goal to share geoscience data and visualization tools. The computers are user and password protected and the lab is available to students during normal business hours.

3.2 Procedures and Experiments

3.2.1 PRE-DEEP Grant

An opportunity arose to fund a part of this research to allow students to get dedicated time and experience to forecast. The grant was aligned with an ongoing master's project that involved radiosondes and precipitation allowing students to get practical forecasting experience and assist in research. This aligns with the methods used in Rauber et al. (2007), Barrett and Woods (2012), Mullendore and Tilly (2014), and Market (2015). This was also considered a paid internship for students as it was dedicated time to develop forecasting skills and communicating the forecast. Students created a forecast that included both an AFD for the technical communication and a more layman forecast for the public. Thus, students can potentially develop the skills mentioned by Stewart et al. (2006), including soft skills.

This opportunity was offered to students in the second iteration of ATM_SC 4710 (FS 18). Students signed up for either a morning or afternoon shift to forecast with an experienced forecaster. The four experienced forecasters who aided in the shifts had taken the course prior and were familiar with the instructor's forecasting methods and approach. Three of these forecasters were graduate students and one was an advanced undergraduate with well vetted forecasting skills. One of the forecasters was the researcher of this work. Each shift allowed students two hours to write and forecast but could vary depending on schedules and weather. During forecast shifts, relevant topics were stressed as they occurred. For example, inversions affecting fog development or how to forecast temperatures the first clear night after cold frontal passage. This was done to help connect classroom material with a practical purpose.

The forecast sessions used the AWIPS-II program to emulate real-world resources and applications they may use. Since this software program and the forecasting process were potentially new to the students, a scaffolding approach was applied. They were guided through the forecasting process and how the program worked. In addition, class time for ATM_SC 4710 was also dedicated to both these goals as well.

Students also were scheduled to obtain real world experience through assisting in radiosonde launches for the ongoing master's research project. This was weather dependent due to limited resources. A decision was made by the master's student conducting the research project to determine if a radiosonde launch that day was possible. The student also gave a presentation during one of the class periods about the ongoing work and how the students would be contributing. In addition, students were invited to the thesis defense.

Data gathered for this project came from student observations, closed- and open-ended surveys, and student interviews. All students who participated were in the ATM_SC 4710 class. This allowed for comparisons of students with dedicated forecasting time outside the classroom, compared to students from the first year who only had class time and projects.

The project was funded by a mini-research grant from the University of Missouri School of Natural Resources. This funding paid for the student salaries and necessary equipment to conduct radiosonde launches. This was considered a paid internship, a rarity in the meteorological fields overall. All who participated in this study had to consent to signing an IRB from. This was IRB project 2012502 and a copy of the letter is included in Appendix C

3.2.2 Classroom Instruction Design, Structure, and Observations

This research was conducted over a total of two years, in 4 different classes, but as described above, due to the structure of the program, each of the years can be treated as two different cohorts. Any variations from the groups are described in the results section.

Both classes were designed to cover the same exact material with essentially the same timeline. In addition, all assignments, labs, and tests were exactly same, allowing for a comparison between the two groups. While the specifics of each class period and what occurred were dependent on student engagement, receptiveness to the material, and the weather, the core content was the same.

As stated previously, both ATM_SC 4710 and ATM_SC 4720 classes are scheduled for two hours with the first-class hour dedicated to class content work and the second hour dedicated to lab work. The hour of lecture often contained the instructor walking around the room during their lecture time presenting the slides. Occasionally, the second hour would be used for lectures as well if concepts needed more coverage or to make up for missed class periods.

While the class may have had a traditional lecture approach, the instruction was such that about halfway through class periods, a think-pair share or thought question would be conducted. While these questions were normally unscripted, think-pair-share questions can be quickly integrated into the classroom to allow the instructor to help galvanize the material discussed (Lyman 1981). In addition, the approach allows students who may normally not respond to questions a chance to share thinking and insight (Prahl 2017). The think-pair-share or thought questions asked were left to the instructor to decide based on a real time assessment of student comprehension. Questions, student responses, and perceived reception to this practice were recorded.

In ATM_SC 4720, the second hour was often used for student map discussion, discussed in further detail in a following section. This shift took place after the first month of the second semester. The education approach covered in ATM_SC 4720 was the same as in ATM_SC 4710.

The researcher sat in many of the class periods to conduct student observations. Things noted were the students, receptiveness to questions, materials, and general interactions. General attendance was written, but also student prep for example, did they print the notes in advance or were they taking handwritten notes. Observational notes were used as supporting evidence and were not a primary source of data.

3.2.3 Area Forecast Discussions

In ATM_SC 4720, the culmination of the learning is shown through two primary assignments, writing area forecast discussions (AFD) and through weather briefings. Both activities are highly interactive and fit within the active learning pedagogical approach. The weather briefing also fills the lab component of the course. These two assignments are both collaborative as they work with up to two other classmates to write and or present. The collaborative nature allows for accountability and help when needed on comprehension and guidance, similar to Grundstein et al. (2011). In addition, there was time deadline for students to meet, emulating the real-world component of having a deliverable, as seen in Barret and Woods (2012). Finally, due to the complexity and uncertainty inherent in weather forecasting, effective communication is a way for students to understand the given problem (Walton 2020).

For the AFD, students in the 2017-2018 year of study learned AFD writing through reading them from various forecast offices of their choice. In addition, one assignment was for students to find an AFD and "peer review" it. They were asked to highlight scientific phrases, clear and concise language, meteorological concepts they knew and did not know, and then comment with any questions that they may have had. After this activity, a discussion was held about the hallmarks of a good AFD. As necessary, AFDs were read, analyzed, and discussed in class to provide additional guidance before students were assigned the task.

Students in the 2018-2019 year of this study however had the AFD tied into their forecasting duties. While PRE-DEEP was only funded for the first semester, the researchers decided to keep it going as a part of this experiment. This would allow a comparison between the two groups by comparing experience and training. However, while students still worked with an experienced forecaster this semester, this individual only helped to serve as oversight and provide guidance when asked. They did not write any component of the AFD nor did they review it. Students were graded on their original work.

A rubric was developed for this assignment and provided to students. Appendix E contains the rubric. The assignment was worth 20 points and the rubric had four components with each component worth a maximum of 5 points with clear indications of what the assignment was looking for to give clear expectations to students (Walvoord and Anderson 2011). These components were: technical content, technical application, organization, and writing quality. By having these clear expectations in a rubric, students were able to see where issues may exist, allowing for feedback with the goal of students raising their score. This iterative feedback approach is an effective way to improve student technical writing (Walton 2020). This rubric also draws upon the components needed to meet writing intensive requirements for the University of Missouri Campus Writing Program.

In both spring semesters that ATM_SC 4720 was taught, students worked in groups of two to create an AFD which had to have a current discussion, a short term (0-36 hours) discussion, and a long term (36 hours-5 day). This allowed students to divide the work if they chose and complete components as they saw fit. If a student was stronger in short-term forecasting, they could take that portion on, as long as the writing was cohesive and logic was maintained. As stated in the rubric and assignment sheet, this was the time for students to communicate to their audience and apply meteorological knowledge learned over the previous and current semester. Correct usage of meteorological jargon was allowed. The first iteration of the class emailed these AFDs to the instructor and the researcher/TA.

In the second iteration, the public communication component was added but was not considered a part of the writing quality. Emphasis was still placed on the meteorological component when grading. In this group, the organization was slightly different as they had a public component and a more traditional AFD component. Both were viewable by the public but the components and structure of the AFD remained. The AFDs were posted on a blogspot to allow the public to read them if they wanted. The meteorological component was clearly denoted in the structure of the blog.

3.2.4 Weather Forecast Discussions

The second way in which students were assessed with a cumulative approach was through weather forecast discussions. The instructor has been using this assignment for many years and is implemented in ATM_SC 4720. This activity is a way for students to orally convey meteorological information. The ability to communicate was noted by professionals in Stuart et al. (2006) as a necessary skill to develop.

For the assignment, students are split into groups of three where each student was responsible for a specific portion of the forecast. The three forecast components were: a diagnostic discussion, a short term (0-36 hour) prognostic forecast, and a long term (36-168 hour) prognostic forecast. In the initial assignment sheet, students were given explicit examples of what to look for in each category. For example, in the diagnostic section students had to include current conditions in some way such as readings from Sanborn Field or the Columbia Regional airport. In the short-term prognostic forecast, examples of various height maps and what to plot on them were suggested. In long-term prognostic forecast, students were strongly encouraged to use ensemble methods in their forecast for part of it. Finally, before students conducted these briefings, both the instructor and TA gave demonstrations of these approaches, what to look for, and discussed with students effective strategies to complete the assignment.

The goal of the instructor in the class was to allow students to give a briefing a minimum three times during ATM_SC_SC 4720/7720. This approach allows each student to get practice forecasting and communicating for each of these sections at least once. When a class is smaller, each student may get the chance to do additional weather briefings. In addition, an extra window of time is allotted in case a student was sick or missed a day for any reason.

The total assignment was worth 40 points (Appendix F). When grading the assignment, there are four sections that students are graded on each worth ten points each. Since each student was required to go a minimum of three times with each student doing at least each portion of the assignment once, the final grade was averaged among the three scores. These four components were: scientific content of discussion, quality of the analysis, completeness of the presentation, and presence/voice quality. The scientific content focuses on applying their knowledge to the forecast as it logically makes sense such as, having a negatively tilted trough and how the tilt promotes cyclogenesis and an increase for significant weather potential. The quality of the analysis focuses on using appropriate sources like AWIPS, GARP, NOAA products, or specific online approved sources. This was necessary because sometimes the WAV lab had technological issues. In addition, quality of analysis included using scientifically sound data plotted such as avoiding plotting surface data and 700mb omega. The completeness of presentation area included giving all the necessary information in a way that made sense such as observational data before forecast data. In addition, students had to present information in a logical manner in a top-down (i.e. upper troposphere to the surface) or bottom-up approach. Jumping around meteorological levels was not encouraged. Also, while not always the case, if there was an event of interest in a student's forecast period, students were suggested to focus on the time/event of interest. The final area they were graded on was presence and voice quality. For each presentation, they had roughly 7 minutes to present the information as necessary. As such, the student was tasked with being concise and highlighting the important information. This area also focused on their presentation and presenting with confidence and in an articulate way.

After the presentation, non-presenting students were able to ask questions for either clarification of the forecast or to inquire more about the weather that day and/or why they made the choices they made. While the presentation was delivered to the class, it was open to the whole department to come. There was generally a mixture of undergraduate and graduate students. On days with weather of interest, there was a potential for additional students to attend.

3.2.5 Forecast Game

The University of Missouri hosts a forecast competition like many universities (Roebber and Bosart 1996; Bond and Mass 2009). In this competition, students and staff test their forecasting skills with three variables to forecast daily: daily maximum temperature, daily minimum temperature, and a precipitation category. These three products are the simplest components of a forecast and are what the public looks for and what they concern themselves with. At other universities, they evaluate different components such as wind and sky cover, but those are not standard across the various forecast contests (Hoffman et al. 2017).

Students submit their forecast to an email account set up. Forecasts are due by 0000 UTC of the day before the forecast period, as to not give one student an advantage when using the latest model runs. These forecasts are then entered by a student who has volunteered to oversee data entry. Once completed, the data are published to a webserver, which is publicly accessible. This allows students to view their forecast results when they are updated.

Table 3.1. Precipitation categories as a part of scoring in the MU forecast game.

Category Number	Precipitation Amount
0	0
1	Trace-0.05”
2	0.06”-0.24”
3	0.25”-0.49”
4	0.50”-0.99”
5	1.00” or greater

When a student forecasts, their goal is to be as to as close to the minimum and maximum temperature and forecast the correct precipitation amount. A difference of zero means that the student forecasted the minimum and maximum temperature and precipitation range perfectly, there was no difference between the forecasted value and the actual value. As the difference increases, the point value that is counted towards the student is increased. For example, if a student was one degree Fahrenheit off the maximum high, they earned one point for that category. For precipitation, there are five different categories with different ranges for various amounts of precipitation values, listed in Table 3.1. When a student correctly forecasts the amount of precipitation that falls, they receive 0 points but may also get 5 points for every category that they are off.

The scoring system is similar to golf, where the lowest score wins the overall contest for the semester. In the ATM_SC 4710 and ATM_SC 4720, students are required to participate as a part of their learning process. The lowest point getters are given an incentive by having extra credit percentages added to their final grade at the end of each course. In addition, while their overall performance does not affect their grade, they are still required to forecast 70% of the days as part of the participation portion of the grade. If a student did not participate in this amount, they had participation points deducted and were not included in this study.

Student forecasts were verified from 0000UTC to 2359UTC and had to forecast for a full 24-hour period. This meant that students had to forecast and pay attention to timing of impactful weather features, mainly frontal passage. The verification site and location used is the same as used in Athar and Sara (2014), the Columbia, Missouri regional airport (KCOU). If a student did not forecast for the day by the required time, the student was given climatology. The climatological temperatures students are given are from the 30-year average for that given day. All climatology days have a 2 in the precipitation category. As such, if a student is forecasting every day, students SHOULD be able to do better than climatology. Very rarely would climatology be a zero-point day. This was how student participation in the forecast process was assessed. If a student's total point value at the end of the semester was not more than 30% of climatology, they were considered not participating in the contest. Since climatology was added to student scores, this was considered a part of the student's final score and not filtered out.

3.3. Research Design

The research method used is a quasi-experimental research approach. In a quasi-experimental research approach, there is little ability to manipulate the independent variable as students were not randomly assigned (Price et al. 2017). Students enrolled in the courses in this research by their time in school and schedule availability. Quasi-experimental research allows for an understanding of casual effects of different educational approaches (Gopalan et al. 2020). The PRE-DEEP research grant and the students enrolled created a non-equivalent group design. In this design, one group is exposed to a treatment while the other is not (Price et al. 2020). In the research, the biggest difference is the role that explicit forecasting training has on meteorological topics and assessments that impact meteorological skills as discussed in Stuart et al. (2006).

The methodology used is the qualitative and quantitative approach as put forth in McNeal et al. (2020). This research methodology approach is better known as a mixed methods approach as defined by Creswell and Plano Clark (2018). Specifically, this approach uses a convergent parallel design with a data-validation variant in which quantitative and qualitative data are run in parallel and analyzed separately. Once analyzed separately, the qualitative data and the quantitative data are combined to identify themes and provide recommendations (Creswell and Plano Clark 2018). The research uses surveys, observations, interviews, and student test and assignment scores results to evaluate their growth as a forecaster. Observations are used as supporting evidence, not primary evidence.

3.4 Data Analysis

3.4.1 Surveys

Surveys have a long history of use and are commonly used in a variety of research due to their low cost of use and ease of implementation (Phillips 2017). Surveys are primarily used to collect information about human emotions and opinions (Phillips 2017; Prince et al. 2017) but the design of questions allows for surveys to have quantitative data (Ponto 2015; Prince et al. 2017). Surveys can also be used to allow for self-assessment, which is a key objective of this research by assessing growth on the novice-expert continuum

Various surveys were given to students to obtain data and their feedback. These were self-reported and given at the end of class time. Students were given surveys at various points or that aligned with core and challenging topics related to forecasting. This was done in a way to assess the student's interpretation of how successful the instruction was and how it helped develop them as forecasters. In addition, surveys were given at the beginning of the course, the end of the first course, and at the end of the second course. If a student joined the class at the beginning of the second course, they were given the first survey as well. These were given in a pre- and post-situation to track their development. By giving these with an assignment or project, the student's perceived growth could be matched with the student's grade as it related to a student's grades. These surveys were designed differently than those the university gives at the end of the semester. These were used as well for more general feedback about the course.

All surveys given were designed with a Likert 5-point scale and with open-ended questions. This approach was chosen because the novice to expert continuum is also a 5-point scale, thus keeping things consistent (Benner 1984). In addition, the 5-point scale tends to enhance response rate with no quality of data loss (Revilla et al. 2014). In addition to the typical agree-disagree Likert scale, students were also asked where they would rate themselves on the novice to expert continuum. The same format for each survey was given before and after each assignment.

3.4.2 Statistical Analysis

Data were analyzed with a variety of methods. The n-value changed throughout the experiment for each semester as students either did not continue forward to ATM_SC 4720 or had taken it previously or elsewhere and finished the synoptic sequence at the university. For student assignment data, basic univariant data analysis was carried out.

With the Likert scale data, since the data is non-ordinal, a non-parametric data analysis was conducted. The Mann-Whitney U test was used. This is an acceptable and common way to handle this type of data (Bishop and Herron 2015). All results were rated on a 1-5 scale that allowed for the data to be analyzed with a numerical component with 1 being the lowest response (i.e.. strongly disagree) and 5 being the highest response (ie. strongly agree). When a Likert-like response was written such that students self-assessed on the novice-to-expert continuum, novice was considered a 1 and expert was a 5. Responses are indicated as necessary in associated tables.

For the forecast game, students were compared against the persistence forecast, as done in Bond and Mass (2009). In addition, the forecast skill score from Bond and Mass was used, with the following equation used:

$$SS = (FP_{per} - FP_{ind})/FP_{per}$$

where FP_{per} is the point total of the forecast point total of the persistence forecast and FP_{ind} is the point total of the student forecaster.

In addition, as indicated by Roebber and Bosart (1996), students showed the most development in the first six weeks before leveling off. Using the approach from Athar and Sara (2014), each semester will be broken into two equal time periods based on when forecasting started. This approach allows the ATM_SC 4710 groups to be compared and the ATM_SC 4720 groups to be compared. Those students who remained for both classes were also compared for an overall assessment of forecast skill. While the number of days forecasted were not equal, both groups forecasted at least 80 days.

Student data were not compared to LSX NWS due to a data error giving the NWS a constant precipitation, maximum temperature, and minimum temperature. Students were not compared to climatology because on days they didn't forecast, they were given climatology data for that day. If a student did not forecast 70% of the time for the semester, they were not included.

3.4.3 Qualitative Analysis

In addition to Likert-style response questions, the surveys also contained free response open-ended questions. For free responses from the surveys both administered by the university and the researcher, general summaries of these were provided to guide the assessment of the class and educational assignment. The predominate themes were analyzed and discussed as relevant for the questions or assignments.

Students who participated in the PRE-DEEP project were interviewed about their experience at the end of the project. Questions were designed that focused on the success of the project, and their growth as a forecaster with a self-evaluation of skill and confidence. The interviews were semi-structured allowing for the student to expand if they felt necessary or for the researcher to probe further. In addition to the students who took part, the students who lead and helped guide the student forecasters were also interviewed. This was done to assess student growth and the leader's growth in the mentorship that was established.

Each interview was recorded and transcribed. These interviews were then analyzed in Microsoft Word. The interviews were coded using an inductive thematic analysis approach in which codes were derived (Punch 2019). The inductive approach allows for a bottom-up view that uses the participants view to build broader themes (Creswell and Plano Clark 2017). These codes are then sorted into categories allowing for an iterative approach. The category is a collection of similar data where characteristics of a category are identified and described (Peel 2020). This approach allows for patterns to emerge, allowing the researcher to see commonalities and overall themes. These identified themes are then applied to theory. Theories are combined with the results from the student's surveys and grades to add additional support. Internal validity is established through prolonged engagement with the participants (Brown et al. 2002) and through use of participant words in the theory and the analyses (Cooney 2011).

Each interview was read through twice to become familiar with the content. Any excessive words were cleaned up. From there, each response was coded by their content. Example codes include "forecast process," "forecast tools," "forecast reasoning," "experience." This was not conducted word by word, but rather by paragraphs or even response to the question. There could be more than one code assigned to each paragraph allowing for overlapping data. By using the open coding approach, all statements are analyzed allowing for all codes to potentially be developed (Punch 2019). Then, the codes were collated into the code categories. Finally, themes were established by identifying the connections between them. These themes, and relevant sub-themes, are discussed as described in the results section.

Chapter 4 Results

The results presented in this chapter compare the performance of students using assignment and survey data from the same class term, 4710 or 4720. An overview of both classes' performance is presented before addressing select classroom activities. Quantitative results are presented first before qualitative results. The PRE-DEEP initiative is presented individually as the event was treated as an internship to assess student forecast skill growth with a focus on an authentic real-world experience.

4.1 Student Backgrounds

The demographics of each class can vary. Below are the demographics for both terms of ATM_SC 4710 and ATM_SC 4720. While the course is designed as a sequence, students may not proceed from 4710 to 4720 for a variety of different ranging from poor performance in the ATM_SC 4710, conflict of schedule with other courses, or other outside factors.

Table 4.1. Student grade level and degree-seeking level as reported by students.

Term (# of Students)	Class	Sophomore	Junior	Senior	Graduate	Major	Minor
FS 2017 (22)	ATM_SC 4710	3	10	9	1	21	1
SP 2018 (23)	ATM_SC 4720	1	10	9	1	20	0
FS 2018 (12)	ATM_SC 4710	2	3	5	1	10	1
SP 2019 (9)	ATM_SC 4720	2	3	3	1	9	0

Both classes are at the 4000 level so each session being comprised of ~80% upper-level students (junior, senior, or graduate level) fits the narrative of an upper-level class (Table 4.1). Each session of the course had a graduate student enrolled who completed the two-course sequence. Additionally, both ATM_SC 4710 fall sessions had a student who was obtaining a minor in the discipline. Neither of these students proceeded to take ATM_SC 4720. Since these are self-reported by the students, the total number in the course are on the left hand most column while how students identified their grade level and degree are on the other columns. This leads a slight difference in the number of students in the grade level compared to the total enrolled in the course.

Table 4.2. Student self-identified gender.

Term (# of Students)	Male	Female	Non-Binary
FS 2017 (22)	15	7	0
SP 2018 (23)	17	6	0
FS 2018 (12)	5	4	1
SP 2019 (9)	5	3	1

The self-identified gender of each student for each term is provided (Table 4.2). In the first cohort of the series, there was a two-to-one ratio of male to female students in the class. In the second cohort, there was a more equal distribution. It should be noted that this was self-identified so the number of students may not match because if a student did not select a gender, they were not counted for this part of the data collection.

The prerequisites for ATM_SC 4710 stated that students "complete Math 1700 and one physics course." The following are the breakdowns of each group's prerequisites completed and overall GPA (Table 4.3).

Table 4.3. Student Pre-requisite Course Completed by percentage. Class GPA is also included.

Term (Number of Students)	**# Intro (%)**	**# Math (%)**	**# Physics (%)**	**Complete all Physics (%)**	**Class GPA**
FS 2017 (22)	21 (95%)	21 (95%)	21 (95%)	15 (68%)	3.12
SP 2018 (23)	22 (96%)	23 (100%)	22 (96%)	16 (70%)	3.17
FS 2018 (12)	11 (92%)	10 (83%)	9 (75%)	4 (33%)	2.83
SP 2019 (9)	8 (89%)	8 (89%)	9 (100%)	4 (44%)	3.00
Total					3.04

In every section, 89% or more of the students had taken Introduction to Meteorology. The person who did not take the Introduction to Meteorology course in each term was the graduate student enrolled in the course. Additionally, each term had 80% or more of the participants who completed Math 1700. Each term had three-fourths of the students that had completed at least one physics course but given the demand of the course, it was evaluated further to see if they had completed the entire physics sequence. The second cohort (2018-2019) had a lower number of students who had completed the sequence. When comparing the two physics courses required by the department for graduation, the first physics course is more relevant to the content covered in the course.

The demographic background in the second session presented an unanticipated set of challenges. In the FS 2018 group, there were students with various disabilities and there were slight modifications that had to be made. The biggest change was that for all lecture content, Panopto was used to record course material to aid in these students' learning.

4.2 Overall Classroom Performance, Growth, and Feedback

4.2.1 ATM_SC 4710/7710 Grades and Feedback

Since the two years were taught the same, the overall final grades for both terms were assessed and compared.

Table 4.4. ATM_SC 4710 Descriptive Statistics and Mann-Whitney results for ATM_SC 4710 class grades.

Class Statistics							
	N	Minimum	Maximum	Mean	Std. Deviation	Skewness	
							Std. Error
Year1	22	65.16	96.33	85.05	6.80	-1.15	0.49
Year2	12	68.98	94.86	81.65	7.55	.010	0.64
Mann-Whitney U		89.000					
Wilcoxon W		167.00					
Z		-1.55					
Asymp. Sig. (2-tailed)		0.12					

Both classes had a similar range of values, with the first-year group showing a slightly lower minimum and a slightly higher maximum compared to the second year (Table 4.4). The first year group overall had an almost five point higher mean than the second year with a lower standard deviation. The final course grades between the ATM_SC 4710 FS 2019 and FS 2018 indicate there is no statistical difference between the groups (U=89.000, p =.0121 [> 0.05]).

Table 4.5. University of Missouri End of Semester Survey Results for ATM_SC 4710.

Question	Mean for Year 1 (n=22)	Mean for Year 2 (n=11)
The instructor effectively used examples and illustrations to promote learning.	4.77	4.82
The instructor fostered questions and/or class participation.	4.82	4.73
The instructor effectively used teaching methods appropriate to this class (e.g., critiques, discussion, demonstration, group work).	4.81	4.82
The instructor stimulated student thinking and learning.	4.91	4.82
The instructor helped students to be independent learners, responsible for their own learning.	4.96	4.73
This instructor taught effectively considering both the possibilities and limitations of the subject matter and the course (including class size and facilities).	4.86	4.73

The University of Missouri's end-of-semester "Evaluation of Instruction and Course" survey also indicates a positive takeaway from the course. Questions from the survey are presented in Table 4.5. Neither cohort reported a "disagree" or "strongly disagree" on the Likert scale. Additionally, all the means for course content and structure, teaching delivery, learning environment, assessment, and teaching effectiveness were above a 4 (out of 5). Table 4.5 focuses on student growth and the methods used to teach the course. The frequent use of examples, including real-time weather situations as applicable, helped to make those important connections. Engaging students to ask questions, think, and conduct their own research is a way to help students improve their skills and confidence as they develop in new situations. These results illustrate the positive aspects of the classroom.

The end-of-semester “Evaluation of Instruction and Course” survey open-response questions further indicate the effective nature of the class. When asked “What aspects of the teaching or content of this course were especially good?’ many comments focused on the instructor’s confidence, knowledge, and engaging presentation. One student stated:

> “Content and teaching methodology for all types of learners as visual and hands-on methods were used."

while another stated:

> “They were able to break down the material and explain it in depth.”

This ability to understand material and present it in logical, accessible ways is important to students and can help them grow.

Feedback to improve the course when asked "What changes could be made to improve the teaching or content of this course?" focused on wanting more lab times and even more examples of abstract or difficult concepts such as deformation zones or heavy snow forecasting.

4.2.2 ATM_SC 4720/7720 Grades and Feedback

Table 4.6. ATM_SC 4720 Descriptive Statistics and Mann-Whitney results for ATM_SC 4720 class grades.

Class Statistics							
	N	Minimum	Maximum	Mean	Std. Deviation	Skewness	
							Std. Error
Year1	23	66.06	94.17	84.56	6.45	-0.93	0.48
Year2	9	69.06	95.16	83.80	8.54	-0.11	0.71
Mann-Whitney U		97.00					
Wilcoxon W		142.00					
Z		-0.27					
Asymp. Sig. (2-tailed)		0.79					

Overall final grades were compiled and analyzed for both years for ATM_SC 4720/7720 (Table 4.6). Both classes had a similar mean final score and roughly the same score again while the second-year group had a one-point higher maximum. The first-year group had a lower minimum by three points. The final course grades between the ATM_SC 4720 SP 2018 and SP 2019 indicate there is no statistical difference between the groups (U=97.000, p =0.785 [> 0.05]).

Table 4.7. University of Missouri End of Semester Survey Results for ATM_SC 4720.

Question	Mean for Year 1 (n=19)	Mean for Year 2 (n=8)
The instructor effectively used examples and illustrations to promote learning.	4.63	5.00
The instructor fostered questions and/or class participation.	4.58	5.00
The instructor effectively used teaching methods appropriate to this class (e.g., critiques, discussion, demonstration, group work).	4.58	5.00
The instructor stimulated student thinking and learning.	4.63	5.00
The instructor helped students to be independent learners, responsible for their own learning.	4.63	5.00
This instructor taught effectively considering both the possibilities and limitations of the subject matter and the course (including class size and facilities).	4.63	4.88

The same university end-of-semester "Evaluation of Instruction and Course" survey was distributed at the end of the course. The same selected questions from the previous section are displayed in Table 4.7. Both groups reported higher marks again for many of the topics above with a 4 (out of 5) mean. Interestingly, both years saw the means change. All the means for Year 1 decreased while the means for Year 2 increased.

When again asked "What aspects of the teaching or content of this course were especially good?" in the end of the course survey, students again acknowledged the instructor's passion and willingness to assist at any time. Given the assignments in the class, one student noted that:

> "There are plenty of opportunities through the class to apply what was learned."

The inclusion of Panopto in Year 2 was noted by two in the comments as a positive change, which could potentially indicate why the values increased. Part of the reason is that comments when asked about “What changes could be made to improve the teaching or the content of this course?” many students in Year 1 indicate that they wish they didn’t have to miss class to prepare a weather briefing. Year 2 students had the opportunity to review material if they missed class because of Panopto, further indicating the tool’s role in the classroom.

4.2.3 Student Skill Growth

Student surveys distributed at the start of the class, in the middle, and at the end of the term were used to assess their growth. Students who completed the entire class series were evaluated.

Table 4.8. Student Self-Assessed Skills Using Benner's Novice to Expert Continuum.

Student Self-Assessed Skills				
	Year 1 (n=20)		**Year 2 (n=9)**	
Rating	**Start of Class Series**	**End of Class Series**	**Start of Class Series**	**End of Class Series**
Novice	7	0	2	0
Beginner	8	0	6	0
Competent	5	12	1	2
Proficient	0	8	0	7
Expert	0	0	0	0
		Start of Class Series		**End of Class Series**
Mann-Whitney U		89.5		56
Wilcoxon W		299.5		266
Z		-0.026		-1.85
Asymp. Sig. (2-tailed)		0.98		0.064

Students who completed the entire sequence of Synoptic were asked to rate their forecasting skills using the Benner (1982) novice to expert continuum (Table 4.8). Both years had no students rating themselves as proficient or expert and students only rated themselves as novice, beginner, or competent at the beginning of the series. By the end of the synoptic series, all students in both years had identified themselves as competent or proficient. No students self-identified as an expert. All students who completed the sequence in year two were also students who participated in the internship experience. When comparing student growth from the first-year group, students who did not complete the internship experience, to the second-year group students who did complete the internship, there was no statistical difference between the two groups in their self-identification final skill assessment (U=56, p =.0.064 [> 0.05]).

Table 4.9. Students self-assessed confidence and effort in their forecasting skills.

Student Self Assessed Effort and Confidence							
		Year 1			Year 2		
Confidence in Forecast	**Rating**	**Start of Class Series**	**End of First Term**	**End of Class Series**	**Start of Class Series**	**End of First Term**	**End of Class Series**
	Not at all confident	3	0	0	1	0	0
	Slightly confident	7	4	1	5	0	0
	Moderately confident	9	10	10	6	0	1
	Quite confident	1	3	9	0	8	4
	Extremely confident	0	0	0	0	4	4
			Start of Class Series		**End of First Term**		**End of Class Series**
	Mann-Whitney U		119		12		36.5
	Wilcoxon W		329		165		246.5
	Z		-0.042		-4.2		-2.764
	Asymp. Sig. (2-tailed)		0.97		<.001		0.006
Effort into a forecast	**Rating**	**Start of Class Series**	**End of First Term**	**End of Class Series**	**Start of Class Series**	**End of First Term**	**End of Class Series**
	Almost no effort	4	0	0	0	0	0
	A little bit of effort	2	1	3	2	0	0
	Some effort	11	7	6	7	1	1
	Quite a bit of effort	2	10	11	3	7	6
	A great deal of effort	1	0	0	0	4	2
			Start of Class Series		**End of First Term**		**End of Class Series**
	Mann-Whitney U		101		48.5		55.5
	Wilcoxon W		332		219.5		265.5
	Z		-1.04		-2.82		-1.81
	Asymp. Sig. (2-tailed)		0.29		0.005		0.071

Students were also asked to gauge how confident they were forecasting and how much effort they exerted in a forecast. Table 4.9 shows the student survey feedback. Students were asked “At the end of a forecast, how confident are you in your forecast?” Most students start the class series not being confident in their ability to forecast with no student identifying as being “extremely confident” in their ability to forecast. Most students at the start of the class in both years identified as “slightly confident” or “moderately confident.” Student responses to the question “How much effort do you feel you exert when forecasting?” varied across all possible responses with about half of the students reporting that they exert “some effort.”

Student open-ended responses at the start of the class reveal further insight into why students rated themselves the confidence level and effort. Responses to “How long does it take you to forecast? Why does it take you this amount of time?” had various responses. Time responses ranged from a few minutes, with 15-30 minutes being the most common response with a few being over an hour or more. The reason for time differences ranged from a quiet vs. active weather day (with an active weather day taking longer) or not really knowing what to evaluate and look for in a forecast. The motivating factor behind the reason for forecasting was also factored in. If a student was forecasting for a class, responses indicated that the student would take longer.

Effort and uncertainty were also reflected in the process used for forecasting. Responses ranged from using National Weather Service websites to get the answer right away to evaluating models. By the end of the class, a defined process should exist for students.

The end of the first semester did indicate that there is a difference between students in the two groups. There was a statistically significant difference in both the “At the end of a forecast, how confident are you in your forecast?” ($U=48.5$, $p < 0.001$ [<0.05]) and “How much effort do you feel you exert when forecasting?” ($U=12$, $p = 0.005$ [<0.05]) question. By the end of the first semester, the second group, the group that had the internship, rated their confidence as either “quite confident” or “extremely confident” which is not reflected in the survey from the first group where no one rated themselves as “extremely confident.” Both groups had more than half of the students saying they exerted "quite a bit of effort" in their forecast but four students in the second group exerted “a great deal of effort.”

Students in an open response question were asked “How long does it take you to forecast now? Has it increased or decreased? Why does it take you this amount of time?” All but one in the second-year group either had the same amount of time or increased their time on active weather days. Those that remained the same were already on the longer end of the time scale, an hour or more in their initial responses. The student who decreased the time replied:

> “~1 hour give or take depending on how much is going on. It has decreased due to having more confidence.”

This shows that increasing the skill of the student can potentially lead to less effort exerted and more confidence in their forecast. For students that increased their time, it was because they knew what weather phenomenon was occurring, what features were necessary to evaluate, or used more data than before. Only four students in Year 1 by the end of the class had reported that they took an hour or more to forecast. Many students reported about 30 minutes as the most frequent length of time it took to forecast. The lack of confidence or focused effort in forecasting could lead to a difference in confidence. Both groups, however, did respond that they had a better sense of the forecast process. Lecture material in both classes addressed various forecast processes in addition to demonstrations of the forecast processes led by the instructor and researcher. This was done to help connect material to the content covered that day or answer weather-related questions such as "Will it snow today?"

By the end of the class series, the statistical difference between the two groups decreased. However, confidence in the forecast is just above being statistically significant ($p = 0.006$ (> 0.005)). Roughly half of the students the first year indicated that they were "moderately confident" and "quite confident" with their ability to forecast as shown in Table 4.9. The second-year group in contrast continues to identify as "quite confident" or "extremely confident." One student did decrease their confidence to "moderately confident." The student noted that the reason for the decrease was that they struggled with writing the Area Forecast Discussion. The student noted that they felt like they struggled to feel like their message was coming across clearly or that they were effectively communicating what they intended. The fact that no student in the first-year group identified as being "extremely confident" in their forecast indicates that the additional time and practice allowed to the second group could impact student skill growth related to forecasting.

The amount of effort to complete a forecast by both groups had over half of the responses in both groups rating it as taking "quite a bit of effort" with two students in the second year saying that it takes "a great deal of effort." Interestingly, the year one group had 3 students who said forecasting only required "a little bit of effort" but open-ended responses don't indicate a reason why. One student did indicate they were only "slightly confident" in their forecast.

Since the second class (ATM_SC 4720/7720) was focused on developing forecasting skills and delivering both an Area Forecast Discussion (written) and a forecast discussion (verbal) the time question was slightly adjusted. The question asked "How long does it take you to forecast for AFDs? For forecast discussion? (Please answer both parts) Why did it take you this amount of time?" The overwhelming response for writing an AFD was about an hour. Some students noted they could do it in thirty minutes while some had upwards of three hours so there was quite a spread. Students reported that preparing for the forecast discussion took about 45 minutes as the most common time. Some students commented that they would do some forecasting the night before to help start putting their ideas together. Students commented that they struggled with the AFD portion as written communication was more of a struggle than the verbal portion. The exact specifics of these two assignments are discussed further in section 4.3.

The main takeaway from the two groups is that the second-year class gained confidence in their forecast skills and the process sooner than the first-year class, potentially due to the forecast experience. Additionally, these students saw an increase in the level of effort, due to their understanding and application of concepts sooner. By the end of the lesson series, the two groups were about even in their rankings. Students in both groups also spent more time forecasting due to their growth in understanding and applying the ideas at hand.

4.3 Key Assignment Performance and Feedback

4.3.1 Map Discussions

The ability to verbally communicate a forecast to a room full of individuals is an important and necessary skill. The synoptic sequence of classes builds to this as a culminating task and has been a part of the synoptic sequence for many years.

Table 4.10. Statistical Results for Student Grades for Map Discussions.

Data Results for Map Discussion					
	N	Minimum	Maximum	Mean	Std. Deviation
Year 1	23	30.66	38.33	35.01	1.83
Year 2	9	33.33	36.83	35.09	1.34
Mann-Whitney U	99				
Wilcoxon W	144				
Z	-0.19				
Asymp. Sig. (2-tailed)	0.85				

When comparing both groups in Table 4.10, there is no statistical difference between the two groups when comparing the final aggregated grades (U = 99, p = 0.85). Both groups had roughly the same mean but the spread between the two groups was wider with the first year having an eight-point difference while the second year only had a three-point difference.

Table 4.11. Survey Results from both groups about Map Discussions.

Survey Results for Map Discussion					
		Year 1		Year 2	
Question	Ranking	Pre	Post	Pre	Post
How challenging do you expect these assignments to be? / How challenging was this assignment?	Not Very Challenging	0	0	0	0
	A little Challenging	1	0	1	2
	Somewhat Challenging	4	6	1	1
	Moderately Challenging	9	9	6	4
	Very Challenging	8	4	1	2
How helpful have lectures and in-class activities been to prepare you for these assignments?	Not all Helpful	0	2	0	0
	A little helpful	3	1	0	0
	Somewhat Helpful	6	5	1	1
	Moderately Helpful	8	7	5	2
	Very Helpful	4	4	3	6
How confident do you feel headed into the assignment? /About your performance?	No Confidence	1	0	0	0
	A little Confident	7	1	1	0
	Somewhat Confident	8	7	4	1
	Moderately Confident	6	6	4	5
	Very Confident	0	5	0	3
How much do you feel you learned from this assignment?	I Did not learn		0		0
			0		0
	I learned somewhat		4		0
			5		1
	I learned a lot		10		8
Where would you rate your skill level after completing this assignment?	Novice		0		0
	Beginner		0		0
	Competent		13		4
	Proficient		6		5
	Expert		0		0

The assignment has a reputation of being difficult and the cumulative assessment in a weather map discussion is indicated in the results from surveys taken (Table 4.11). Before the assignment was started, 17 of 23 students surveyed in the first-year group indicated that they expected the assignment to be “Moderately Challenging” or “Very Challenging” and seven of nine in the second-year group had the same sentiment. After the assignment was done and students were asked how challenging the assignment was, there was a slight decrease for both classes. Only 15 of 21 students felt it was “Moderately Challenging” or “Very Challenging” while six students of nine students surveyed in the second year gave the same rating.

When asked how helpful lectures and in-class activities were to prepare students, surveys indicated that students felt prepared to a moderate to a very high degree, but only about half the students surveyed in the first-year group felt that way. The second-year group however felt more prepared with eight of the nine students rating "Moderately Helpful” or “Very Helpful.” Students were provided with example discussions before the assignment by both the instructor and research throughout the class. In addition, for the entire last half of the semester, students either attended or participated in a forecast discussion three times a week. When asked in a post-assessment survey how helpful these activities were, student scores became a bit more diverse in the first-year group. Three students in the first-year group felt these activities were “Not at all Helpful” or “Only a little helpful”. When compared to the second-year group, the ratings increased as six of the nine students surveyed felt these activities were “Very Helpful”. Despite the additional observations, practice, and feedback, students in the first year didn’t feel prepared to lead a forecast discussion.

While students may not have felt prepared for the assignment, students overall felt a certain degree of confidence before starting the assignment with an increase afterward. The first-year group survey results indicate that the seven students in the class were only “a little confident” with eight feeling “somewhat confident” and six as “moderately confident.” One student even felt they had no confidence in their ability to complete the assignment. There appears to have been a bit more reserved about their ability to provide a map discussion when compared to the second-year group where the lowest rating was one student as “a little confident.” The remaining students were evenly divided as “somewhat confident” and “moderately confident.” After completing the assignment, student confidence grew as no student in either group gave a rating of “no confidence.” In the first-year group, 57% of the students surveyed rated their confidence as “moderately confident" or "very confident" about their performance. Seven students however were only “somewhat confident,” and one was a “little confident.” When compared to the second-year group, eight of the nine students felt “moderately confident” and “very confident” about their performance. While the class sizes were smaller, the second-year group seemed to feel more confident. The group also got more practice than the first-year group, which may have contributed to their ratings.

When assessed about how they felt they would rate their skills level, the “Competent” or “Proficient” levels were the two selected. The other three levels were not selected. Thirteen students in the first-year group (68%) of the students selected "competent" compared to only four students in the second-year group. When students were asked about what uncertainty or potential issues they may have regarding delivering a map discussion, there was a robust set of answers. The responses from the first-year group varied from being able to deliver the information in a meteorological and meaningful manner, dealing with time constraints, using the WAV lab equipment, answering questions, and public speaking. The second-year group also shared some of the same sentiments about public speaking and lack of familiarity with delivering meteorological content in this manner. The second-year group, however, did not comment on their lack of familiarity with using the WAV lab equipment because they had been using it for the entire first semester as these were the internship students.

When students were asked what they enjoyed the least, the first-year group least enjoyed the time constraints, missed class periods, and use of the technology to present. The second-year group also shared the time constraint issues but, otherwise, had little in terms of what they enjoyed least. The familiarity with the forecast process for the second-year group and familiarity with the WAV lab equipment may have helped further with their comfort and confidence in delivering a map discussion.

When students were asked what they enjoyed the most, both groups commented that they enjoyed the forecasting process, delivering content, and even answering questions. Answering questions one student said it "challenged them the most, but felt they grew the most doing that" while another said, "it forced me to be more confident in my forecasting ability and answer questions on what I presented." One student said "I loved getting to talk about the weather! It was a good challenge to share my knowledge." The first-year group had seven students comment that the reason they liked the map discussion was that it allowed them to practice forecasting, provided real-world experience, and connected to material learned in class. This is something the second-year group already had, due to their experience (to be discussed more thoroughly in section

4.4). Based on these comments and where students felt they grew, the ability to practice and connect to material is what students enjoyed most and helped solidify content.

4.3.2 Area Forecast Discussions

Area Forecast Discussions are another cumulative assignment that is assigned in the synoptic sequence. This assignment tasks students to communicate a forecast using meteorological terms and the application of content. Students traditionally start writing a few weeks into the start of the second semester. Table 4.12 evaluates the statistical performance using student grades.

Table 4.12. Results for Student Grades for Area Forecast Discussions.

Data Results for Area Forecast Discussion					
	N	Minimum	Maximum	Mean	Std. Deviation
Year 1	23	11.25	15.25	13.75	1.49
Year 2	9	14.2	16.85	15.2	1.34
Mann-Whitney U	55				
Wilcoxon W	331				
Z	-2.04				
Asymp. Sig. (2-tailed)	0.042				

The results from students' grades indicate that there is a statistically significant difference between the two groups (U = 55, p = 0.042). The second-year group also outperformed the first-year group. The second-year group had a higher minimum score, higher maximum score, higher mean, and lower standard deviation for student final grades. The second-year group's performance is a plausible outcome as the second-year group had a semester of writing AFDs with guidance that the first-year group did not.

Table 4.13. Survey question results for student grades for Area Forecast Discussions.

Survey Results for Area Forecast Discussion					
		Year 1		Year 2	
Question	Ranking	Pre	Post	Pre	Post
How challenging do you expect these assignments to be?	Not Very Challenging	0	0	0	0
	A little Challenging	0	0	1	0
	Somewhat Challenging	4	0	3	1
	Moderately Challenging	8	13	3	7
	Very Challenging	10	6	1	1
How helpful have lectures and in-class activities been to prepare you for these assignments?	Not all Helpful	0	1	0	0
	A little helpful	4	6	0	0
	Somewhat Helpful	10	7	1	0
	Moderately Helpful	8	2	3	2
	Very Helpful	0	3	4	7
How Confident do you feel headed into the assignment?/About your performance?	No Confidence	1	0	0	0
	A little confident	7	1	0	0
	Somewhat confident	8	3	5	1
	Moderately Confident	6	14	3	6
	Very Confident	0	1	0	2
How much do you feel you learned from this assignment?	I Did not learn		0		0
			0		0
	I learned somewhat		10		0
			3		0
	I learned a lot		6		9
Where would you rate your skill level after completing this assignment?	Novice		0		0
	Beginner		5		0
	Competent		7		3
	Proficient		7		6
	Expert		0		0

Both groups when surveyed (Table 4.13) indicated that they felt the assignment would be challenging with 10 of the 22 students in the first year saying that it would be "very challenging" and eight as "moderately challenging." This group had no prior experience writing until this class, as commented on an open-ended question. It is interesting that the second-year group, all of which had a semester writing AFDs, still had three students feeling the assignment would be "moderately challenging" and one as "very challenging." One student, likely due to the experience, felt that the assignment would be only "a little bit challenging." The second-year group was nervous to write AFDs for a grade which they hadn't done up until this point. The first-year group commented that they felt like they didn't have much experience, were nervous about using the WAV Lab systems, and were nervous about being graded as a group. In the post-assignment survey, the assignment for the first-year group didn't find it as challenging as they had thought as 13 of the 19 students found it "moderately challenging" while six still found it "very challenging." The second-year group had seven of the nine students finding it "moderately challenging" which was an increase. The grading and the fact that they no longer had assistance when forecasting and writing their AFDs, may have contributed to this as this was a large difference from the last time they were writing.

While both groups were given guidance and examples over what makes an AFD successful and discussing the aspects throughout the course, the first-year group had ten students saying that it was "somewhat helpful" and eight finding it "moderately helpful." After the assignment, however, students upon reflection had a more diverse response with students covering all aspects of the ratings. The second-year group, however, felt that the work they had done previously in the last semester was helpful to prepare them for the assignment. By the end of the assignment, seven of the nine students found it “very helpful” while the remaining two found it “moderately helpful.” There was a noticeable difference between the two groups, likely related to their experience.

The confidence headed into writing an AFD for both groups differed. While the second-year group was “somewhat confident” (five students) or “moderately confident” (three students), the first-year group, with little experience or dedicated training, had a much broader spectrum of feelings. One student had “no confidence,” seven students had “a little confidence,” eight felt “somewhat confident,” and six were “moderately confident.” This is a large contrast between the two with the second-year group feeling more prepared and ready. The grade aspect was one area in the second-year group that students were a bit anxious about. By the end, however, most students in both groups surveyed felt “moderately confident” about their ability to forecast and write an AFD. One student in the first year was only "a little bit confident." The second-year students had more confidence from the beginning and their overall performance in Table 4.12 is evidence of their confidence to a degree.

The lack of confidence and experience was noted when students were asked to rate their skill level. Despite the practice and feedback throughout the course, five students in the first-year group felt that they were at a “beginner” level. Seven students felt they were “competent” and the remaining seven felt “proficient”. The second-year group in comparison had two-thirds of the students surveyed feeling that they were "proficient" while the remaining third felt "competent." The experience again seems to play a role in students’ assessment of their skills.

Both groups when asked what they least enjoyed about the experience were: forecasting in the WAV lab, the time commitment, forecasting on certain days, ill-defined criteria, or that the writing didn't match what the National Weather Service does daily. Most of these comments came from the first-year group of students. During AFD forecast operations, some students would lament that forecasting on non-active weather days was boring and felt they didn't have as much to say. Students were provided with the rubric of the assignment which could indicate a lack of familiarity with the assignment and expectations.

When asked what they enjoyed about the experience, students commented that they liked being able to apply content learned in class and dig into the meteorological details. Students also commented that it was another way to practice forecasting. The group of students in the second-year group also enjoyed their forecasts were used in the Campus Weather Forecast every day which helped add important context and a sense of contribution to providing weather for the day. Overall, the experience and sense of purpose led to a better grade outcome and sense of success for those in the second-year group, indicating the important role practice has in developing these skills for students.

4.4 Internship Experience

The funded PRE-DEEP grant was treated as an internship experience as it allowed an authentic experience of work with students that emulated many different career options. All 12 students from ATM_SC 4710/7710 in FS2018 chose to participate but were not required. Students were given a survey at the beginning, in the middle, and at the end of the experience that asked them to self-assess various questions. In every question asked, students self-reported growth from the start of the internship to the end of the internship.

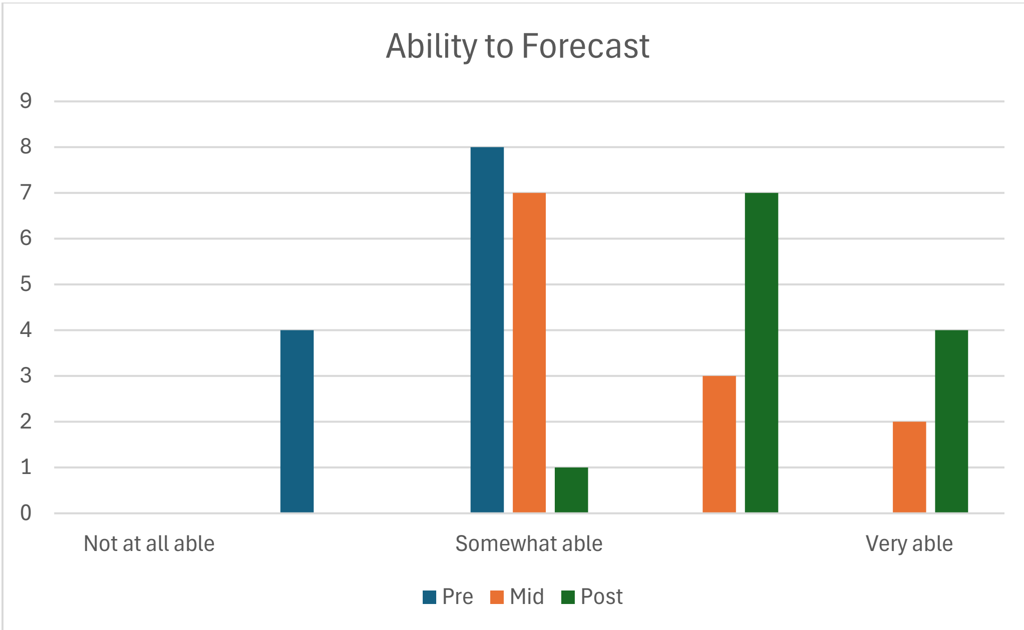


Figure 4.1. Student Pre-, Middle, and Post-Survey to "How would you rate your ability to forecast?"

When students were asked to assess their ability to forecast, there was a clear growth in skills for the students as shown in Figure 4.1. Three-fourths of the students rated themselves as "somewhat able" and the remaining students rated themselves one step lower (category 2). The mid-point check-in showed that all students rated themselves as somewhat able or higher. By the end of the internship, half of the students rated themselves as a level four out of five while four students rated themselves as very able, the highest level. One student remained as "somewhat able" by the end of the period. This student typically had the lowest values on all ratings across all surveys. They still however reported growth over the experience.

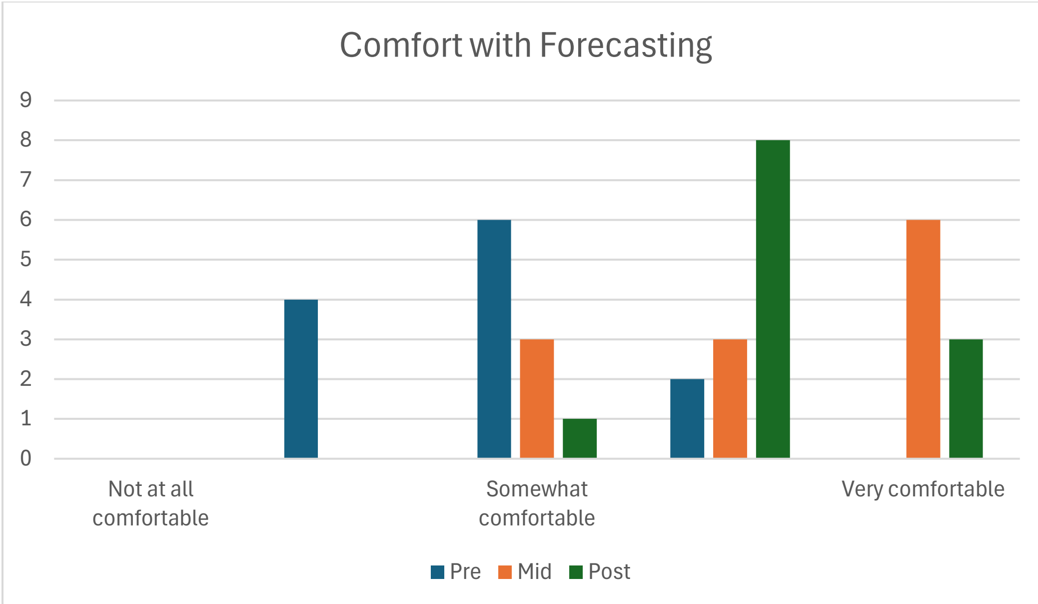


Figure 4.2. Student Pre-, Middle, and Post-Survey to "How comfortable do you feel forecasting?"

Similar to the distribution observed in students' forecasting ability, responses to the question "How comfortable do you feel forecasting?" (Figure 4.2) revealed a comparable pattern. At the beginning of the internship, four students rated their comfort level as 2 out of 5, indicating low confidence. Half of the students selected a 3 out of 5, representing a moderate level of comfort, while two students rated themselves at 4 out of 5. By the midpoint of the internship, all students reported feeling at least "somewhat comfortable" or higher. Notably, six students rated themselves as "very comfortable" (5 out of 5) at the midpoint, compared to only three at the conclusion of the internship. However, the final survey showed that eight students rated their comfort level at 4 out of 5, indicating sustained, though slightly moderated, confidence in their forecasting abilities.

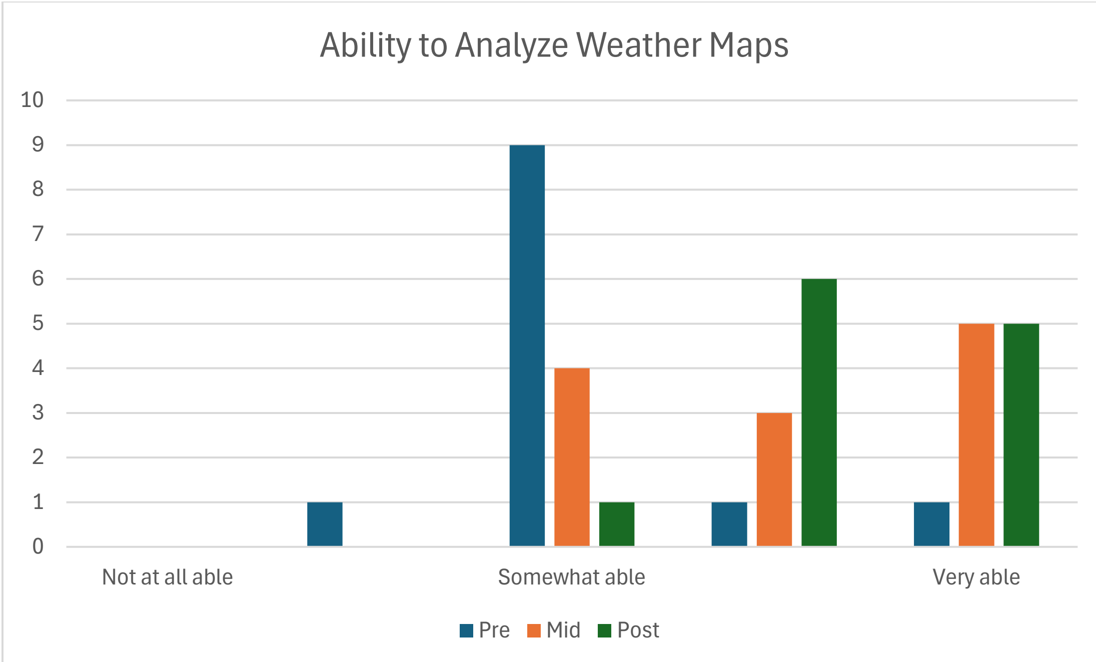


Figure 4.3. Student Pre-, Middle, and Post-Survey to "How comfortable do you feel forecasting?"

The ability to analyze maps was one of the main emphases of the experience and as such, students were asked to rate their ability to analyze weather maps. Survey results are shown in Figure 4.4.3. Again, there is a similar initial distribution with three-fourths of the students rating themselves as "somewhat able" to analyze weather maps. There was one student who rated themselves as "very able" at the pre-, midpoint, and post-survey so their rating was consistent. At the midpoint check-in and post-experience survey, all students rated themselves as three or higher.

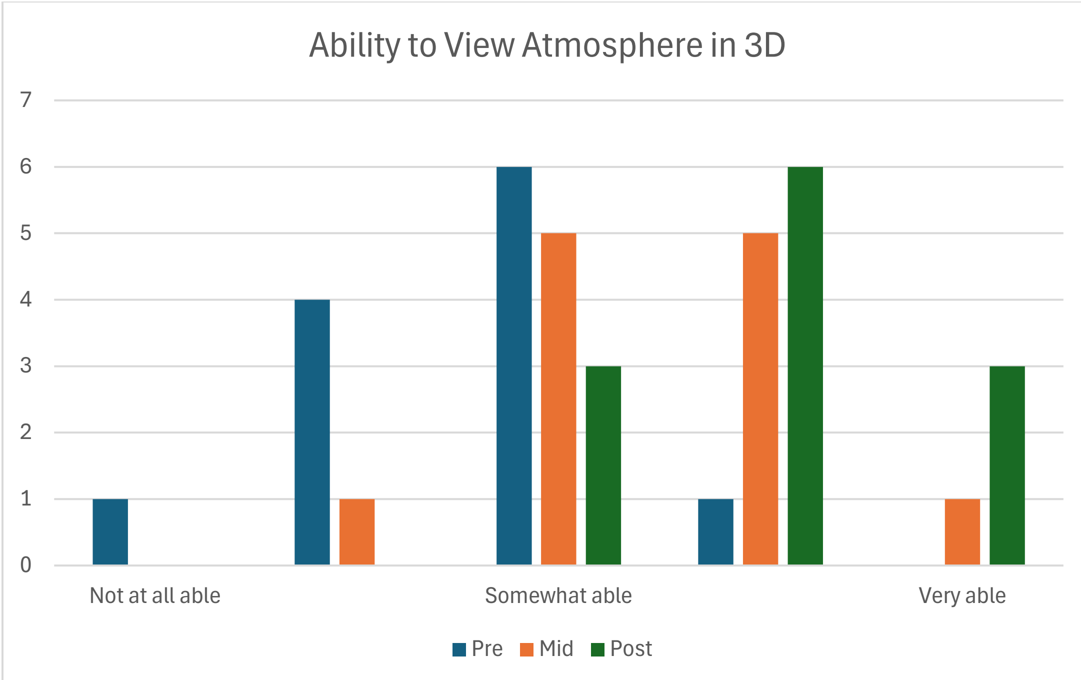


Figure 4.4. Student Pre-, Middle, and Post-Survey to "How would you rate your ability to view the atmosphere as a 3D feature?"

The ability to conceptualize the atmosphere in three dimensions is another critical skill that supports students' progression along the novice-to-expert continuum. In the pre-experience survey, this was the only instance in which a student rated themselves as "not at all able," as shown in Figure 4.4. Overall, initial ratings were relatively low: five of the twelve students rated themselves at 2 or below, while half rated themselves as "somewhat able" (3 out of 5). Growth was evident by the midpoint survey, where no students selected the lowest rating, and all responses were a 2 or higher. By the conclusion of the internship, all students rated themselves at 3 or above, with half indicating a 4 out of 5, reflecting increased confidence in their ability to visualize atmospheric processes in three dimensions.

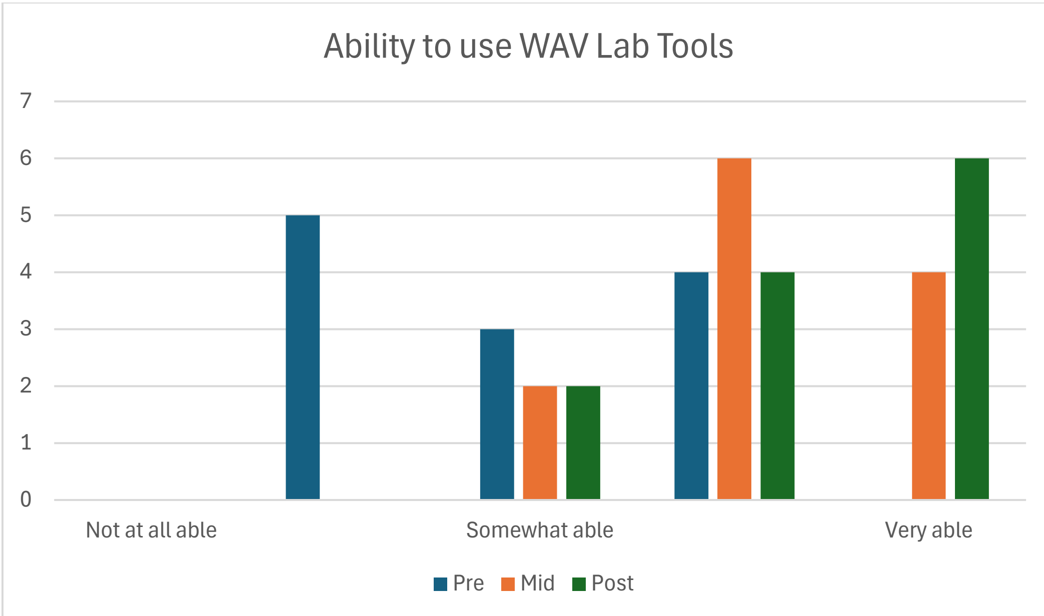


Figure 4.5. Student Pre-, Middle, and Post-Survey to "How would you rate your ability to use the forecasting tools in the WAV Lab?"

While completing the experience, students were able to use the resources and products in the WAV Lab that are equivalent to what are used by professionals. By this point in the student's career, they should have been in the WAV Lab, but the experience may be limited. The pre-experience survey indicates a differing level of experience using the various products on the computer systems as students show some degree of familiarity with the tools. Five out of the twelve rated their ability to use the tools as a two out of five before the start of the internship. The experience was beneficial to student growth because by the end of the experience, six students felt "very able" to use the tools. Two students by the end felt "somewhat able." Figure 4.5 shows the growth of the student's ability to use the WAV Lab tools.

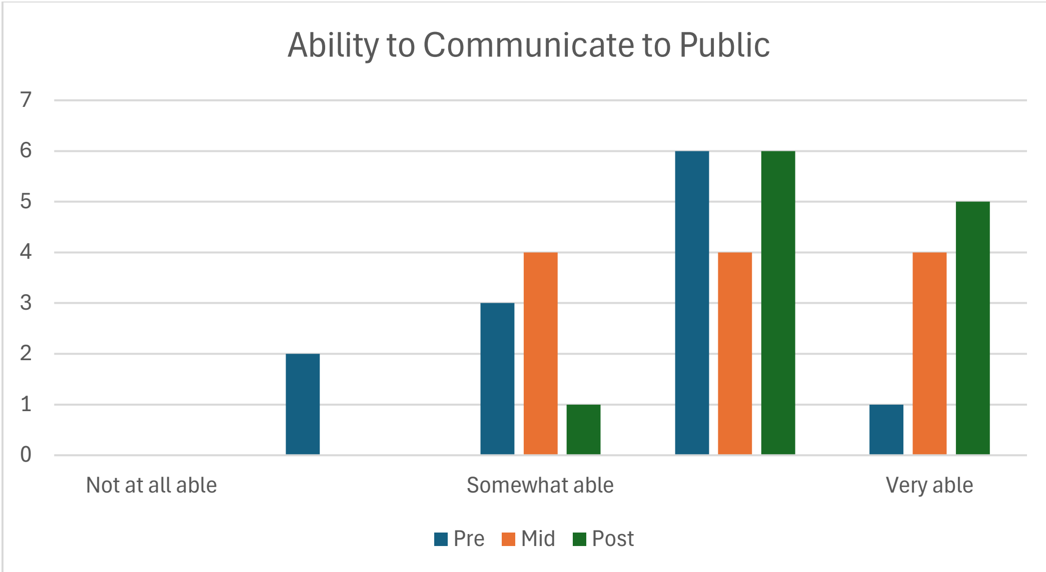


Figure 4.6. Student Pre-, Middle, and Post-Survey to "How would you rate your ability to communicate weather to the general public?"

Students had to write a public discussion as a part of the experience, and Figure 4.6 shows students' survey responses on their ability to communicate to the public. From the start of the experience, there was a spread with students self-reporting from two to five on the survey. Knowing some students were interested in broadcast as a career could have placed some of these students higher at the beginning. By the end of the experience, all students but one rated themselves as a four or five on the scale. Writing a public report was something they had to do during their internship so there was constant practice to improve this skill.

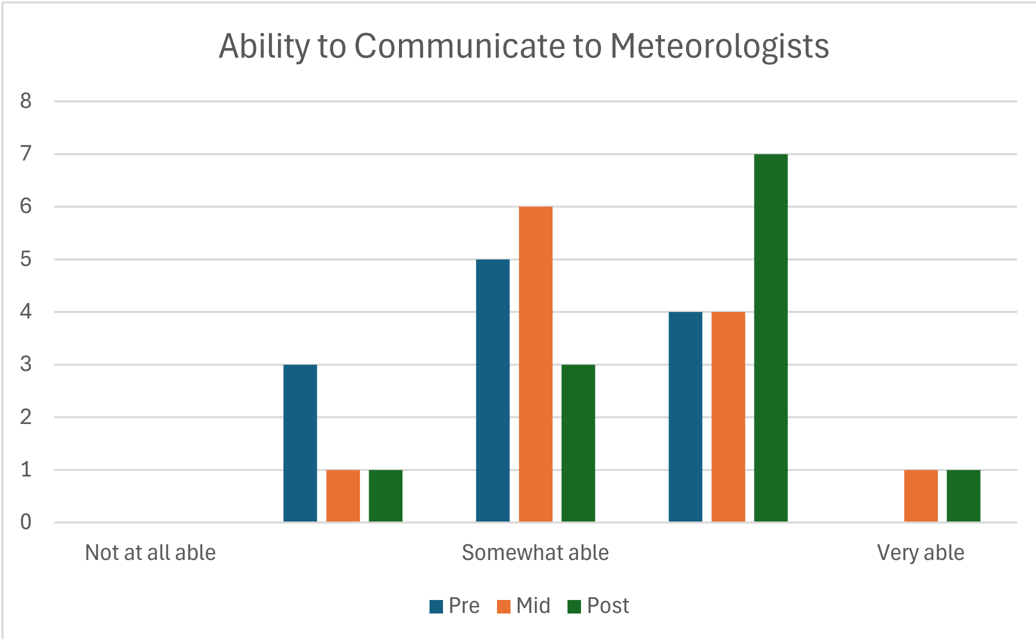


Figure 4.7. Student Pre-, Middle, and Post-Survey to "How would you rate your ability to communicate weather to other meteorologists?"

In addition to communicating a forecast to the public, students were asked to assess their ability to communicate to other meteorologists. Figure 4.7 shows the survey responses. Like many previous figures in section 4.4, the ratings were between a two and four at the beginning. Three students rated themselves as a two at the beginning and as the midpoint and post-experience survey indicate, a student on each survey self-rated as a two. There was also only one who rated themselves as "very able", or a five, on the midpoint and post-experience survey. The ability to communicate with meteorologists is a skill that relies more on practice, as it involves using the correct vernacular, so students feeling slightly lower in their ability to do so makes this understandable. By the end of the experience, seven students rated themselves as a four out of five.

Figure 4.8. Student Pre-, Middle, and Post-Survey to "How would you rate your forecasting skill level?"

The final way student growth was tracked was through the Benner (1984) novice to expert continuum scale as shown in Figure 4.8. Over the course of the internship experience, students showed noticeable growth. At the beginning of the internship, one student rated themselves as a novice, nine rated themselves as a beginner, and two rated themselves as competent. By the midpoint survey, no students considered themselves to have novice level forecasting skills. As shown by Figure 4.4.8, only one student felt they had beginner forecasting skills. The rest of the students felt they were either competent (nine students) or proficient (two students). In the final survey, no one considered themselves to be an expert forecaster, all students felt they were either competent (five students) or proficient (seven students).

Table 4.14. Statistical analysis survey results to questions about the internship experience.

Statical Results from Internship comparing Pre and Post Surveys							
	How would you rate your ability to forecast?	**How comfortable do you feel forecast?**	**How would you rate your ability to read and analyze weather maps?**	**How would you rate your ability to view the atmosphere as a 3D feature?**	**How would you rate your ability to use the forecasting tools in the WAV Lab?**	**How would you rate your ability to communicate weather to the general public?**	**How would you rate your ability to communicate weather to other meteorologists?**
Mann-Whitney U	4	13	18	15	19	35	44
Wilcoxon W	82	91	96	93	97	113	122
Z	-4.105	-3.595	-3.307	-3.436	-3.172	-2.309	-1.74
Asymp. Sig. (2-tailed)	<.001	<.001	<.001	<.001	0.002	0.021	0.082

Figures 4.1 to 4.8 show the student survey data in the pre- and post-survey environment. Table 4.14 shows the statistical results using the Mann-Whitney approach. In five of the seven questions, there was a statistically significant difference from the start of the experience compared to the end of the experience. The questions where there was statistical significance were:

- How would you rate your ability to forecast?
- How comfortable do you feel forecast?
- How would you rate your ability to read and analyze weather maps?
- How would you rate your ability to view the atmosphere as a 3D feature?
- How would you rate your ability to use the forecasting tools in the WAV Lab?

The results of these questions indicate the quantitative aspect of student growth. The perceptions of growth were shared by many of the students. Students felt more comfortable forecasting, felt capable of analyzing the atmosphere deeper, and using the tools needed to carry out the forecast. These results indicate that the internship experience is a positive way for students to develop their meteorological skills and connect concepts.

While survey data indicates a positive experience, post-internship experience interviews were conducted with each student to further capture additional insight. Students overwhelmingly enjoyed the experience as it helped develop and apply practical skills and content while building a sense of collaboration and teamwork. The mentorship and guidance were also a key component to the success of the internship.

Practical Application of Skills and Content

One of the biggest common themes from the experience was that it allowed students to connect the material they learned in the classroom to the practical application in a forecasting environment. This hands-on experience was a key implementation and takeaway for this entire experience. One student commented that:

> "It gave me some practicality towards what we're learning. It helped me, I think it made me a better scientist because I was able to take all the conceptual stuff that we learned in class and apply it to real-life situations."

While another stated:

> "This internship actually helped integrate both a class material and also the learning experience on an actual computer and actual forecasting [to] real-world situations."

Activities in class were constructed to fit a time frame while the forecast experience was focused on developing practical skills and solidifying concepts in class. For example, students in the class would learn about Skew-Ts, plot them, and discuss the meteorological features, but this was done with just the Skew-T data alone. The forecast experience allowed them to see the Skew-T along with other relevant meteorological data. Students were able to implement concepts through the weekly forecast shifts. One student noted that they would use classroom materials to help understand and connect content as it applied. Students actively looked to make these connections on their own.

Students were challenged during the experience, and it pushed them to make these connections. One student commented that working in this environment allowed students to realize where they needed to focus on their skills and grow. While the course couldn't cover all the content and examples, students were able to determine where they struggled and how to improve. One student noted that they needed to work on analyzing certain products. One participant responded:

> "I think it just helped to grow every time 'cause I feel like I like pushed myself a little further with trying to like see certain things in the atmosphere and then whenever you would step in and be like 'Oh also this is like' Oh well, clearly this is something I missed and this is how I try to not miss in the future."

While students were not judged on the forecast, they would take a moment to reflect on their previous forecast and do better. Students also learned the correct technique and approach for the forecast. As shown in section 4.2.3 in student skill growth, students may have initially used incorrect forecast techniques before the class. By the end of this experience, students were able to think deeper about the forecast and what it was telling them. One student noted how their forecast skill changed over time:

> "Just thinking critically about everything, every piece of data that you can pull in because you know you're not a great forecaster if you just look at model data and then plug it into your forecast…How is the model been performing? Does it have a bias? Has it been, you know, printing out spurious precipitation all over the place when there's really none? It just being able to think about, you know 'hey, this is what this is what I'm seeing. This is what I know has happened in the past. How do these two things relate and how do I adjust what I'm being shown to line up with

what I'm being shown, but also what I know has been happening over the recent period of time.'"

The process of critically analyzing forecast models, accounting for potential biases, and identifying model errors represents a level of forecasting sophistication that students likely had not engaged in prior to this course. This approach is typically associated with more advanced forecasting skills. As shown in Figure 4.8, ten of the twelve students initially identified themselves as beginner forecasters at the start of the experience. The ability described above aligns with skill sets characteristic of the proficient level—skills commonly exercised by professional meteorologists in their routine work. This progression underscores both the students' skill development and their growing confidence over the course of the internship.

One potential reason for the success in the growth of forecasting skills was due to the implementation approach used during the internship. Students were not simply left free to forecast. Rather it was an iterative approach. One student even noted the approach in their quote "I really liked how kind of gradually took it like baby steps at 1st, and now we're writing for AFDs." Writing AFDs was a part of the component, but students really didn't start writing the technical portion on their own without guidance until later in the experience. Generally, students worked on the public portion of the forecast discussion at the start of the internship. This required less work and was more straightforward. As one student commented, "I feel like I'm better at explaining to the general public than writing the scientific part of the AFD." The student's ability to communicate to the public was higher than to fellow meteorologists as indicated in Figures 4.6 and 4.7. By the end, students were responsible for writing both the public and meteorological discussions. Improved ability to write an AFD was a common area of growth that students noted.

Collaboration and Teamwork

Not only did students gain practical skills that related to content, but students also developed their "power skills." These skills are necessary to be successful in any career that a student may pursue. Since students were paired up, teamwork and collaboration were common themes that students discussed. Two students discussed their process:

> "I liked how we had it set up to where I could make my own forecast and then my partner could make his own forecast and then we could kind of collaborate and adjust to make a final probably better overall product."

while another commented on a similar component:

> "I think we should interact more too but I think both of us we were like, OK, we're not sure at the beginning, and I think we were like kind of with the same questions in our mind. So yeah. Like it's our interaction improved on at the end because we were sharing and he was looking other tools and I was looking at other tools and try to compare. So yeah it improves with time."

The pattern of working alone to analyze maps at the beginning was a common practice observed. While forecasting and writing during the internship was a collaborative experience, the actual process of forecasting is an individual component. Students needed time to analyze maps and draw their conclusions. Students may either make mental notes or take physical notes that they would later collaborate on together. As the second quote above illustrates, the dynamic with the forecaster partner evolved.

Another discussion was breaking up the responsibilities that added to the sense of teamwork. As one student said:

> "I like the interaction like the sense of team that you had when you were here, so like [my forecast team] would all work together to make a forecast rather than just "Well, I'll do the AFD and you can do that" and while we did break it up it was very collective so that everything would agree with each other. But like I don't know, it was like you're forecasting with the team rather than just on your own."

For this group, it led to success in the team to achieve the necessary goals. While each person may have had a specific responsibility, the teams still checked each other's work for consistency between messages and proper grammar. This provided an idea of a safety net. The sentiment is shown in one student's comment:

> "I felt good enough to make my own forecast, but I didn't feel like I was kind of left out in the open kind of to do it myself. I always had a little safety net, whether it was you or someone else forecasting with me."

Working with a team would help reduce the responsibility of forecasting and add stress to these new forecasters. By easing students into the situation, they could focus on developing the skills as necessary, knowing that assistance was there.

Having another individual forecasting also allowed for discussions. As one student said:

> "I'm just like, you know overall hashing ideas by like you know, I like the I like how [my forecast partner] and I kind of got into a rhythm of kind of making our own forecasts and then like going through them together and

> being like well, ‘This is why I chose this’ and kind of settling on an on a reason. I think it's valuable to like do it separately and then discuss certain reasons why it should be one way or the other.”

Working alone before coming together for a final decision for a forecast was important. There was communication between the two individuals that allowed them to express their thoughts and have a scientific discussion while addressing their reasoning. This was towards the end of the internship. At the beginning of the internship, the forecast lead would provide guidance but still ask for input and see if the students had any differing opinions and ask why. This shows a certain level of trust/respect with the groups that would emulate real-world collaboration.

Some days were more challenging. On days with more difficult weather, students felt challenged:

> “Like the one where it's easy to forecast when we're just under like a high pressure, good ole little weather. But when I get to more complicated, it helps having like extra opinions to bounce ideas off of just getting a second set of eyes and getting a better idea of what data to pull up and start to look at to better analyze the situation.”

The inclusion of a team member allowed students to gain confidence as they were able to discuss ideas and connect to classroom material if necessary. Snow forecasting is one of the more challenging occurrences for forecasting and having the ability to discuss snow potential and amounts can help find nuances. This emulates the real-world discussions that occur in the professional industry.

While most teams were successful, some had a bit more difficulty working together. This was noted due to a lack of preparation between the individuals or the ability to come to a consensus on a forecast. Despite the difficulties, students were still able to achieve the end goal of writing the two discussions needed for the forecast period. As shown in previous quotes from the interview, students were able to find a way to achieve a goal and establish a pattern that works best for them.

Guidance and Mentorship

For many of the participants, the experience may have been the first chance for them to apply meteorological knowledge and content. They were not alone as the experienced forecasters served as a mentor to provide guidance emulating the master-apprenticeship approach. The lead forecasters had completed the class previously and were a constant presence during the internship. While each lead forecaster had a slightly different approach to forecasting, the starting approach was the same. One student noted the approach:

> "I think it was useful that we had guidance, but also the fact that you guys kind of started to back off and kind of let us go at it. And then I think wouldn't you guys help us like fill in the gaps of what we missed."

Another student commented:

> "[Our forecast lead] never gave us the answer, but simply kind of challenged us to find what the answer is."

All lead forecasters focused on developing the relevant forecasting skills and the writing components. In the beginning, the lead forecasters were very hands-on, oftentimes doing much of the writing, especially the AFD, but would explain what things to consider or why the lead forecaster was doing what they were doing. They were always present during the sessions and would answer questions and provide feedback. Lead forecasters were invested and wanted students to learn as well to become better forecasters.

Through the interaction with a lead forecaster, a positive learning environment was fostered. This positive learning environment allowed students a level of comfort to ask questions in an attempt to learn and develop their skills. One student discussed how they felt comfortable asking questions:

> "I never felt shame for asking. I never felt like I asked a stupid question or I got shamed for asking a dumb question. You know every question I asked had a response and how you know like you know. I remember sophomore year I was is like 'What the hell is thickness?', and you know you guys not only told me what thickness is, you showed me how to find it. You show me different ways I can use thickness for and stuff like that. And so I really appreciate that. Like anything I asked everyone is really helpful and answers weren't given to you but help was always provided."

The student in this situation had encountered a common meteorological map feature but was still uncomfortable analyzing or looking for the feature. As the relationship between the student and lead forecaster developed, they felt comfortable asking. The lead forecaster also provided important useful information that seemed to extend beyond the general questions that the student asked.

The lead forecaster and students not only worked together, but the lead forecaster also celebrated successes with the students. One student commented that they felt supported and appropriately recognized when necessary:

> "[They were] so helpful because [they gave] constructive criticism and [didn't] hover over you and say "Oh, you know I, I don't think that" you know [they] really work with you and kind of like peel the layers off why you think something to get to like the root of the cause and then kind of make you think again, you know if you're going on the wrong track, but [they were] super supportive if you know you're getting it right and [they got] excited when you get things like on the nose and stuff."

As a learning experience for newer inexperienced forecasters, it was important to recognize and celebrate their success. This further developed a positive learning environment knowing that the sense of teamwork extended to not only their forecasting partner but also to the lead forecasters.

The small groups were also preferred by some students. One student felt that it was beneficial as it allowed for some additional material to be covered:

> "I really liked the more one-on-one...like the more personalized forecasting experience. Stuff that you know you can't really just learn in lecture but learn by doing."

While the lead forecasters were good about covering topics as necessary, as students themselves, this was a new experience for the lead forecasters as well. Some groups commented that they would have liked their lead forecaster to ask questions that prompted them to think a bit more or provide more constructive feedback. There were only a few comments related to more support from the lead forecaster, but overall, they are potential things that more experience would allow for these lead forecasters.

The internship experience ended up being a positive experience overall for the students. They were able to apply content from the class to real-world experiences, develop skills necessary for success in any job they may hold, and develop a positive relationship with their lead forecaster.

4.5 Forecast Game Performance

A class requirement was that all students participate in a forecast contest for maximum temperature, minimum temperature, and precipitation amount. All students in every instance but one that joined in the second semester, first year, forecasted at least 70% during the period so all students' forecasts were valid. During the two forecast years, there was an unequal opportunity to forecast. The first year had an extra week in both semesters to forecast and data in the second semester of the second year had a data lull after the first 8 weeks. The results for the daily mean forecast game points score are shown in Table 4.15.

Table 4.15. Mean daily forecast point total for the two groups broken into weeks, semesters, and students completing the entire sequence.

Forecast Point Totals								
		First 6 wks	Second 7 wks	First Semester	First 6 wks	Second 7 wks	Second Semester	Full Series
Year 1	Mean	9.87	10.32	10.11	12.03	12.86	12.48	11.21
	Median	8.00	8.00	8.00	10.00	10.00	10.00	9.00
	Mode	2.00	5.00	3.00	3.00	8.00	3.00	3.00
	Std Dev	8.35	8.53	8.71	9.28	9.40	9.43	9.17
	Range	43.00	55.00	55.00	52.00	46.00	52.00	55.00
	Min	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Max	43.00	55.00	55.00	52.00	46.00	52.00	55.00
Year 2		First 6 wks	Second 6 wks	First Semester	First 4 wks	Second 4 wks	Second Semester	Full Series
	Mean	12.84	11.00	11.92	13.81	11.36	12.88	11.73
	Median	10.00	8.00	9.00	11.00	10.00	11.00	9.00
	Mode	4.00	8.00	3.00	3.00	10.00	10.00	7.00
	Std Dev	10.46	10.12	10.32	11.59	7.05	9.79	9.62
	Range	48.00	58.00	58.00	61.00	49.00	61.00	62.00
	Min	0.00	0.00	0.00	1.00	1.00	1.00	0.00
	Max	48.00	58.00	58.00	62.00	50.00	62.00	62.00

The average daily point value for the first year was lower at every check-in in the first semester. The difference between the two groups was almost three points in the first 6 weeks. However, the difference between the two groups narrows a bit by the end of the semester with less than a point average separating them. The second-year group also decreased their score by almost 2 points in the second six weeks of the semester. Overall, the first-year group performed better, in most categories in the first year. The same trend is seen in the second semester as well. When comparing the students who completed both classes, the daily point difference was only about half a point difference. One interesting difference is the range over the two periods. The second-year group had a wider range. Typically, these high values are climatology reports and negatively impact a student's score. The fact there was a difference indicates potentially slightly more challenging or drastic weather during the forecast period. Also, in the second-year group, no student at any point got a zero-point day or perfect forecast, which further indicates potentially slightly more drastic weather.

Table 4.16. Point total skill scores for the two groups broken into weeks, semesters, and students completing the entire sequence.

Overall Skill Scores								
		First 6 wks	Second 7 wks	First Semester	First 6 wks	Second 7 wks	Second Semester	Full Series
Year 1	Mean	-0.38	0.09	-0.12	0.26	0.06	0.15	0.03
	Median	0.33	0.45	0.40	0.58	0.39	0.48	0.44
	Mode	0.00	0.00	0.00	-1.00	0.00	0.00	0.00
	Std Dev	3.09	1.19	2.28	0.79	0.97	0.91	1.75
	Range	43.00	11.00	43.00	4.00	5.33	5.33	43.00
	Min	-42.00	-10.00	-42.00	-3.00	-4.33	-4.33	-42.00
	Max	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Year 2		First 6 wks	Second 6 wks	First Semester	First 4 wks	Second 4 wks	Second Semester	Full Series
	Mean	-0.02	0.30	0.14	0.36	0.23	0.29	0.26
	Median	0.44	0.53	0.50	0.50	0.35	0.41	0.47
	Mode	0.50	0.75	0.50	0.00	0.00	0.00	0.50
	Std Dev	1.42	0.82	1.17	0.46	0.66	0.58	0.84
	Range	12.00	5.11	12.00	2.22	6.20	6.20	6.67
	Min	-11.00	-4.11	-11.00	-1.27	-5.25	-5.25	-5.67
	Max	1.00	1.00	1.00	0.95	0.95	0.95	1.00

While the mean daily point total may have indicated a better point performance daily, the forecast skill score (Table 4.16) for the second-year group was higher in many statistical categories. Values closer to zero or negative scores indicate no skill while values closer to one indicate more skill. Both groups also improved their forecast skill score in the second half of the first semester in every category. However, in the second time frame of the second semester, the skill scores dropped for both terms. When comparing the average skill score for students who completed the entire class sequence, the second group outperformed the first year. The median between the two groups however is much closer to each when comparing them. Even when removing the extreme minimum in the first six weeks for year one, the skill score gap between the two groups doesn’t decrease a significant amount. The reason for this score is if the persistent score was either significantly higher or lower than the climatology for the day. Since the students forecasted the required 70%, their climatology forecast remained. This negatively impacted the average, but not the median.

Table 4.17. Maximum Temperature skill scores for the two groups broken into weeks, semesters, and students completing the entire sequence.

Maximum Temperature Skill Scores								
		First 6 wks	Second 7 wks	First Semester	First 6 wks	Second 7 wks	Second Semester	Full Series
Year 1	Mean	-0.01	0.04	0.02	-0.04	-0.04	-0.04	-0.01
	Median	-0.01	0.02	0.00	-0.01	-0.02	-0.02	0.00
	Mode	0.00	0.00	0.00	-0.25	0.00	0.00	0.00
	Std Dev	0.11	0.17	0.16	0.28	0.20	0.24	0.20
	Range	0.70	0.86	0.86	1.28	1.09	1.28	1.24
	Min	-0.33	-0.39	-0.39	-0.75	-0.68	-0.75	-0.71
	Max	0.37	0.47	0.47	0.53	0.41	0.53	0.53
Year 2		First 6 wks	Second 6 wks	First Semester	First 4 wks	Second 4 wks	Second Semester	Full Series
	Mean	0.04	-0.05	-0.01	-0.23	-0.11	-0.17	-0.07
	Median	0.01	0.03	0.02	-0.15	-0.05	-0.08	0.00
	Mode	0.00	0.09	0.00	-0.38	0.00	0.00	0.00
	Std Dev	0.11	0.24	0.20	0.92	0.28	0.70	0.47
	Range	0.68	1.25	1.28	5.61	1.29	5.61	5.61
	Min	-0.37	-0.96	-0.96	-4.71	-0.96	-4.71	-4.71
	Max	0.31	0.29	0.31	0.90	0.33	0.90	0.90

When looking at the individual factors that comprise the skill score, one of those is temperature (Table 4.17). Temperature overall did not have much skill for the students and largely wasn't a factor. The first-year group did perform slightly better at the end of both semesters and overall. The first-year group did improve their skills score slightly in the first semester in the second seven weeks with an increase in both the mean and median, but the variation between values did increase. The second-year group decreased their mean, but the median remained about the same. The variation between forecast skill scores also increased. The second-year group in the second semester had a worse skill score in the first four weeks of the semester but did improve for the last half of the semester. Overall, the first-year group proved better than the second-year group, while the first-year group's skill score did decrease, similar to the second-year group.

Table 4.18. Minimum Temperature skill scores for the two groups broken into weeks, semesters, and students completing the entire sequence.

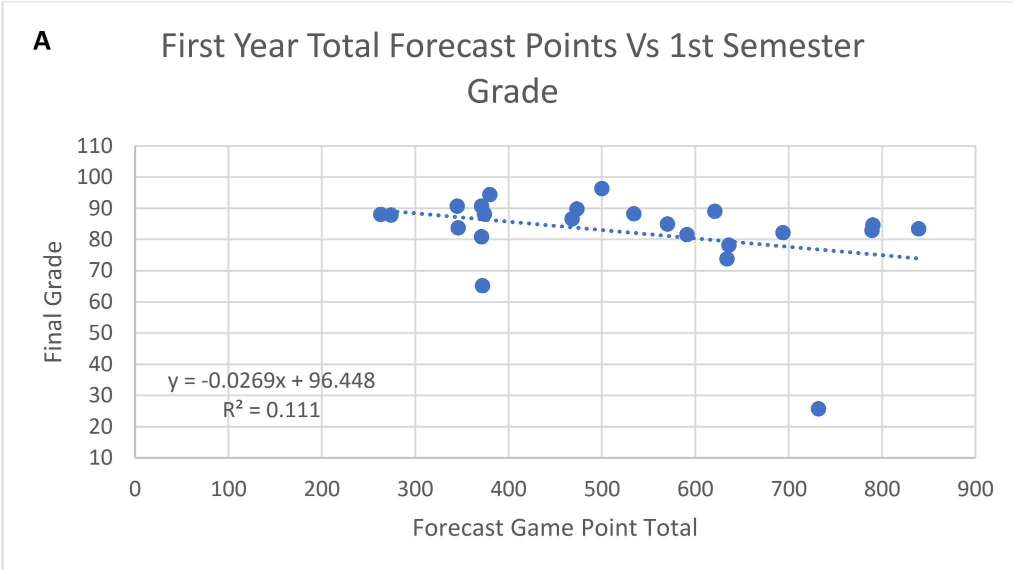
Minimum Temperature Skill Scores								
		First 6 wks	Second 7 wks	First Semester	First 6 wks	Second 7 wks	Second Semester	Full Series
Year 1	Mean	-0.01	0.00	0.00	-0.13	-0.06	-0.09	-0.05
	Median	-0.01	0.03	0.00	-0.05	0.00	-0.01	0.00
	Mode	0.00	0.18	0.00	0.14	0.00	0.00	0.00
	Std Dev	0.12	0.24	0.19	0.46	0.25	0.37	0.30
	Range	0.78	1.62	1.62	2.49	1.41	2.49	2.49
	Min	-0.46	-1.17	-1.17	-1.77	-0.96	-1.77	-1.77
	Max	0.31	0.45	0.45	0.72	0.45	0.72	0.72
Year 2		First 6 wks	Second 6 wks	First Semester	First 4 wks	Second 4 wks	Second Semester	Full Series
	Mean	0.01	-0.11	-0.05	-0.52	0.33	-0.08	-0.06
	Median	0.00	0.00	0.00	0.03	-0.09	-0.03	0.00
	Mode	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Std Dev	0.16	0.38	0.30	2.79	2.72	2.87	1.83
	Range	1.00	2.18	2.18	18.00	18.38	28.00	28.00
	Min	-0.61	-1.73	-1.73	-13.00	-3.38	-13.00	-13.00
	Max	0.39	0.45	0.45	5.00	15.00	15.00	15.00

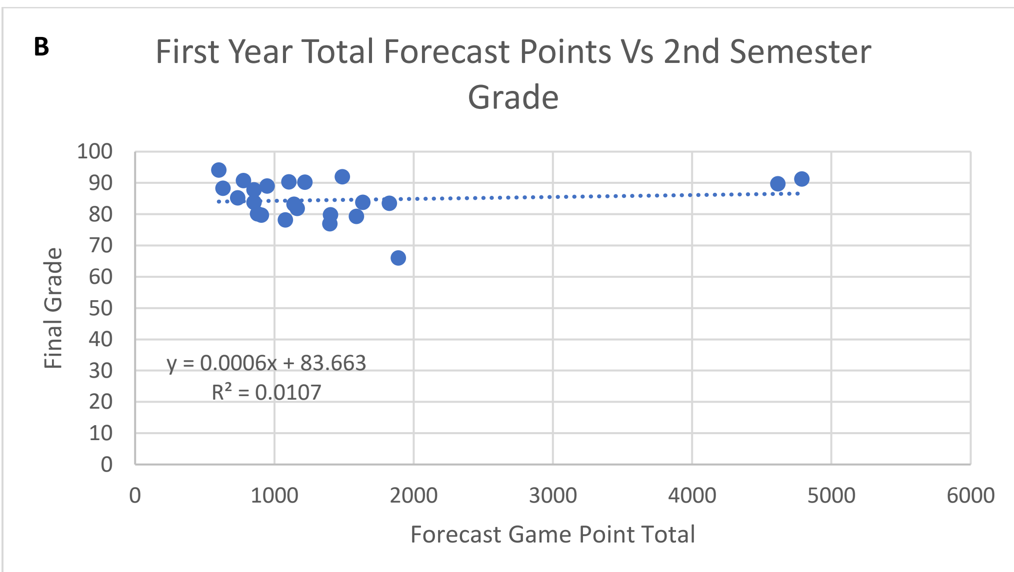
Table 4.18 shows the skill score for minimum for the two groups. Similar to the maximum temperature skill score, there is a similar pattern where the first-year group performs better in the first semester and overall. The second-year group sees a decrease in the mean skill score in the last six weeks of the first semester. The results in ATM_SC 4720, however, are reversed as the second-year group increased their mean skill score much more rapidly than the first-year group. While both groups increased their mean skill score over the two time periods in the second semester, it was more noticeable in the second-year group as they posted a positive value.

Table 4.19 Precipitation skill scores for the two groups broken into weeks, semesters, and students completing the entire sequence.

Precipitation Skill Scores								
		First 6 wks	Second 7 wks	First Semester	First 6 wks	Second 7 wks	Second Semester	Full Series
Year 1	Mean	0.51	0.38	0.44	0.61	0.76	0.69	0.56
	Median	0.00	0.00	0.00	0.20	0.00	0.20	0.00
	Mode	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Std Dev	0.86	0.66	0.78	0.78	0.91	0.86	0.82
	Range	4.00	2.00	4.00	5.00	4.00	5.00	5.00
	Min	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Max	4.00	2.00	4.00	5.00	4.00	5.00	5.00
Year 2		First 6 wks	Second 6 wks	First Semester	First 4 wks	Second 4 wks	Second Semester	Full Series
	Mean	0.69	0.54	0.61	0.78	0.77	0.77	0.65
	Median	0.20	0.25	0.25	0.50	1.00	0.50	0.33
	Mode	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Std Dev	0.89	0.72	0.81	0.84	0.84	0.85	0.82
	Range	4.00	4.00	4.00	3.00	4.00	4.00	4.00
	Min	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Max	4.00	4.00	4.00	3.00	4.00	4.00	4.00

When compared to maximum and minimum temperature, the precipitation skill score was largely in favor of the second-year group (Table 4.19). In the first and second semester and overall, the second-year group had a larger mean and median skill score than the first-year group. However, both groups decreased their skill score. Both groups had about the same standard deviation in the first semester, but there was a larger decrease from the first-year group in the second half of the first semester. In the second semester, the second-year group slightly outperformed the first-year group, but the end-of-semester results were similar. The first-year group did improve in the second half of the second semester while the second-year group remained about the same.


A
First Year Total Forecast Points Vs 1st Semester Grade
Final Grade
110
100
90
80
70
60
50
40
30
20
10
y = -0.0269x + 96.448
R² = 0.111
0
100
200
300
400
500
600
700
800
900
Forecast Game Point Total


B
First Year Total Forecast Points Vs 2nd Semester Grade
Final Grade
100
90
80
70
60
50
40
30
20
10
0
y = 0.0006x + 83.663
R² = 0.0107
0
1000
2000
3000
4000
5000
6000
Forecast Game Point Total

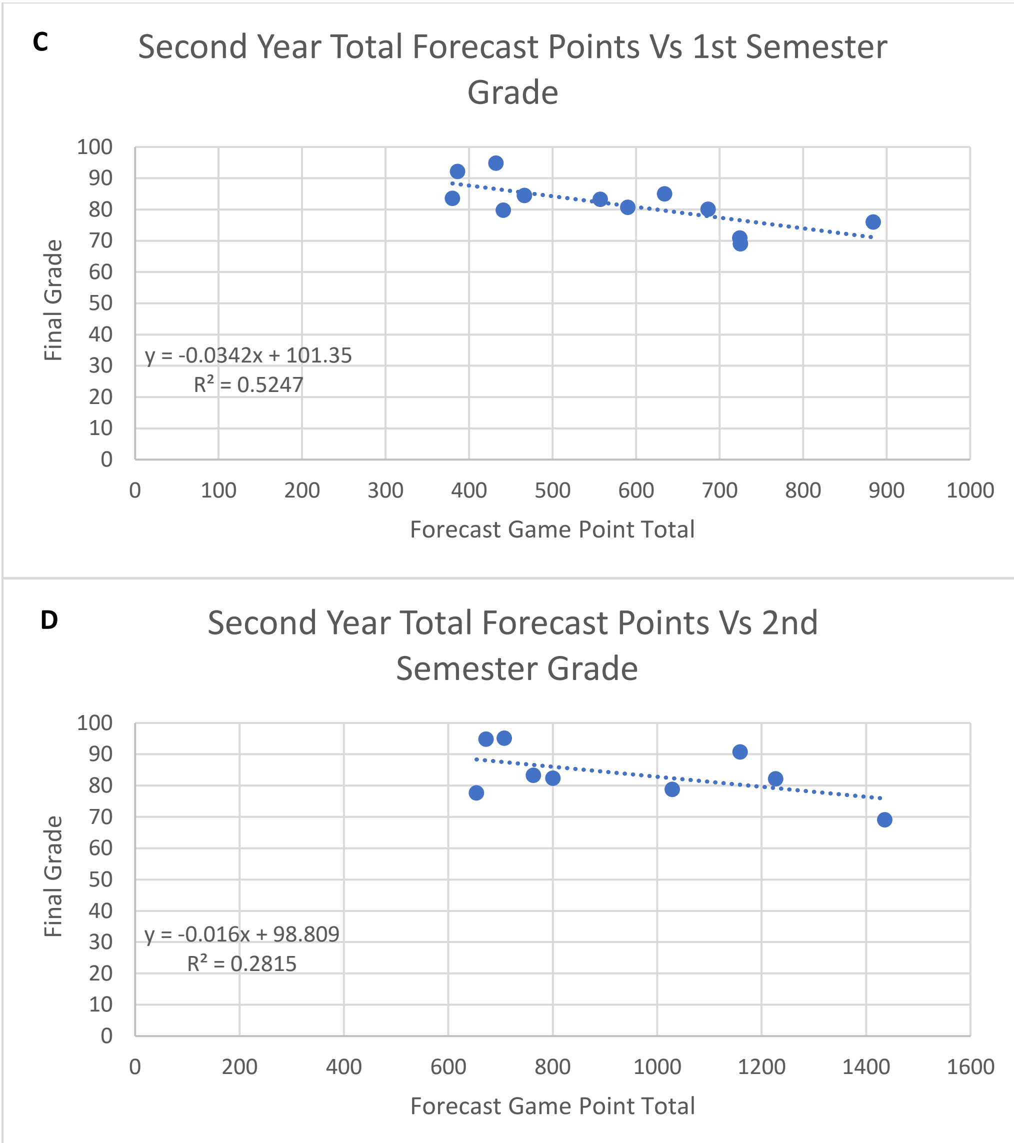
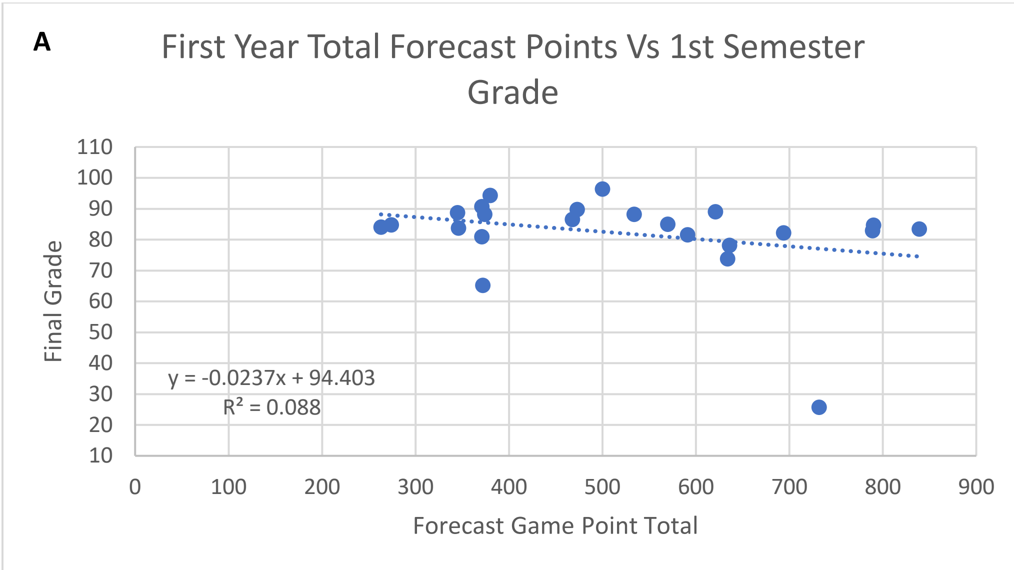
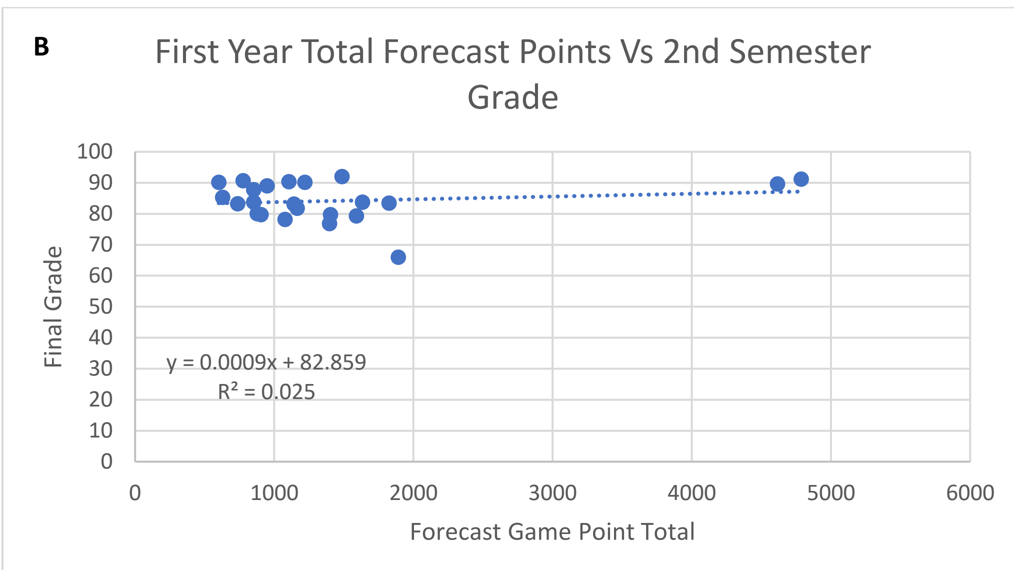
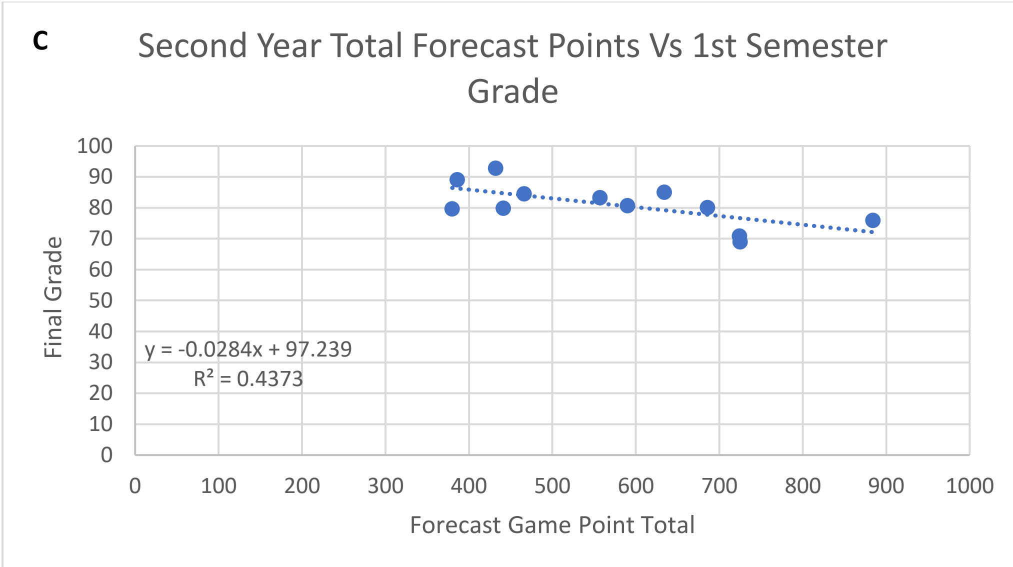


Figure 4.9. Student Final Grades compared to the Semester end Final Forecast Game Point Total with extra credit for (a) First Year in the First Semester, (b) First Year in the Second Semester, (c) Second Year in the First Semester, and (d) Second Year in the Second Semester.

Since students are required to forecast as a part of the course and there is a repeated emphasis on practice in the course, the final grade for the semester for each class was compared to the final forecast game point total. Figure 4.9 indicates the results of the data plotted. There is no correlation for grades in the first-year group (Figure 4.9a and Figure 4.9b). The students who performed the best were not the highest scores in the class in the first semester (Figure 4.9a) but were in the top half for the final grades. The same two students finished ranking first and second respectively in both semesters while the third place finish was different where the individual ranked fourth at the end of the first semester swapped rankings with the third place finisher of the first semester in the second semester. The second-year group however shows a slight correlation between the final score in the first semester (Figure 4.9c) but has a weak to almost no correlation in the second semester (Figure 4.9d). Interestingly, the class ended with the same first, second, and third place finisher for both semesters. In the first semester of the second group, the top three forecast game finishers ranked in the top four for final grades. However, in the second semester, the first place forecast game finisher ranked second to last when comparing final grades.


A
First Year Total Forecast Points Vs 1st Semester Grade
Final Grade
110
100
90
80
70
60
50
40
30
20
10
0
100
200
300
400
500
600
700
800
900
Forecast Game Point Total
y = -0.0237x + 94.403
R² = 0.088


B
First Year Total Forecast Points Vs 2nd Semester Grade
Final Grade
100
90
80
70
60
50
40
30
20
10
0
0
1000
2000
3000
4000
5000
6000
Forecast Game Point Total
y = 0.0009x + 82.859
R² = 0.025



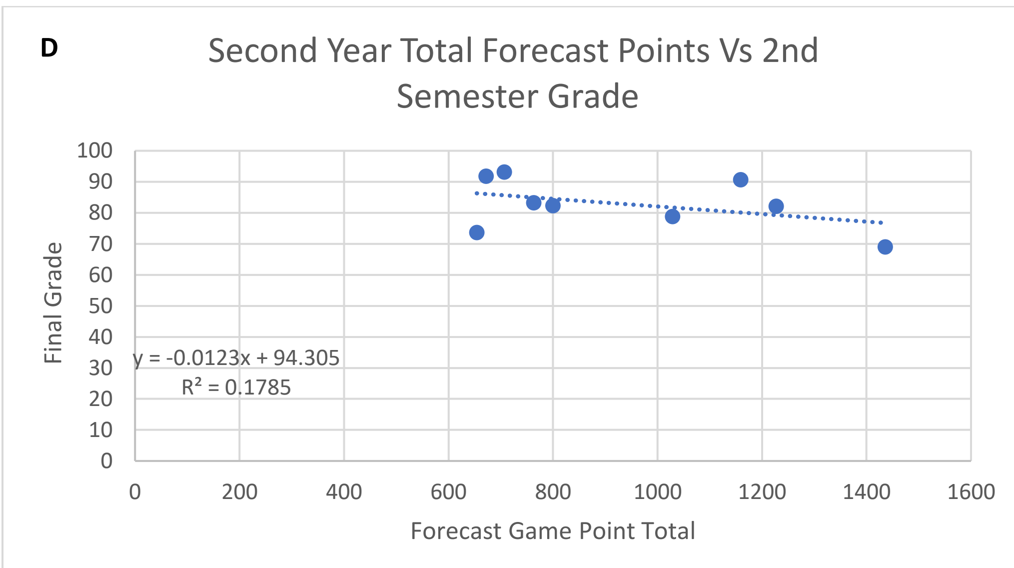


Figure 4.10. Student Final Grades compared to the Semester end Final Forecast Game Point Total without extra credit for (a) First Year in the First Semester, (b) First Year in the Second Semester, (c) Second Year in the First Semester, and (d) Second Year in the Second Semester.

Table 4.20. Grade Letter Comparison with and without Extra Credit for the two years divided by each semester.

Letter Grade Comparison with and without Extra Credit					
	Grade Letter	Fall No Extra Credit	Fall Extra Credit	Spring No Extra Credit	Spring No Extra Credit
Year 1	A	4	5	5	5
	B	15	14	12	12
	C	2	2	3	3
	D	1	1	1	1
	F	0	0	0	0
	Grade Letter	Fall No Extra Credit	Fall Extra Credit	Spring No Extra Credit	Spring Extra Credit
Year 2	A	1	2	3	3
	B	8	7	3	3
	C	2	2	2	2
	D	1	1	1	1
	F	0	0	0	0

Figure 4.9 includes the extra credit from finishing in the top three for the semester in the forecast game. These scores are valid to use because these are official scores submitted to university but including the extra credit had an impact when comparing class performance to forecast performance. Removing the extra credit from the grades decreases the correlation. Figure 4.10a 4.10b continues to show no correlation for the first-year group. Figure 4.10c and Figure 4.10d continue to show a moderate correlation in the fall semester and weaker to almost no correlation in the spring semester. The impact on the letter grade reported to the university only slightly changes between the fall semester as shown in Table 4.20. In both groups, the A letter grade increases by one and the B letter grade decreases by one when the extra credit is added to the final overall grades. This indicates that the final grades were not greatly impacted by the extra credit.

A potential reason the top finishers maintained their status is potentially due to motivation. Students who finished ranked in the top three were given extra credit for their final grade. If a student missed a forecast, they were given climatology which could be anywhere from zero to sixty-one points during an extreme weather event, such as a cooler wet day in the summer. After too many days of these, a student may not be as motivated to perform well in their forecast knowing they may not be able to catch up. This is more evident in the first-year group which was a larger class than the second-year group. Alternatively, if a student has a current score that they are happy with in the class, they may not put as much effort into the forecasting thinking they may not need the points. While one cannot know the student's motivation for forecasting, these comments were observed and made during the class periods that could explain the instances. Finally, a student may simply forget to forecast regularly with can quickly impact forecast performance.

Chapter 5 Discussion and Conclusions

5.1 Summary

The ability to forecast and to do so well is an essential skill to meteorology and is integrated into course work or classes at many universities across the country. The topic most aligns with the Synoptic Meteorology courses and has been integrated into the coursework at the University of Missouri for 25 years. Given the importance that forecasting has and students' general interests in meteorology, this research set out to evaluate the growth of the forecaster in the classroom during the two-class series.

A two-year research project was implemented for two sequences of the ATM_SC 4710/7710 and ATM_SC 4720/7720 classes to evaluate student forecast growth in the Synoptic Meteorology classroom. The two groups were taught using the same content, material, assignments, and tests to ensure continuity between the approaches. The main difference between the two groups was that the second group was offered the opportunity to forecast with experienced forecasters.

For many years, the Atmospheric Science Program at the University of Missouri offered a Campus Weather Forecast which was a chance for students to learn the forecast process, the computers and systems in the WAV Lab, and discuss meteorological content and phenomena. For this research, the Campus Weather Forecast was brought back during the second-year students in the ATM_SC 4710/7710 and 4720/7720 course sequence. Due to internal grant funding from the School of Natural Resources, this opportunity was brought back for students for ATM_SC 4710/7710. With this opportunity available for students again, the goal of the research shifted to focus on student skill forecast development and noting the impact that dedicated time to forecast has on students and the impact that it has on students in the classroom.

The students that participated in the internship experience were given the opportunity to develop their forecasting and communication skills in a more meaningful way. The students in the second-year group ATM_SC 4710/7710 worked with experienced forecasters to develop their forecasts. Students during their forecast shift wrote both a public (non-scientific) and an Area Forecast Discussion (scientific). The experience proved to be an overall positive experience for the twelve students that participated. Self-reported surveys indicate that students grew more confident in their forecasting skills, gained confidence in their ability to communicate meteorological events and features to different audiences, and learned meteorological software. A semi open-ended interview further highlighted themes and takeaways from the experience. The most common comment during the interviews was that students were able to have the practical application of their meteorological content. Students were able to apply the knowledge gained in the classroom and see the meteorological event unfold and/or practice a new skill. Students also appreciated having the ability to learn from experienced peers that were supportive of their learning and helped provide guidance. Student self-assessed skill level grew significantly.

Students in the Synoptic Meteorology series are required to forecast as a part of the Campus Weather Forecast game. Forecasts are required to include a daily high and low temperature and a precipitation category. The precipitation ranges in five unequal intervals from zero to more than an inch. The range is most narrow at the lower ends of the range, and the range becomes broader as the values increase. Students forecasted four days a week and try to get a perfect forecast by correctly predicting temperatures and precipitation. If a student didn't forecast, students were given climatology as a forecast which could negatively impact their score if a student didn't forecast at 70% during the forecast period, their score was dropped overall. Only one student was dropped during this research period.

With the two groups having different forecast experiences, the results from the forecast game do indicate that the second-year group performed better in some respects. There was a moderate correlation between the final game score and their overall performance in the classroom each semester. However, motivation and lack of ability to catch up to those students higher in the standings may have affected overall scores. While students in the second year may have had a weak correlation between their performance and final grade, the first-year group overall outperformed the second-year class by half a point for daily mean score. The second-year group, however, had a higher overall skill score and precipitation skills score.

The Synoptic Meteorology series builds towards two highly synthesized activities in ATM_SC 4720/7720: writing an area forecast discussion and providing a weather briefing. Both groups' grades and surveys were analyzed. While there was no statistical difference in the student performance for the weather briefings, there was a difference in their survey results. The second-year group felt more confident headed into the assignment. Part of the first-year group's issue was the lack of familiarity with the equipment and communicating weather information. Both groups, however, found the experience beneficial, as it allowed them to apply concepts they learned, the forecast process, and challenged them to think on their feet and respond to questions in an appropriate and scientific manner.

While there was no statistical difference between the two groups for the weather briefings, there was a noticeable difference between the two groups for writing area forecast discussions. The second-year group that had weekly experience and practice for writing AFDs outperformed the first-year group. While both groups had the chance to discuss what makes a successful AFD and the approach needed to succeed, the practice seems to have played part in the second-year group performance. In addition, surveys indicated the additional practice was beneficial to a student's confidence before starting the assignment. While both groups grew in confidence, the starting and final confidence level was higher for the second-year group. The second-year group also felt they learned more. Both groups in open-ended responses appreciated the ability to apply end content learned in class, practice forecasting, and build relevant job skills.

5.2 Synthesis

The Synoptic Meteorology classroom is a foundational location for students to develop their forecasting skills. The research set out to evaluate student skill growth in the classroom through observations, content delivery, assignments, and forecasting. Following a student's development was based on the work of Benner (1982: 1984) which focused on student growth in a novice to expert continuum.

Student self-assessment can range from novices all the way up to expert, as shown in some of the surveys in the research. An instructor should guide the students, give them the support necessary to grow their skills, and have benchmarks for success. Each student comes into a class with different expectations, skills, and experience, but providing a common ground in the classroom can help move them along. There was at least one student at the start of the class series for both groups that considered themselves a novice forecaster. By the end of the series, every student identified as competent or proficient with a larger percentage of students in the second-year group identify as proficient. Benner (1984) defined the competent level as someone having a couple of years of experience and that they have a certain level of confidence to handle the roles and responsibilities of the job. There is, however, still anxiety related to the positions. Student comments for AFDs and weather briefings clearly reflect this. However, the level of anxiety and comfort for the two assignments was different between the two groups. The ability to apply and learn content in association with an authentic forecasting experience aligns with the work by Kolb (1984) about authentic real-world experience. While the career opportunities may be shifting, the ability to analyze complex meteorological data and communicate it in different formats is paramount to student success.

Recent work by Handlos, Davenport, and Kopacz (2022) evaluated the state of active learning in the meteorological classroom. They found that the one underutilized approach is the case study approach. The area forecast discussion and weather briefings can fall to a degree into this category. Students work with each other in open communication to the question of “what is the forecast for today” with a clear end goal. As observations and comments indicate, students first analyze the data on their own, discuss their analysis, and put together a final answer that is sent to the instructor (AFD) or given to the class (weather briefing). This process fosters development of meteorological context understanding, applies content learned in class, and develops other relevant skills. Students received this as the last hour of class would oftentimes deal with analysis in the WAV Lab or the classroom to address the weather or analyze content. While a case study can use archived data, meteorology is a rich and active field where each day could lead to potential real world event case analysis. The forecast can easily be verified by the next class period. Engaging directly and analyzing these in class and lab sections can again build important skills.

The biggest benefit of developing a forecaster in the classroom is *outside* the classroom. Before this research, the Campus Weather Forecast had stopped being conducted but was brought back. While it doesn't have an overall impact on students' overall grade in the class, it did improve their writing scores, comfort with the WAV Lab equipment, ability to communicate, and overall confidence. It also led to slightly better skill scores overall and precipitation skill scores for the forecast game. Students also felt like their skills were stronger overall. It is strongly recommended that the Campus Weather Service continue to develop skills as established in this research. Students enjoyed working with experienced forecasters that were equally invested in their success. They proved a valuable role in mentoring and passing along knowledge since they had been there before. While not a part of this research, a Campus Weather Service can help build better relationships between students of the different levels, engage students early on if open to incoming students, and serve a vital role to the school and potential end users. This can further develop meteorological skills and career skills as well.

5.3 Limitations

In to achieve the dissertation in a timely fashion, the work conducted here was limited to one university over a two-year period. The time limit allowed the work to be completed but created a small sample size. It was not expected for there to be such a drastic difference between the two groups as traditionally the number of students is consistent. As such, the total overall group studied was small with an unequal distribution between the two groups. Due to the size difference, sex and grade level differences and connections between the two groups were not conducted and findings were kept broad. A larger group or a few more years of data could have allowed for deeper analysis. The work still adds value however as the tools and approaches can be integrated into forecast focused classroom and sets a foundation for those looking to emulate this research.

5.4 Future Research

The work conducted in this writing was focused on establishing a baseline for forecaster growth in the Synoptic Meteorology classroom. The overall focus was on a few specific synthesis activities at the end of the second semester in ATM_SC 4720/7720. Further research can focus on these synthesis activities and determine which areas students may struggle with and/or track their growth overtime. For example, in a weather briefing, students struggle with the observational analysis, short-term forecast, or long-term forecast. The long-term forecast could be an emphasis area to research given the breadth of ensembles that are available for forecasters. Students were apprehensive about using these products but given how integrated they are in forecasting, further research can determine why and the best way to train students.

If the Campus Weather Service continues and is implemented, it would be worthwhile determining how students use the skills in the other classes and what they bring from the class to the practice. This would include radar, dynamics, and thermodynamics courses. This could be taken through observations or surveys both in the classrooms and during a forecast session with the aim of results focusing on the connectedness and opportunity that a forecast service has on a department overall to develop their students. Additionally similar assessments can be applied to courses to assess student growth.

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Appendix A

CONSENT FORM TO PARTICIPATE IN A RESEARCH STUDY

Researcher's Name(s): Dr. Patrick Market and Adam Hirsch
Project Number: 2009131

Project Title: Evaluating the Novice-Expert Continuum to Improve Student Forecasting Skills

INTRODUCTION

This consent may contain words that you do not understand. Please ask the investigator or the study staff to explain any words or information that you do not clearly understand.

You are being asked to participate in a research study. This research is being conducted to investigate the transition from a novice forecaster to a more experienced forecaster and the effectiveness of the tools and education techniques used. When you are invited to participate in research, you have the right to be informed about the study procedures so that you can decide whether you want to consent to participation. This form may contain words that you do not know. Please ask the researcher to explain any words or information that you do not understand.

You have the right to know what you will be asked to do so that you can decide whether or not to be in the study. Your participation is voluntary. You do not have to be in the study if you do not want to. You may refuse to be in the study and nothing will happen. If you do not want to continue to be in the study, you may stop at any time without penalty or loss of benefits to which you are otherwise entitled.

While the material presented and covered will coincide with class teachings, your grade will not be affected by declining to participate. The materials designed for the research are designed to help the participant gain a better understanding of the forecasting process. You will still do the activity, but your results will not be collected.

WHY IS THIS STUDY BEING DONE?

The purpose of this research is to investigate the transition between novice and expert forecasters and test a variety of different ways to achieve this goal. The use of education techniques and methods is well documented in other disciplines, but there is a gap applying these to the meteorology field. This research will investigate how students respond to these variety of methods in a forecasting and synoptic based class.

HOW MANY PEOPLE WILL BE IN THE STUDY?

About 50 people will take part in this study at the University of Missouri, specifically, the students in ATM_SC 4710/4720. Half of these students will be in year one of the study and the other half in the second year.

WHAT AM I BEING ASKED TO DO?

You will be asked to do a variety of different meteorological tasks focusing on the method of scaffolding. Scaffolding is a technique that helps guide you towards a more complete understanding by using small steps and examples. There is generally more teacher/instructor guidance in the beginning with more independent learning placed on you as the topic becomes further developed. This will be done during the second part of lecture where forecast maps, forecasting software, and case studies will be conducted and lead by the instructor and researcher. In addition, a writing component and presentation component will be conducted in ATM_SC 4720 to see how you are synthesizing and using the information presented on a higher level. These two components of the forecast discussion are essential to future endeavors you may pursue once done with school. You will be given five surveys during this study. Two surveys will be pre- and post- test survey conducted to see where students stand before and after the material presented. These will be given to you before predetermined by the researcher. The other 3 surveys will be conducted only once each, at the start of the semester, halfway throughout, and at the end of the semester. These three surveys will assess your current skill level and growth over this study as a whole. Students on the survey will be given a chance to give feedback that will help adjust material presented to best instruct students.

The projects, homeworks, quizzes worked on in class will a part of the class and a part of the research. As such, grades will be accessed to allow for statistical analysis.

In addition, observations will be taken in class to assess student engagement during in class lectures and projects to gather further understanding of your

HOW LONG WILL I BE IN THE STUDY?

This study will take two semesters approximately to complete and most work will be completed within the classroom, while case studies and writing assignments may be completed outside the classroom. This will take place 3 times a week during the 10:00 a.m.-12:00 p.m. class period for the two semesters. You can stop participating at any time without penalty.

WHAT ARE THE BENEFITS OF BEING IN THE STUDY?

Your participation will benefit you as it will allow for more dedicated time to understanding, interpreting, and applying meteorological concepts applied in class. With frequent feedback, students should be able to improve their forecasting and meteorological skills in class. In the long term, this will be used to further meteorological education to help create a successful basis for a forecasting class and a potential national standard used in both academia, government, and private sector meteorologist. In addition, the results should hopefully identify the more successful techniques to be further refined and tested to improve education in meteorology across the board.

WHAT ARE THE RISKS OF BEING IN THE STUDY?

Your participation in this study does not involve any physical or emotional risk to you beyond that of every day.

WHAT OTHER OPTIONS ARE THERE?

Instead of being in this study, you have these options:
You will not participate in the surveys and the information collected from the study in class will not be used in data other than for grading as noted in the syllabus. You will still complete the assignments in class, but your results will not be used in the research being conducted.

You also have the option of not participating in this study, and will not be penalized for your decision.
Deciding not to participate in this research study will have no effect on your course standing or grade in this course.

CONFIDENTIALITY

The data collected will only be seen by the instructor and researcher. In addition, per FERPA rules and regulation, no personal information or results will be shared. In data analysis, no names will be used, only comments and general statements as to not reveal any personal data. In addition, the data collected may be published or presented but no identifying information will be used or displayed.

WILL I BE COMPENSATED FOR PARTICIPATING IN THE STUDY?

You will receive no payment for taking part in this study.

WHAT ARE MY RIGHTS AS A PARTICIPANT?

Participation in this study is voluntary. You do not have to participate in this study.

You will also be informed of any new information discovered during the course of this study that might influence your health, welfare, or willingness to be in this study.

WHO DO I CONTACT IF I HAVE QUESTIONS, CONCERNS, OR COMPLAINTS?

Please contact Dr. Patrick Market or Adam Hirsch if you have questions about the research. Additionally, you may ask questions, voice concerns or complaints to the research team.

WHOM DO I CALL IF I HAVE QUESTIONS OR PROBLEMS?

If you have any questions regarding your rights as a participant in this research and/or concerns about the study, or if you feel under any pressure to enroll or to continue to participate in this study, you may contact the University of Missouri Campus Institutional Review Board (which is a group of people who review the research studies to protect participants' rights) at (573) 882-9585 or irb@missouri.edu.

You may ask more questions about the study at any time. For questions about the study or a research-related injury, contact Dr. Patrick Market and Adam Hirsch.

A copy of this Informed Consent form will be given to you before you participate in the research.

SIGNATURE

I have read this consent form and my questions have been answered. My signature below means that I do want to be in the study. I know that I can remove myself from the study at any time without any problems.

____ ____________

Subject Date

Appendix B

ATMS-4710/-7710

Synoptic Meteorology I

Syllabus

Fall 2018

Overview:

The objectives of this course are to learn about synoptic-scale meteorology, meteorological analysis and forecasting, and operational meteorology. Students will 1) become fluent in operational meteorological data sets and codes, 2) become proficient in methods of decoding and plotting, 3) employ methods of meteorological analysis and interpretation, and 4) practice the basics of weather forecasting.

Along the way, we will study the principles of scalar analysis and their application to surface and upper air data; subjective (*hand-drawn*) analyses will be employed. Students will also learn how to interpret plan view analyses in isobaric and isentropic coordinates, rawinsonde soundings, hodographs, cross-sections, and time sections. Newer, asynoptic data sets will also be addressed; objective analysis, time permitting.

Associated with these crucial materials, include the rudiments of weather forecasting (though that is more of an ATMS-4720 topic), and the use of several data analysis packages, such as ***NMAP***, the ***IDV***, and ***AWIPS-II***. Concurrent with the last of those topics will come a discussion of UNIDATA data feeds and Linux operating system basics, without which modern analysis software is not generally possible.

Lecture: Monday, Wednesday, and Friday – 10a.m.-10:50 am, ABNR 114
Lab: Monday, Wednesday, and Friday – 11a.m.-11:50 am, ABNR 114 **or** *WAV* Lab (Ag 1-120)
Instructor: Dr. Patrick S. Market
Office: ABNR, Room 331
Office Hours: Monday and Wednesday, 9:00-10:00 a.m. **Also, by appointment**
Office Phone: 882 – 1496 (ABNR 331)
E-mail: marketp@missouri.edu

Texts:

<u>**Required**</u>:

Synoptic Lab Package, **Must be *purchased* from the COMET site, show right here: (https://courses.comet.ucar.edu/enrol/index.php?id=208). Details to follow. *You will need to set up an account. <u>Cost is $40.</u>***

<u>And available online at Canvas:</u>

2. *A Primer on Weather Forecasting,* P. Market, © 2018.
3. *Isentropic Analysis and Interpretation*, J.T. Moore, 1993.
4. *The Use of the Skew-T, log p Diagram in Analysis and Forecasting*, AWS/TR-79/006, Revised.

5. *Meteorological Thermodynamic Diagrams and Processes*, G. Darkow, S. Mudrick, and P. Market
© 2007-2018.

Suggested:

- *Applied Thermodynamics for Meteorologists,* S. Miller
- *Weather Map Handbook*, T. Vasquez. Available at http://www.weathergraphics.com/mapbook/
- *Weather Forecasting Handbook*, T. Vasquez. Available at http://www.weathergraphics.com/fcstbook/
- *Weather Forecasting Redbook*, T. Vasquez. Available at http://www.weathergraphics.com/redbook/

Supplies:

There are certain items that will come in handy in a course like this, and **you should have them on**

hand for *every* class, just in case:

- Regular pencils (**required**)
- Colored pencils (**required**): red, blue, yellow, green, purple, brown, black (standard colors)
- Ruler/straight edge, preferably clear; *C-Thru* makes a good one (**required**)
- Scientific calculator (**required**)
- 3-ring binder (recommended)

Grading System:

Exam #1	20%	**Oct. 12, 10 am-Noon**
Exam #2	20%	**Dec. 5, 10 am-Noon**
Lab Work/Homework	40%	
Weather Forecasts	10%	
Class Participation	10%	

Grading Scale:

Percent	Grade
92.0-100	A
89.0-91.9	A-
87.0-88.9	B+
82.0-86.9	B
79.0-81.9	B-
77.0-78.9	C+
72.0-76.9	C
69.0-71.9	C-
60.0-68.9	D
< 60.0	F

Exams: Exams are comprehensive. Class time may be allotted for review prior to tests. Grades may be curved if the scores show a need for such.

Make Up Exams: If you know you won't be able to take a scheduled exam, you must let me know ahead of

time so that arrangements can be made to take a make up. Of course, a valid excuse will be needed
to take a make up a test. No, ***really!***

Homework/Lab Assignments: There will be various lab exercises (decoding, plotting, analyses, etc.)
throughout the semester. Additionally, I may assign one or more of the COMET modules.

Late Work: Late work (homework, assignments, etc.) will be accepted, but a penalty will be assessed for
each day late (includes weekends, holidays, etc.). The going rate is 10% off per day; for example: an
otherwise perfect 10-point homework handed in 2 days late will get you no more than 8 points.
Also, if you know that you will be absent for a long period of time (e.g., due to illness), let me know
so that we can arrange for class notes and the turning in of assignments.

Attendance: Daily roll call will not be taken. However, the majority of test material will be taken from class
notes. Therefore, it will be in your best interest to attend each class. Excessive absence will be
noted (this is a fairly small class), and will not reflect favorably in your final grade (e.g., borderline
between 2 grades). If you can't make class, please let me know in advance (if possible).

Class Participation: *On a related note, class participation is expected. Most of you are on the brink of being professional meteorologists; as such, being able to question and comment on the course content, to question the statements of the instructor and your peers, is crucial. And remember the words of one popular advice columnist: "...there are no stupid questions, just stupid people who don't ask questions, fearing they'll look stupid."* ***So, speak up!***

Notes: I do not plan to post ***all*** of my notes on the class website (some just aren't in a format that permits
posting…) Then again, you, your parents, or ***someone***, paid a lot of money for you to ***be*** here in
Columbia and in this class. This is an educational system, I might add, that has worked well for
centuries. 80% of life *is* just showing up (see **Attendance** above), so if you want notes, come hang
out with the rest of us and jot them down, or get them from someone else. . .

Forecast Game: This course will require participation in the UM contest. Forecasts are made
Monday through Thursday, unless otherwise noted (due to holidays, conference attendance, etc.).
These instances will be announced in advance. **In order to pass this course, you must participate in *at least 60%* of the forecast days.** No kiddin'. Those who finish 1st, 2nd, and 3rd will have 4%, 3%, and 2%, respectively, **added to their final** grade at the end of the semester (provided that the Forecast Game is run to its conclusion).

Storm Chasing: Should you feel the need to forgo this class for the purposes of storm chasing, be advised
that you must return with video or still photography in hand and be prepared to give a 5-minute,
substantive, professional presentation to the class on some meteorological aspect of this storm. This will become part of your individual homework grade---it is not guaranteed to be 100% and if you make no presentation, then a zero (0) will be entered in as a part of your

homework average. Confusion on this point may be allayed by re-reading the **Attendance** or even **Notes** portions of this document. Lingering confusion will be dispelled totally by speaking with the instructor directly.

Course Outline:

1. Introduction, Syllabus, Orientation, Unix/Linux cluster account, Forecasting Primer
2. Calculus refresher
3. METAR reports, Surface Station Model and Plotting
4. TTAA TTBB reports, Rawinsonde Station Model and Plotting
5. Principles of Scalar Analysis
6. Surface Analysis
7. Upper Air Analysis
   - Isobaric Techniques
   - Isentropic Techniques
8. Sounding (Skew-T log p) Analysis
9. Hodograph Analysis
10. Cross-Section Analysis
11. Time section analysis

Time permitting:

12. Asynoptic Data:
    - ACARS
    - Lightning
    - GPS moisture

12. Satellite Imagery Interpretation
13. RADAR Imagery Interpretation

The University's Statement on Academic Dishonesty

Academic integrity is fundamental to the activities and principles of a university. All members of the academic community must be confident that each person's work has been responsibly and honorably acquired, developed, and presented. Any effort to gain an advantage not given to all students is dishonest whether or not the effort is successful. The academic community regards breaches of the academic integrity rules as extremely serious matters. Sanctions for such a breach may include academic sanctions from the instructor, including failing the course for any violation, to disciplinary sanctions ranging from probation to expulsion. When in doubt about plagiarism, paraphrasing, quoting, collaboration, or any other form of cheating, consult the course instructor.

The University's Statement on ADA

If you need accommodations because of a disability, if you have emergency medical information to share with me, or if you need special arrangements in case the building must be evacuated, please inform me immediately. Please see me privately after class, or at my office (ABNR 331). To request academic accommodations (for example, a notetaker), students must also register with the Office of Disability Services, (http://disabilityservices.missouri.edu), S5 Memorial Union, 882-4696. It is the campus office responsible for reviewing documentation provided by students requesting academic accommodations, and for accommodations planning in cooperation with students and instructors, as needed and consistent with course requirements. For other MU resources for students with disabilities, click on "Disability Resources" on the MU homepage.

The University's Statement for Intellectual Pluralism

The University community welcomes intellectual diversity and respects student rights. Students who have questions concerning the quality of instruction in this class may address concerns to either the Director of SNR, or the Director of the Office of Students Rights and Responsibilities (http://osrr.missouri.edu/). All students will have the opportunity to submit an anonymous evaluation of the instructor(s) at the end of the course.

Appendix C

ATMS-4720/-7720

Synoptic Meteorology II

Syllabus
Spring 2019

Overview:

This course is a continuation of the Synoptic Meteorology I/II sequence. Here you will learn about the features and processes of day-to-day weather in the mid-latitudes. From cyclone climatology to the structure of individual storm systems and the fronts that help comprise them, we will make use of every technique that we studied in Synoptic Meteorology I. Dynamic techniques, especially those used to diagnose those regions of the atmosphere that are moving vertically, will also be discussed. Numerical weather prediction models will be detailed, with particular attention to their design and architecture ("*How* does this model simulate the atmosphere?"), as well as the products they generate.

Daily forecasting will be continued as will the use of *ntl*, NMAP, NSHARP, IDV, and AWIPS-II. Concurrent with the last of those will come additional instruction on the use of the Linux operating systems without which effective analysis software is not possible. In-class weather briefings are required. Regular writing assignments will be required, as **this is a designated *writing intensive* class**.

Lecture: Monday, Wednesday, and Friday / 10 a.m. – Noon / ABNR 114
Instructor: Dr. Patrick S. Market - marketp@missouri.edu
Office: ABNR, Room 331 and 103
Office Hours: **By appointment**
Office Phone: 882 – 1496 (ABNR 331 and 103)

Texts:

Required: None.
Recommended: Lackmann, G., 2011: *Midlatitude Synoptic Meteorology: Dynamics, Analysis, and Forecasting*, Amer. Meteor. Soc., Boston, MA, 360 pp.

Supplies:

There are certain items that will come in handy in a course like this, and **you should have them on**

hand for *every* class, just in case:

- Regular pencils (**required**)
- Colored pencils (**required**): red, blue, yellow, green, purple, brown, black (standard colors)
- Ruler/straight edge (C-Thru makes an excellent clear one; **required**)
- Scientific calculator (**required**)
- 3-ring binder (recommended)

Grading System:

Exam #1	20%	March 08
Exam #2	20%	May 08
Lab Work/Homework	25%	
Writing Assignments	15%	
Weather Briefings	10%	
Class Participation	10%	

Undergraduate *** Grading Scale:**

Percent	Grade
92.0-100	A
89.0-91.9	A-
87.0-88.9	B+
82.0-86.9	B
79.0-81.9	B-
77.0-78.9	C+
72.0-76.9	C
69.0-71.9	C-
60.0-68.9	D
< 60.0	F

*Click here for ***Graduate*** **Grading Scale**.

Exams: Exams are comprehensive. Class time may be allotted for review prior to tests. Grades may be curved if the scores show a need for such.

Make Up Exams: If you know you won't be able to take a scheduled exam, you must let me know ahead of time so that arrangements can be made to take a make up. Of course, a valid excuse will be needed to take a make up a test. No, ***really!***

Homework/Lab Assignments: There will be various lab exercises throughout the semester. Additionally, I may assign one or more of the COMET modules. Also, there will be ***weekly writing assignments*** that will be due.

Late Work: Late work (homework, assignments, etc.) will be accepted, but a penalty will be assessed for each day late (includes weekends, holidays, etc.). The going rate is 10% off per day; for example: an otherwise perfect 10-point homework handed in 2 days late will get you no more than 8 points.

Also, if you know that you will be absent for a long period of time (e.g., due to illness), let me know so that we can arrange for class notes and the turning in of assignments.

Attendance: Daily roll call will not be taken. However, the majority of test material will be taken from class notes. Therefore, it will be in your best interest to attend each class. Excessive absence will be noted (this is a fairly small class), and will not reflect favorably in your final grade (e.g., borderline between 2 grades). If you can't make class, please let me know in advance (if possible).

Class Participation: *ON A RELATED NOTE, CLASS PARTICIPATION IS EXPECTED. MOST OF YOU ARE ON THE BRINK OF BEING PROFESSIONAL METEOROLOGISTS; AS SUCH, BEING ABLE TO QUESTION AND COMMENT ON THE COURSE CONTENT, TO QUESTION THE STATEMENTS OF THE INSTRUCTOR AND YOUR PEERS, IS CRUCIAL. AND REMEMBER THE WORDS OF ONE POPULAR ADVICE COLUMNIST: "…THERE ARE NO STUPID QUESTIONS, JUST STUPID PEOPLE WHO DON'T ASK QUESTIONS, FEARING THEY'LL LOOK STUPID."* ***SO, SPEAK UP!***

Notes: I do not plan to post all of my notes on the class website (some just aren't in a format that permits posting…) You, your parents, or ***someone***, paid a lot of money for you to ***be*** here in Columbia and in this class. This is an educational system, I might add, that has worked well for centuries. 80% of life *is* just showing up (see **Attendance** above), so if you want notes, come hang out with the rest of us and jot them down, or get them from someone else. . .

Forecast Game: This course will require participation in the UM contest. Forecasts are made Monday through Thursday, unless otherwise noted (due to holidays, conference attendance, etc.). These instances will be announced in advance. **In order to pass this course, you must participate in *at least 60%* of the forecast days.** No kiddin'. Those who finish 1st, 2nd, and 3rd will have 4%, 3%, and 2%, respectively, **added to their final** grade at the end of the semester.

Storm Chasing: Should you feel the need to forgo this class for the purposes of storm chasing, be advised that you must return with video or still photography in hand and be prepared to give a 5-minute, **substantive**, professional presentation to the class on some meteorological aspect of this storm. This will become part of your individual homework grade---it is not guaranteed to be 100% and if you make no presentation, then a zero (0) will be entered in as a part of your homework average. Confusion on this point may be allayed by re-reading the **Attendance** or even **Notes** portions of this document. Lingering confusion will be dispelled totally by speaking with the instructor directly.

Course Outline:

Topics

Objective analysis, data assimilation, and
model initialization
NWP and NCEP models

Cyclone climatology
Cyclones and Cyclogenesis: structure and
evolution of cyclones
Potential vorticity considerations

Quasi-geostrophic theory, ω, χ & $\boldsymbol{Q}$
Baroclinic instability

Severe weather forecasting
Kinematics and dynamics of fronts
Jets and jet streaks

The University's Statement on Academic Dishonesty

Academic integrity is fundamental to the activities and principles of a university. All members of the academic community must be confident that each person's work has been responsibly and honorably acquired, developed, and presented. Any effort to gain an advantage not given to all students is dishonest whether or not the effort is successful. The academic community regards breaches of the academic integrity rules as extremely serious matters. Sanctions for such a breach may include academic sanctions from the instructor, including failing the course for any violation, to disciplinary sanctions ranging from probation to expulsion. When in doubt about plagiarism, paraphrasing, quoting, collaboration, or any other form of cheating, consult the course instructor.

The University's Statement on ADA

If you anticipate barriers related to the format or requirements of this course, if you have emergency medical information to share with me, or if you need to make arrangements in case the building must be evacuated, please let me know as soon as possible.

If disability related accommodations are necessary (for example, a note taker, extended time on exams, captioning), please establish an accommodation plan with the MU Disability Center, S5 Memorial Union, 573-882-4696, and then notify me of your eligibility for reasonable accommodations. For other MU resources for persons with disabilities, click on "Disability Resources" on the MU homepage.

The University's Statement for Intellectual Pluralism

The University community welcomes intellectual diversity and respects student rights. Students who
have questions concerning the quality of instruction in this class may address concerns to either the
Chair of the SEAS Department, the Director of SNR, or the Director of the Office of Students
Rights and Responsibilities (http://osrr.missouri.edu/). All students will have the opportunity to
submit an anonymous evaluation of the instructor(s) at the end of the course.

Appendix D

CONSENT FORM TO PARTICIPATE IN A RESEARCH STUDY

Researcher's Name(s): Dr. Patrick Market and Adam Hirsch
Project Number: 2012502

Project Title: Preliminary Research and Education-Downdraft Evolution through Evaporated Precipitation (PRE-DEEP)

INTRODUCTION

This consent may contain words that you do not understand. Please ask the investigator or the study staff to explain any words or information that you do not clearly understand.

You are being asked to participate in a research study. This research is being conducted to investigate the transition from a novice forecaster to a more experienced forecaster and the effectiveness of the tools and education techniques used. When you are invited to participate in research, you have the right to be informed about the study procedures so that you can decide whether you want to consent to participation. This form may contain words that you do not know. Please ask the researcher to explain any words or information that you do not understand.

You have the right to know what you will be asked to do so that you can decide whether or not to be in the study. Your participation is voluntary. You do not have to be in the study if you do not want to. You may refuse to be in the study and nothing will happen. If you do not want to continue to be in the study, you may stop at any time without penalty or loss of benefits to which you are otherwise entitled.

A daily forecast will be made where you will work with a more advanced forecaster. Daily products will be a four day forecast posted on the Mizzou Campus Weather Service blog page.

WHY IS THIS STUDY BEING DONE?

The purpose of this research is to investigate the transition between novice and expert forecasters and provide an internship experience for students to assist in authentic research. This experience is expected to be valuable for students as it will provide weekly practice for forecasting. Scientific communication is another aspect being evaluated. This research will not how students grow confident in their forecat skills and how effective this approach is to student growth.

HOW MANY PEOPLE WILL BE IN THE STUDY?

Fourteen people will take part in this study at the University of Missouri, specifically, 12 students in ATM_SC 4710 and two students in ATM_SC 4730.

WHAT AM I BEING ASKED TO DO?

You are being asked to forecast once a week for Mizzou's campus forecast service. You will be working in the Weather Analysis and Visualization Lab using the product provided to forecast. This will be done outside of class during a scheduled time and will be led by the instructor, researcher, and two students in ATM_SC 4730. In addition, a writing component is included synthesizing and using the information presented on a higher level. Finally, both pre- and post-test surveys will be conducted to see where students stand before and after the internship experience. Students will survey will be given a chance to give feedback that will help adjust material presented to best develop the experience further.

HOW LONG WILL I BE IN THE STUDY?

The study will last one semester. The study will take place for each student during their assigned forecast period one a week during the 6 forecast shifts. You can stop participating at any time without penalty.

WHAT ARE THE BENEFITS OF BEING IN THE STUDY?

Your participation will benefit you as it will allow for more dedicated time to understanding, interpreting, and applying meteorological concepts applied in class. With frequent feedback, students should be able to improve their forecasting and meteorological skills in class. In the long term, this will be used to further meteorological education to help create a successful basis for a forecasting class and a potential national standard used in both academia, government, and private sector meteorologist. In addition, the results should hopefully identify the more successful techniques to be further refined and tested to improve education in meteorology across the board.

WHAT ARE THE RISKS OF BEING IN THE STUDY?

Your participation in this study does not involve any physical or emotional risk to you beyond that of every day.

WHAT ARE THE COSTS OF BEING IN THE STUDY?

There is no cost to you.

WHAT OTHER OPTIONS ARE THERE?

Instead of being in this study, you have these options:
You will not participate in the surveys and the information collected from the study in class will not be used in data analysis. You will still foreast.

You also have the option of not participating in this study, and will not be penalized for your decision.

CONFIDENTIALITY

The data collected will only be seen by the instructor and researcher. In addition, per FERPA rules and regulation, no personal information or results will be shared. In data analysis, no names will be used, only comments and general statements as to not reveal any personal data. In addition, the data collected may be published or presented but no identifying information will be used or displayed.

WILL I BE COMPENSATED FOR PARTICIPATING IN THE STUDY?

You will receive payment for one hour of work every week during the semester at $8 an hour

WHAT ARE MY RIGHTS AS A PARTICIPANT?

Participation in this study is voluntary. You do not have to participate in this study.

You will also be informed of any new information discovered during the course of this study that might influence your health, welfare, or willingness to be in this study.

WHO DO I CONTACT IF I HAVE QUESTIONS, CONCERNS, OR COMPLAINTS?

Please contact Dr. Patrick Market or Adam Hirsch if you have questions about the research. Additionally, you may ask questions, voice concerns or complaints to the research team.

WHOM DO I CALL IF I HAVE QUESTIONS OR PROBLEMS?

If you have any questions regarding your rights as a participant in this research and/or concerns about the study, or if you feel under any pressure to enroll or to continue to participate in this study, you may contact the University of Missouri Campus Institutional Review Board (which is a group of people who review the research studies to protect participants' rights) at (573) 882-9585 or irb@missouri.edu.

You may ask more questions about the study at any time. For questions about the study or a research-related injury, contact Dr. Patrick Market and Adam Hirsch.

A copy of this Informed Consent form will be given to you before you participate in the research.

SIGNATURE

I have read this consent form and my questions have been answered. My signature below means that I do want to be in the study. I know that I can remove myself from the study at any time without any problems.

____ __________

Subject Date

Appendix E

Area Forecast Discussion (Written) Rubric

	Exceed Expectation (4-5 points)	Meets Expectation (2-3 points)	Below Expectation (1 point)
Content (Technical)	• Uses a variety of evidence to support claims • Uses forecast tools and techniques appropriately • Descriptive details given for variables used	• Uses evidence to support claim but lacks specifics • Uses forecast tools and techniques but some issues may exist • Gives details for variables used by may have some vagueness	• Lacks evidence of evidence for forecast • Does not use appropriate forecast tools or support • Details are vague
Application (Technical)	• Analysis defends choices made for forecast • Ties concepts learned in class	• Analysis attempts to defend choices for forecast • Ties concepts learned in class but may miss or inaccurately use them	• No attempt to defend forecast • Does not tie concepts together
Organization (writing & technical)	• Follows NWS AFD format • Uses top down approach • Sentences are logical and flow • Creates a logical weather story	• Attempts to follow NWS AFD format • Follows a top/down approach • Makes a logical weather story, but may contain issues	• Does not have any format • No top/down approach • Makes no weather story
Writing Quality (writing)	• Little to no grammatical errors • Uses jargon appropriately • No more than 2 pages	• Grammatical errors may exist, but don't distract from main point	• Riddled with grammatical errors • Does not use jargon appropriately or incorrectly

			• Does not meet length requirements

Appendix F

ATM_SC-4720 - Synoptic Meteorology II
P.S. Market

Map Discussion Evaluation Date: ______________________________

	Diagnostics	**Prognostics** *(0-36)*	**Prognostics** *(36-168)*
Name of Analyst			
Scientific content of discussion *(e.g., discussion of events and features using accepted models and diagnostics)*			
Quality of Analyses *(e.g., from a known, reliable source; easy to see/read; scientifically sound)*			
Completeness of Presentation *(e.g., top-down or bottom-up approach; obs before forecasts; focus on a specific time/event)*			
Presence / Voice Quality *(e.g., speaker speaks clearly and is sufficiently loud as to be heard; hits their time mark; covers all necessary factors in that time)*			

Additional comments:

VITA

Adam Hirsch was born in St. Louis, MO to the parents of Jeff and Carol Hirsch. His younger brother Kyle unexpectedly passed away during the pursuit of this degree.

Adam has wanted to be a meteorologist since fourth grade during a pretend performance with a mock newsroom. It was during this experience that he learned of his love presentations. This experience was also the catalyst that taught Adam that thunderstorms weren't as scary as he had perceived them and gained a newfound respect for severe weather.

With family living in Columbia and the potential to be third generation graduate, there was no way Adam wasn't attending the University of Missouri, even if he did look elsewhere for a while. Adam started at the University of Missouri in the fall of 2008, graduating with a Bachelor of Science in 2012 and started the pursuit of his master's in fall of 2012. Adam obtained his Masters in 2016 before starting his PhD.

At the start of freshmen year, Adam started working with Eric Aldrich at KOMU in pursuit of his passion to be on air and this continued until the end of spring 2013 when Adam's interest shifted to numerical weather modeling. This was the focus of his Masters work. Towards the end of his Masters, Adam caught the teaching bug, and his research focus again shifted to education research.

He spent his summers at Mizzou working as a backpacking guide in the mountains of New Mexico. The skills, guidance, and ability to live out this dream were some of Adam's favorite times where he made some great friends. In addition, during his time as graduate student, Adam taught the online Introduction to Meteorology course for Central Methodist University.

Towards the initial perceived end of his PhD, Adam sought employment with The Cooperative Program for Operational Meteorology, Education and Training (COMET). He got a job and started in 2020 and has been gainfully employed since enjoying all the position has to offer. With the PhD complete, Adam is looking forward to exploring all that Colorado has to offer and making a life for himself in the shadows of the Rocky Mountains.