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USING SPATIAL VISUALIZATION TESTING TO SELECT RECRUITS AS WEATHER TECHNICIANS IN THE UNITED STATES AIR FORCE

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USING SPATIAL VISUALIZATION TESTING TO SELECT RECRUITS AS WEATHER TECHNICIANS IN THE UNITED STATES AIR FORCE

A DISSERTATION APPROVED FOR THE
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BY THE COMMITTEE CONSISTING OF

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Abstract

This study reviews the current qualities and requirements that the United States Air Force (USAF) uses to select its enlisted weather forecasters. Specifically, I will focus on spatial visualization skills and researching their application on personnel taking the Armed Services Vocational Aptitude Battery (ASVAB) test for selection to enlist in the USAF as a Weather (Meteorological) Technician.

Recent research "suggests that spatial abilities may be an important predictor of performance, particularly in scientific and technical fields" (National Research Council of the National Academies, 2015). This study is concentrated on uncovering antecedents that may assist during the process of selecting personnel for AF Weather (AFW). The premise of this research is to find out if spatial visualization tests could be used as predictors of performance for AFW technicians. The utilization of spatial visualization testing could be especially important in a projected future competitive recruiting environment by providing assistance in identifying the right recruits who can succeed in the AFW career field.

During operations, meteorologists can become too reliant on weather forecast models. On occasion, there are periods when model data is inaccurate (off) or not available due to computer outages (both deliberate and undeliberate). There may also be instances where a person cannot access weather model data, for example, during a power outage. It is during these critical situations that meteorologists must be able to use their mental models and spatial visualization skills to assist in determining a forecast of what the weather will do when the model is off, inaccurate, or unavailable.

Additionally, in a world where cyber-attacks are becoming more common—in both military and commercial industry website enclaves—the likelihood that weather data availability

and data reliability may be questionable at times in the future will also increase. As a consequence, USAF Weather Technicians (forecasters) can become over-confident and over reliant when it comes to their expectation of data flow and communication capabilities via the internet by assuming that weather data will always be available and always be accurate. Lack of or manipulation of this data would also require the use of spatial visualization skills to predict the weather of the future and its impacts on USAF missions.

Currently, the ASVAB includes a spatial-visualization test battery known as Assembling Objects (AO) that all candidates must take. However, this score is not used as a selection determinant for classifying someone to enter the USAF in the scientific Weather Technician specialty. Additionally, the Santa Barbara Sense of Direction (SBSOD) survey, developed by Hegarty, also considers spatial visualization skills as being an important factor in the natural science fields (Hegarty, Crookes, & Shipley, 2010). I posit that utilizing spatial visualization testing, like the ASVAB AO score and the SBSOD, would be advantageous for the USAF to use as selection determinants for future Weather Technicians.

It is imperative that the USAF select the right people (those with spatial visualization skills) for the right jobs (the Weather Technician specialty) at the right time to ensure future mission success. Examining the use of the AO test battery from the ASVAB and the Santa Barbara Sense of Direction survey to assist in determining spatial visualization capabilities could go a long way in supporting the endeavor of selecting the right people to become weather-recruits for the USAF.

Dedication

This work is dedicated to:

My Mother, Amber Minyon
for being tenacious, thought provoking, and always loving.

And

My Wife, Weiyin Liu-Minyon
for having patience and believing in me even when I didn't believe in myself.

"Know the enemy, know yourself; your victory will never be endangered. Know the ground, know the weather; your victory will then be total."

Sun Tzu, 500-430 B.C.

Acknowledgements

Many times over the years and similar to Tom Hanks' character, Chuck Noland, in the 2000 film "Cast Away," I also felt as though I was by myself on an island,' unsure if I would ever complete this dissertation. In the end and similar to the movie's plot, I learned that I had to rescue myself.

That said, I could not have accomplished this personal feat without the tutelage, guidance, support, and never-ending assistance provided by my Committee Chair, Dr. Randa Shehab. During times of frustration and panic—and there were many—Dr. Shehab was always able to provide a calming influence and sage advice that allowed me to move ahead. Again, using the film "Cast Away" as a basis for reflection, Dr. Shehab's words of wisdom helped me rescue myself—she kept me sane and she acted as my Wilson. Thank you!

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I would certainly be remiss if I did not mention my wife, Weiyin, and children, Zoe, Zeo, Kellen and, Sabrina who understood the importance for me to finish this project. Over the years, many hours were sacrificed being away from family dinners or family time together. Add in the change in location of our home four times within five years—Germany to Alabama, Alabama to

Nebraska, Nebraska to Virginia, and Virginia back to Germany—there is no doubt that I could not have completed this program without their love and support. Similar to a support function during the construction of a home, my family acts as my strong and stable foundation. For that, I will always be extremely grateful. Thank you and I love you!

Although they have passed, I must not forget my parents, Mike and Amber Minyon—you instilled in me the importance of working hard, not giving up, and finishing a job. Although this endeavor may have taken me a lot longer to complete than I would have liked, I kept my parents in the back of my mind believing and knowing that they were there, prodding me and rooting me on to finish. Mom, I hope I have finally made up for quitting Boy Scouts at sixteen and disappointing you by giving up on making Eagle Scout so many years ago! You were right and your disappointment was valid; it provided me with a lifelong lesson that when you begin something you need to finish it. Dad, I will always remember you telling me that I can learn something from a person every day and it doesn't matter what their social status is, from a janitor to a doctor—you can learn something. You always reminded me that the first day that you think you know everything is the day you actually know nothing. Thank you, Mom and Dad—I love you and I miss you both very much. In addition, I received support from my two siblings, as well—my sister, Kathy Minyon, and my brother, Mike Minyon. They were instrumental in providing moral support throughout this process. Thank you and I love you both.

I would also like to thank my United States Air Force (USAF) family and friends in the Weather career field community who participated and assisted me along the way, many who have traveled with me over my 35 years of forecasting the weather in support of military missions and operations around the world. A "weather world" that I gratefully still work in and support. Specifically, I would like to thank USAF Chief Master Sergeant (CMSgt) Johnny

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The COVID-19 pandemic; an unwelcome disruptive force—a virus acting with impunity and without discrimination—impacted everyone and everything. How could I continue and persevere against this latest ingredient to world disorder? One word…music. My love of music is such a huge part of my life. It allowed me to maintain my sanity when the world around me seemed to be on the verge of chaos. Undeterred, music was a constant friend and provided me refuge during times of desperation. Without music, I could have survived, but I seriously doubt I could have completed this PhD.

"I would love to tour the southland in a traveling minstrel show." Lyrics from Steely Dan's 1974 song, "Pretzel Logic (Scoppa, 1974)." In many ways this is the way I felt during the development and work on this PhD—as though I traveled in a minstrel show—moving to a new place, setting up and then packing up only to move again. Another musical inspiration that reminded me of my time working on this project was "The Long and Winding Road"—the Beatles last number one single in America (Genesis, 2020). Like the song, I have traveled a "long and winding road" in my efforts to complete this paper. And finally, using Led Zeppelin

and Rolling Stones lyrics, I may have “rambled on” completing this paper and while “you can’t always get what you want…you just might find…you get what you need” to achieve one’s goals. Thank you, music!

In closing, I would also like to thank my fellow OU Cohort VI members who were an inspiration. You gave me hope, many laughs, friendship, and support over the years. Although it has taken me a lot longer than planned, I am grateful for your support. I would have never imagined I would attempt and complete a PhD, but you assisted me in achieving this goal.

BOOMER SOONER!

“In my mind’s eye—one little boy, one little man—funny how time flies.”

—Tears for Fears, “Head Over Heels”

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Chapter One

Introduction

"Okay, we'll go" was the Supreme Allied Commander's (General Dwight D. Eisenhower's) reply to commence the D-Day Normandy invasion on June 6, 1944, when a small break in the weather was forecasted after previously delaying the invasion due to inclement weather (Hand, 1997). Weather forecasting is to many not an exact science, while to some it is an art and not a science at all. Yet, weather impacts all of us in some way or another on an almost daily basis. The history of meteorology and predicting the weather started out as being thought of as sorcery, predicted by astrologists in ancient history and not given much credence or even considered a science. Over time, meteorology has become one of the important Earth Science fields that is now known as atmospheric science. Like the WWII D-day Operation Overlord forecast mentioned above, the US military incorporates weather forecasting in support of the goal to achieve operational mission success. The criticality of a correct weather forecast was never more apparent than the right conditions needed for the Allied invasion at Normandy on D-Day. History has shown that this weather decision was so important to the success of the invasion that it has been highly documented. Although originally conferred in Sun Tzu's famous, *The Art of War*, weather did not appear to be an important American-leader tenet and consideration for its impact on operations until WWII.

There is no doubt that globalization and technology have changed the world in dramatic fashion. Communication, transportation, and economics have never been more "global." Yet, as in the past, the world continues to struggle at the geopolitical level. In response, the United States (US) must utilize its elements of national power (Political, Military, Economics, Social, Infrastructure, and Information; PMESII) to deal with these struggles. Not only does the country have to contend with other rising world-power hegemons, it also must deal with the continued threat of transnational terrorism and humanitarian crises both, manmade and natural, from around the globe. To a large extent, the US government often uses its military element of national power to deal with these geopolitical issues. As a result, the US military needs to be forward thinking in terms of what types of uncertainties and varied contingencies it will face in the future. Weather is a critical "uncertainty" that directly impacts military planning at the strategic, operational, and also at the tactical level of operations.

The US military must determine what kinds of skills will be needed by recruits who will be best suited to fill the roles to support mission contingencies. And while not exact, the importance of meteorology and selecting the right people to accurately forecast the weather cannot be understated, especially when it comes to today's military operations.

As the US all-volunteer force was maturing, the dismantling of the Berlin Wall in 1989 signaled the beginning of the end of The Cold War between the militaries of the US and the USSR. This situation left the US as a hegemon with arguably the best military in the world—the all-volunteer force void of conscripts—highly respected, highly technical and highly proficient at fighting in large, near-peer conflicts. Unfortunately, by 2001 the world order would change again and the US military would have to adapt.

Since the Selective Service discontinued the draft in 1973 at the end of the Vietnam War, the need for increased safety and security provided by the military has never been more paramount. Although hardware acts as the tool of the military, it is the US Soldier, Sailor, Airman, Marine and the new Space Force's "Guardian" who applies and wields the military instrument to the contingency at hand. As a result of the change in military focus and technological advances, it has never been more important to select and retain the right individuals for the right jobs in the US military's all-volunteer force. This military's all-volunteer force utilizes many similar jobs and facets of civilian life, yet it is significantly different. One profession that transcends the civilian world and the USAF is that of the meteorologist or weather forecaster/technician. Something as common as a weather forecast may be similar in the way in which a meteorologist predicts the weather, but the impacts caused by the weather and the forecast accuracy affect civilian life and military operations quite differently.

Air Force Recruiting—Weather Technician

Understanding what an Air Force Weather (AFW) technician does can assist in explaining the differences between weather support provided to the military and the civilian sector. An excerpt from the Air Force Recruiting webpage explains some of the responsibilities of an AFW technician. It is the job of Weather technicians to keep a constant watch over the forecast and conditions that can affect the safety of pilots and aircrew. These experts utilize the latest technology to predict weather patterns, prepare forecasts and communicate weather information to commanders and pilots so that every mission goes as planned (USAF, 2021). Although the technology has changed, the emphasis of today's weather technician—a scientific and technological expert—is not unlike what was needed in the early 1980s as seen in the recruiting ad (Figure 1).

Figure 1. 1980s USAF Recruiting Ad (Source unknown)

In accordance with Air Force Policy Directive 15-1, *Weather Operations*, Air Force Weather (AFW) technicians are trained to analyze weather conditions, prepare forecasts, issue weather warnings, and brief weather information to pilots. Additionally, AFW technicians are trained to observe, record, and transmit space environment observations. They are also taught to read and interpret weather satellite imagery, climatological reports, computerized weather prediction models, and Doppler weather radar imagery. Finally, AFW technicians are expected to understand war fighter tactics their relationship to impacts from weather conditions (USAF, 2021). The Air Force spends millions of dollars a year flying aircraft at different locations supporting different missions around the world. Due to the nature of USAF and US Army ground operations and missions, provided weather forecasts and support require more specific, concise, and timely weather information and are intricately more detailed than forecasts provided for commercial/general aviation and the public. With the amount of time and money spent on selecting personnel to work in the field of meteorology in the USAF, it is important to review the selection process to ensure the right people are being selected for this highly technical field.

With tightening fiscal constraints selecting the right people for the right job to enter the USAF is very important. Currently, the US military uses the Armed Services Vocational Aptitude Battery (ASVAB) for selecting personnel. Within the ASVAB, the Air Force Weather (AFW) career field uses specific batteries to determine which personnel would be best suited to work in the field of meteorology supporting USAF missions. Ensuring the right test batteries are being applied to potential recruits is very important. Identifying the right people can reduce training costs and increase the potential for retaining people. It can also enhance military readiness by reducing future accession requirements while allowing our military to be prepared and ready for any conflicts or emergencies that may occur.

Historical Weather Support to Military Operations

Throughout history, weather has shown to be a significant factor in determining the outcome of military battle and engagements. Napoleon's Russian Campaign in 1812 and the Battle of Waterloo in 1815 would prove that underestimating the impact of the weather, climate, and terrain would result in a significant defeat for Napoleon and his troops (Winters, 1998). An astounding 680,000 men marched towards Moscow as part of Napoleon's Grande Armée in June of 1812—that number was reduced to an amount of 27,000 men by early December, upon their return from the Russian front (Clodfelter, 2017). As such, it is also important to gain an understanding that forecasting the weather to support military operations is very different than to support the public domain. More specificity for the type, impact, and the timing of weather is required in today's military environment in support of today's technological advancements. Having a discussion and an understanding of the historical impacts of weather on military operations is key to conveying the importance of selecting the most qualified and best personnel to become weather forecasters in the USAF. The description of these engagements will help construct the foundation supporting the importance of understanding weather and its impact on military operations. With reference to weather, WWII US Army General Carl "Tooey" Spaatz once said, "in military air operations weather is the first step in planning and the final determining factor in execution of any mission" (Bates & Fuller, 1986). This statement still holds true today. As a result, extremely cold weather and its impact would be Napoleon's undoing on his march in retreat from Russia (Peck, 2017).

Historians also note Napoleon's similar misunderstanding of the impact of weather on his troops during his final military engagement—The Battle of Waterloo. The literal meaning of Waterloo is "wet meadow" and is considered to be a "boggy land" even without the presence of rain. Esposito and Elting (1999) state that on the night of 17 June 1815, a prolonged thunderstorm with torrential rain and frequent lightning strikes deluged the battlefield. The next day, Napoleon attacked by moving up the sloped terrain, a difficult task when the ground is dry, but proved extremely difficult that day because the ground had become saturated and muddy due to the torrential rains of the night before. As described by historians (Neumann, 1993) "the showers and rains turned the ground into a quagmire, severely impeding the trafficability of the fields not only for the artillery and cavalry, but the infantry as well." At Waterloo, the weather played a significant contributing factor in the downfall and demise of Napoleon and his Grande Armee. In the end, Waterloo was a four-day battle that culminated in French defeat on the 18th of June, 1815 ultimately leading to the removal of Napoleon from power and exile to St. Helena.

Pivoting to the young United States, historians talk of the significantly cold weather that plagued General George Washington and his Continental Army. The severe cold weather acted as a major impediment that had to be endured and ultimately overcome. During the Civil War, weather served as an obstacle and as a strategy.

For example, in the Battle of New Market, Confederate soldiers lost their shoes attempting to cross a wheat field turned muddy by a deluge of rain during a thunderstorm—forever known as the "field of lost shoes" (Shively Meier, 2020). Conversely, weather offered a level of concealment for Stonewall Jackson and his men during the Battle of Chancellorsville, VA in 1863. As described by Shively Meier (2020), a steady rain that lasted for two days prior to the battle allowed Jackson and his men to march and sneak up on Union soldiers without creating a visible dust cloud that would normally alert the Union lookout troops of an impending advancement upon their position.

With the introduction of air dirigibles and aircraft to support and assist those fighting a trench war, WWI saw new weather challenges. Clouds, fog, rain, and even, in some cases, aircraft icing and turbulence, impacted the nascent air operations. Not only did weather impact air assets, it caused significant issues for those fighting in the trenches. Bartram (2014) reports that, “The trenches accumulated water quickly at the bottom when it rained, turning them into a squalid mud bath, infested with rodents and insects. Sometimes the water was up to waist height. The muddy conditions caused ‘trench foot’, which caused blisters, open sores, fungal infections and eventually led to gangrene, requiring amputation. One estimate suggests that 20,000 British casualties were caused by trench foot in 1914 alone.” Neumann (1993) also states that, “The extreme low temperatures, especially at night, caused clothes and blankets to freeze solid. The muddy walls became hard as bricks, and any food and water became almost impossible to eat.” The criticality of a correct weather forecast was never more apparent that during WWII and the Allied invasion at Normandy on D-Day. Commander, General Dwight D. Eisenhower intimately worked and coordinated with his meteorology staff prior to making the final decision to launch the invasion on the 6th of June 1944 during Operation Overlord. By this time in the war, General Eisenhower’s Allied forces had encountered too many battle-altering experiences, caused by weather, that they understood the importance and significance of the D-Day forecast and its subsequent impact on the success of the mission (Atkinson, 2002). Eisenhower cancelled the original invasion on 5 June 1944, due to the forecast and anticipated impact of bad weather on his operations. A 24-36 hour break in inclement weather beginning on the 6th began one of the most important invasions in modern history—the mission to remove the German stranglehold on Europe and mark the beginning of the end of WWII.

The weather also played a significant factor in one of the last engagements of WWII in the European theater called the Battle of the Bulge. For the initial attack in the battle, it is now theorized that Hitler used meteorology and the effects of bad weather to Germany's advantage. There are indications that, late in the war, Hitler used his remaining U-Boats operating in the Atlantic to collect and transmit updated weather observations. The weather information was essentially extrapolated for its arrival in Western Europe and Hitler used it to conceal the German offensive that began on December 16th, 1944 (The History Channel, 2017). Subsequently, the poor weather grounded the Allied aircraft that were needed to provide air cover and reconnaissance. It concealed the location of the Germans and severely limited the capability to air drop critical supplies to Allied troops on the ground. As Hitler hoped, inclement weather—low clouds and reduced visibility in snow—grounded the Allied air support needed to "kill tanks" and provide food and medical supplies via airdrop. The foul weather had also caused Patton's Third Army to hold off being able to provide ground support to the cut-off forces in Bastogne, as well. Finally, on 23 December 1944 the bad weather dissipated. As Beevor (2015) describes, "Air controllers joyfully reported 'visibility unlimited' and scrambled P-47 Thunderbolt fighter-bombers to go tank hunting" and this was the beginning of the final Allied offensives that ultimately led to Germany's surrender. Although it would be another two weeks before the Battle of the Bulge would end, the improved weather conditions had turned the tide against the Germans at Bastogne and the war, for that matter.

The Korean War provides another example where weather and inaccurate forecasts had a significant military impact. Warner (2010) states that due to inaccurate planning forecasts, the extreme cold of 1950 started in the middle of November. As a result, American troops were unprepared and did not have the proper cold-weather gear to deal with the very cold temperatures and freezing conditions. Weather would go on to significantly impact US military operations from 1950 to 1953, when the Korean War finally ended in an armistice that still holds today.

The very hot, humid, and wet weather also created significant impacts on the US military during the Vietnam War. The resultant torrential rains created havoc for US troops to include significant logistical problems. The heavy rains also produced low clouds, thunderstorms, and visibility issues for flying operations. The dreary tropical weather affected both rotary- and fixed-wing aircraft and significantly hampered ground operations. The heat and humidity also contributed to health issues associated with malaria. Malaria affected G.I.'s by the tens of thousands impacting US combat strength (Eco In the Know, 2018).

"Operation Eagle Claw" (OEC) in 1980 was designed to fly to the desert in Iran on the outskirts of Tehran to free, extricate, and ferry US hostages, back-and-forth, via helicopter, to waiting C-130 transport aircraft. Unfortunately, OEC was significantly impacted by sandstorms and suspended dust. At the initiation of the mission, one helicopter's visibility was so impaired that, while hovering, it inadvertently flew into another helicopter and C-130 on the ground causing a mishap and explosion that killed eight US forces. The accident caused the mission to be aborted. Balestrieri (2017) explains that in retrospect and after conducting a lengthy investigation, having weather personnel on the ground and working directly with the team to support the mission could have provided real-time weather observational data needed to communicate the presence of "Haboobs" (sandstorms) and suspended dust to adjust the mission's go/no go decision.

In the Middle East, during Desert Storm I, Operation Iraqi Freedom (OIF), and Operation Enduring Freedom (OEF) in Afghanistan, weather impacts were again a factor. Sandstorms, thunderstorms with strong surface gust fronts, and even very high temperature conditions in the Afghanistan Mountains (affecting the maximum flying altitude for rotary-wing operations) hampered safe military operations in this region, as well.

Throughout the history of military conflict, weather has proven to be an important factor that requires risk analysis when planning a battle or an operation. Not planning for the impact of weather will most assuredly alter the anticipated outcome of a conflict or humanitarian mission and at times produce dire results. Although technology, military hardware, tactics, techniques, and procedures used on the battlefield today have changed (e.g., horseback-to-mechanized movement to fighting from the air and even the realm of space with remotely piloted aircraft and satellites) the need for accurate, timely, and relevant weather and weather forecasting will continue to be a major factor that can either help or hinder military operations in the future.

AF weather technicians forecast the weather and assist in minimizing the impacts of poor weather on the AF and missions. The military meteorologist provides terrestrial and space weather information in the form of deciphering observations, satellite, radar, and space weather data to provide forecasts to the fighter pilot in the air or the Army Battalion on the ground—the meteorologist and the pilot both focus on the overarching goal of achieving mission success. Having the right people assigned to provide weather support to military operations is just as imperative as having the right military hardware to complete the mission. Thus, it is fitting that the AF should review how it selects its people to fill this important specialty.

Air Force and Space Force Weather Support Today

As stated in AFPD 15-1, *Weather Operations* (2019), the policy of Air Force Weather is to provide past, current, and predicted terrestrial weather, climate, hydrometeorological, and hydrological services for all elements of the Air Force, designated parts of the Intelligence

Community, and the U.S. Army. This Air Force policy is derived from and in accordance with the overarching Chairman of the Joint Chief of Staff Instruction (CJCSI) 3810.01F, *Meteorological and Oceanographic Operations* (2019).

To accomplish the requirements of CJCSI 3810.01F and AFPD 15-1, the USAF enlists, trains, and utilizes their own weather forecasters. This concept supports AF Department of Defense missions and Combatant Commanders (e.g., US Strategic Command, US European Command, and US Pacific Command, etc.). Air Force Weather (AFW) also provides information and data to other domestic governmental agencies in defense and support of the US. Some examples of these agencies are Joint forces, Coalition forces, National Weather Service (NWS), Federal Bureau of Investigations (FBI), Department of Homeland Security (DHS), Federal Emergency Management Agency (FEMA), and National Security Agency (NSA) (Air Force Weather Directorate, 2016). It is important to note that impacting weather phenomena and forecast requirements are often needed to conduct worldwide military operations in remote and data-sparse locations that do not include local meteorologists, permanently based weather observing systems, weather radar systems or domestic/indigenous meteorological services and capabilities.

Depicted as an inverted pyramid, Figure 2 is a representation of the 557th Weather Wing with the strategic level support at the wide top of the pyramid, moving down through the operational and tactical levels of operation where the pyramid becomes narrow and specific to supporting an operation. As depicted, support is provided to a myriad of airframes, missions, and personnel.

Figure 2. 557th Weather Wing Support to Different Levels of Operations © 2019 USAF/557 WW

To meet weather support requirements, AFW must invest in training to ensure missions receive the weather support needed. The USAF spends approximately $70K per student (with annual inflationary increases) to attend initial weather forecasting school (Caruso, 2016). Selecting the right people to be weather forecasters in the USAF is not only vitally important to military operations but also fiscally responsible to the US government and its taxpayers. Being able to determine if a person is capable to enter the Air Force and train in the Weather AFSC prior to enlisting would also benefit the Air Force, too. Additionally, it takes approximately a year from the time formal and unit training is complete for an AF Weather Technician to be able to work on his or her own in support of mission objectives. With projected limited finances and human resources, selecting the right personnel to enter the Weather career field is critical to supporting Air Force missions of the future.

Weather Support to Missions of the Future

Cyber Issues and Weather Information Data Access.

Weather forecasting relies on data and data flow and it lies at the foundation of cyber dominance. Command and Control (C2), weapon system technology, logistics, personnel movements, and weather forecasting all rely on information and data flow. Cyber security is critical to ensure weather data are available and not corrupted by deliberate means. Nordquist (2018) explains that "Cyber domain operations are the bedrock of American military strength today, and consequently, they are its greatest liability for tomorrow." Interruptions in data flow can significantly impact missions leading to a Contested and Degraded Operational (CDO) environment. If weather data is not available or is limited, manual forecasting techniques will be required and AFW skills and abilities will be vital to producing military operational forecasts.

The ease of obtaining current weather and model data and its availability using technology creates a potential precarious situation. Relying on communication backbones, links, and systems as if the data will always be available (no matter where operations are occurring in the world) could create a situation where current weather and model data may not be available due to communication and dissemination issues. Beyond knowing the current conditions, data loss impedes AFW's ability to understand why specific weather is currently occurring or is forecast to occur. Knowing “why” the weather is occurring leads to understanding “what” weather will happen or is forecast to happen in the future. The atmosphere is very complex and the models are remarkably good which leads to forecasters relying on numerical weather prediction data when reacting to time constraints and short deadlines (McPherson, 2021). As a result, the plethora of automated weather models/applications has created a situation where a meteorologist may be discouraged to understand the “why” of a forecast and what it is anticipated to occur when providing the forecast is time constrained.

The Importance of Selecting the Right People

Selecting and producing a military force in the US is an investment in safety and security paid for by taxpayers of the US. Thus, it is critical to understand the mental and cognitive requirements of the most qualified AFW meteorologists in order to select those most likely to perform at the highest level. Proper selection will produce the best return on investment for the taxpayer while contributing to the safety and security of the USAF.

The USAF Weather career field specialty summary requires that personnel “perform and manage the collection, analysis, and forecast of atmospheric weather and space environmental conditions” (USAF, 2019). Automated monitoring equipment collects the atmospheric and solar weather data while computers and humans analyze the information. The analysis data of what is currently occurring is plotted on global/regional map backgrounds. The result is a picture of the weather that is occurring at a specific time over a specific place.

However, in today’s world of meteorology there is considerable reliance on weather models. Almost all of the data for providing the current weather observation and forecast use automated systems and computers to produce an output for a specific location. In 2017 at the Pacific Air Forces Weather Conference, the previous AFW Career Field Manager, Chief Master

Sergeant Ron Richards (2017), explained that today's AFW personnel must "bring your craft to the fight," referring to being able to forecast the weather by the use of your knowledge of meteorology rather than always relying on forecast model output. This knowledge includes understanding the physics and dynamics of the atmosphere and their application and effect on the forecast. The reality is that computer modeling is fairly accurate in the short-term (8 to 24 hours), but many times a model does not always produce a correct forecast or it is interpreted incorrectly. Therefore, having a solid understanding of the physics and dynamics of the atmosphere is instrumental in assisting the meteorologist in making his/her forecast. For example, it can be assumed that if the short-term forecast is incorrect then the additional forecast output will likely be incorrect, as well. In these cases, a human needs to step in review the current weather data to include observations, radar and satellite imagery and then apply sound scientific and meteorological reasoning with the goal of issuing or correcting the weather forecast. As stated by McNeal, Petcovic, and Ellis (2017), "To see the world as a meteorologist, one must understand and interpret atmospheric processes through representations depicted on two-dimensional weather charts and maps that encode large amounts of spatial and numerical data."

Humans are needed in the forecast process to rectify when the model is off course and its output is likely to be off. This why having the right person with the right spatial visualization skills to fill the AF's meteorological technician position is vital. "A recent upsurge in empirical evidence suggests that spatial abilities may be an important predictor of performance, particularly in scientific and technical fields" (National Research Council of the National Academies, 2015). Similarly, it is believed that spatial visualization is an important trait that forecasters need to rely on when the model is inaccurate. Computers and artificial information can certainly support and supplement the development of a good weather forecast, but it is the human being that determines the "rightness" of the model and/or artificial data and adjusts when necessary. Doswell (2004) notes that "computer reasoning (models) tends to produce highly accurate results, but occasionally produces very large errors whereas, intuitive human reasoning produces results that may have small average errors but are more widely dispersed."

Current Visualization Products

Most people are familiar with current visualization products that are based off numerical weather prediction (NWP) models and are available throughout the field of weather forecasting. Durbin (2018) describes an NWP model as a product that is based upon mathematical equations, founded by physics, and which characterizes how the air moves and heat and moisture are exchanged in the atmosphere. Durbin (2018) continues by stating that "weather observations (pressure, wind, temperature and moisture) obtained from ground sensors and weather satellites are fed into these equations." One only has to tune in to their local evening news to see weather-model data being displayed with the resultant graphics and a local forecast. One can also look at their cell phone to obtain a picture of the weather in the forms of clouds, sun, etc. But more detailed weather information is required like that used for military operations.

Figure 3 presents an example of a numerical weather model output produced over a smaller, mesoscale, region and displayed in graphical/visual mode that is designed and used for military operations. The product is called a meteogram and is produced by Air Force Weather (AFW) for many locations in the United States and other parts of the world, as well. This meteogram provides an example of a Global Air-Land Weather Exploitation Model (GALWEM) output. Vertical cross-sections provide a point-in-time forecast for a specific location. The product displays isotherms, isentrops, wind barbs, relative humidity, icing, turbulence, and clouds. This output displays clouds, winds, precipitation, and temperature and are just a few of the parameters that a forecaster can see using this product to develop their forecast.

For example, the top part of the product in Figure 3 displays a time-referenced (Zulu "Z" time) vertical and horizontal picture of the cloud cover, winds, temperatures, and freezing level (the blue 0° temperature line) at specific times and levels for Will Rogers Airport in Oklahoma City, OK. In this case, the forecast runs from 14 September at 06 Zulu (06Z) thru 20 September at 06Z in six-hour increments. The amount of clouds (Few, Scattered, Broken, and Overcast) are indicated by the color of the clouds. The type and amount of precipitation is also shown in the "3-Hr Precip Amount" section and is listed in hundredths of an inch. The bottom rectangle displays the temperature and the dewpoint trends over time in red and green, respectively. All of the information provided in the meteogram is important for meteorologists and has practical applications on the weather forecast and resultant impacts to aviators and ground-supported personnel.

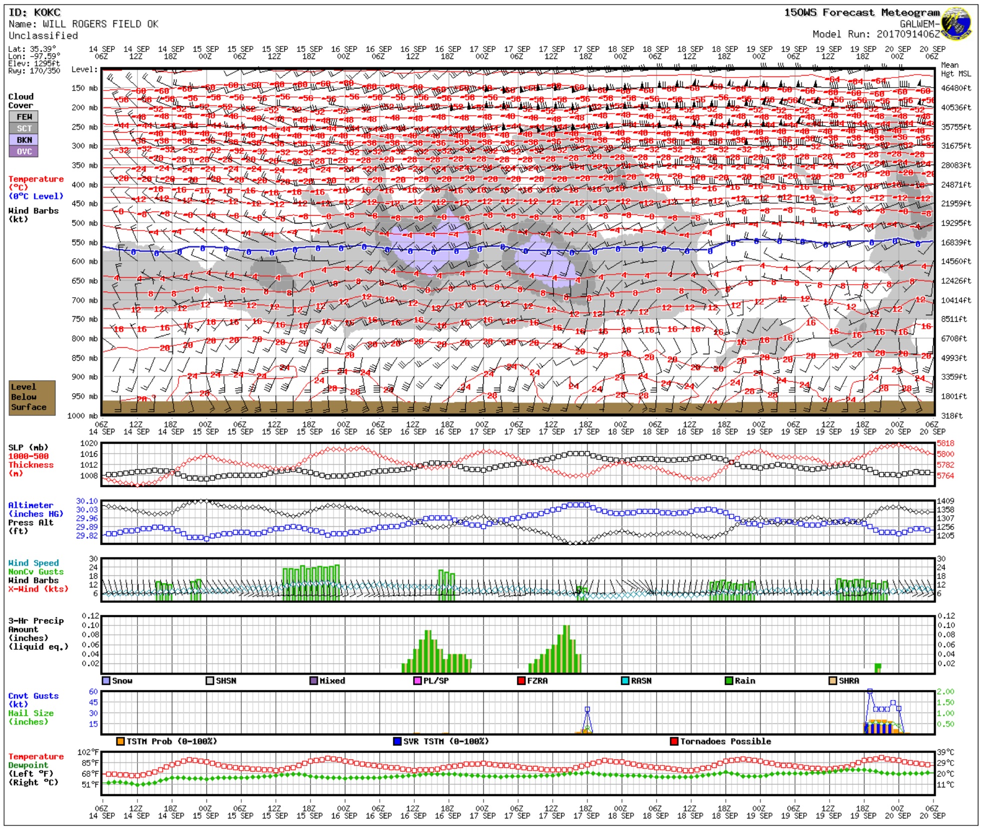

Figure 3. Will Rogers Airport Meteogram, 2017 USAF 557th Weather Wing

Need to Visualize

Although model-output-visualization products can be very useful and beneficial for producing and understanding a forecast, a meteorologist still needs to be able to visualize what the weather will be when the model's forecast has failed. However and again, in today's world of meteorology and technology, there tends to be an over reliance on the output of the model data rather than determining if the model is correct at its initialization point of the model run. That is, is the "initial" model-run, when compared to the actual weather observations and radar/satellite imagery, accurate? After investigation and comparison of the actual data versus the model data (and it is determined that the model is inaccurate) the meteorologist must be able to step in and make meteorological mental adjustments, often "on the fly, to correct the forecast. Being able to adjust and produce an adjusted resultant forecast is why the capability to mentally visualize the future state of the weather is of utmost importance.

Data Degradation

But what if the automated weather observing system becomes inoperative for an extended period? What if the weather computer model output has ingested inaccurate data, or the data is delayed due to an extensive internet connectivity outage? What if the supercomputer that produces the forecast crashes? Or, what about those situations where the computer forecast is being produced but the output is not handling the current weather situation very well? In the US military, for answers to all these questions, the responsibility to correct the data or data gap in weather falls on the meteorologist or weather technician/forecaster. During a data outage, a data-denied situation, or operating in a data sparse location requires these meteorologists to be able to determine the current weather situation and visualize what it will look like, determine its impact, and apply it to the military operation at hand in the future. As previously discussed and also briefed by Chief Richards, instead of saying "the model predicts a phenomena in the forecast" to occur, a forecaster should be asking why did the model predict a phenomenon to occur in the forecast?" Again, knowing "the why" of the forecast model output is just as important as knowing "WHAT" resultant weather the model data produces.

Model Forecast Skill

"If the flap of a butterfly's wings can be instrumental in creating a tornado, it can equally well be instrumental in preventing a tornado"—Edward Lorenz. Although computer models can do a good job of forecasting the picture of the current weather analysis at the macro- and meso-scale into the future, they also can occasionally produce incorrect terrestrial and space environment forecasts. This is particularly true for extreme weather events. As stated by

Sillmann, et al. (2017), “Extreme weather events occurring at temporal and spatial scales much smaller than that of current state-of-the-art climate models are generally difficult to predict.” Meteorologists discuss the skill of a model with relation to its predictive capability in an effort to determine its accuracy. For example, the skill of a model can be measured against persistence (what is happening now will continue to happen without change) and climatology (using historical weather data) and whether the model can do better than these forecast estimates. There are certain weather events that models can forecast very well. However, models can and do have skill and accuracy issues when extreme weather events occur.

Often an incorrect forecast is caused by spatial and temporal resolution issues in the model. For example, when considering total amount of precipitation forecasts, Shrestha, et al. (2013) state, “forecasting precipitation is challenging because it is discontinuous and varies rapidly in space and time.” Additionally, model output may be limited due to the lack of spatial/temporal resolution when it comes to specific locations in the world. The African continent has limited real-time weather observation data to ingest into models. In an article by Lombrana (2021), the author states that “the continent has the world’s least developed land-based weather observation network, amounting to only one eighth of the minimum density recommended by the WMO.” This lack of data can be significant when considering the output of the model for not only that region but on a global scale, as well. When a model is not accurate, the output must be adjusted and corrected by meteorologists.

Lack of Data

In addition, network interruptions may prevent model data flow via the internet. In addition, with reference to corrupted data, Chief Richards stated, “As with any other network-based information system, our weather operations information systems are susceptible to cyber-attacks" (Richards C. M., 2017). Data loss could come from failed technology as well as a cyber-attack, which could include anything from weather-data denial through loss of communication circuits to manipulated observed weather observations or forecast models.

Civilian Impacts

Due to the intricate details of the atmosphere and complexity of weather systems, even at the molecular level, forecast models can be inaccurate and are not perfect. Weather models and their output are affected by imprecision and the time-honored computer science concept of "garbage in, garbage out" or GIGO. For example, a model that incorrectly analyzes a low-pressure system that is off by one degree of latitude (~60 nautical miles) can have huge implications in terms of the resulting forecast and location of the associated weather. In the civilian sector, a resulting incorrect forecast can create second- and third-order effects; subsequent untimely closures of schools and businesses, cancellations and delays for airport operations, unpreparedness or over-preparedness of road surface treatments, just to name a few. Ladue (2011) alludes to this in her description of weather model error in 2000 with a low-pressure system location and resulting incorrect snowfall forecast track—a minor error in the weather model output created a major impact for eastern seaboard cities that encountered the unforecast heavy and crippling snow event. Forecasters failed to intercede and make adjustments to the forecast when they saw that the track of the low in the model run was off when compared to surface observations and satellite imagery. As Ladue (2011) states, the forecasters became confident in a "bad forecast," were too trusting of the model and solely relied on its output. Overreliance on technology can lead someone to neglect what they are seeing when a contradiction between weather models and real-time weather data occurs.

Adjusting the Forecast: Using Mental Models and Visualization Skills

As previously discussed in the LaDue example, accepting the computer model output without determining the model is initially accurate can lead to a major forecasting error. Instead, the forecasters needed to analyze the current weather situation and compare it to the initial model product output. Thoroughly reviewing the data, they could have seen that the model location of current position of the low was off. At this point, the forecasters could have adjusted the initial model output to correctly place the current position of the low. Using sound meteorological reasoning, they could have used their mental models for heavy snow forecasting and visualized the future location of the low, its resulting path of weather, and adjusted the forecasts for those cities that would be impacted with heavy snow. It is imperative that meteorologists have the capability to see when a model is incorrectly forecasting the weather and to make adjustments, incorporating spatial visualization skills and utilizing weather observations in an effort to produce more accurate forecasts. A meteorologist's ability to recognize when a model is incorrect and see how a weather observation can be developed into a forecast relies on critical visualization skills.

In the advent of data loss, today's AF forecasters, more than ever, may have to rely on and revert to a previous forecasting technique, single-station analysis (SSA) weather forecasting. This technique requires the forecaster to take the current weather observation, to include what he/she sees with his/her eyes and incorporate it into developing a weather forecast. For example, if weather data were unavailable, a forecaster could use Buys Ballot's Law to determine where low and high pressure currently resides. This law of physics states, "in the Northern Hemisphere, with your back to the wind, low pressure will always be to the left and high pressure will always be to the right of the wind flow" (Collins English Dictionary -

Complete & Unabridged 2012 Digital Edition, 2021). Knowing where the pressure systems are relative to your current location adds a wealth of information that can assist in making a forecast without the aid of computer models.

Another example is understanding the types of clouds in the current weather observation. Cloud types can assist in determining the stability of the atmosphere, the type of front that may be approaching and potentially the type of weather to expect in the future. For example, observing Towering Cumulus (TCU) or Cumulonimbus (CB) clouds would be indicative of an unstable atmosphere. "To apply the SSA procedures, the forecaster must have a thorough understanding of the three-dimensional structure of synoptic systems, knowledge of seasonal climatology, and knowledge of local conditions that impact upon the meteorological events at his station" (Henry & Brundidge, 1985). Insert the 4^{th} dimension—time—and one can understand the need for and importance of cognitive visualization skills to be able to "see" the atmosphere in the future.

These forms of forecasting the weather, like SSA and using spatial visualization skills, are required during times of weather data loss or inaccessibility. Staying current with the application of the science of meteorology and being able to move the weather are paramount to assisting in answering the "whys" of the weather and must be retained and applied.

These techniques of years gone by are still applicable today, yet they rely on an individual mentally visualizing what a weather system looks like in their mind's eye and moving the system by use of empirical rules to create a forecast (more will be discussed about SSF techniques later in this paper). For example, "The forecaster should have a thorough knowledge of the three-dimensional structure of atmospheric pressure systems and the sequence of weather events normally associated with moving systems. This is a crucial factor for the ability to make a forecast on the basis only of what the forecaster can observe at his location" (Henry & Brundidge, 1985).

The Differences between Commercial Weather and Military Weather

Commercial Weather

Historically, weather has been impacting lifestyles and events for hundreds of years and it continues to influence all of us on a daily basis. Weather affects the clothes you wear, the thermostat setting in your home, whether a sporting event will be played, delayed or cancelled, having a picnic, leaving early to get to work on time, and even how you feel. These examples are just some of the personal daily activities that are impacted by the weather. However, the way in which weather is observed, forecast, communicated, disseminated, and reacted to have changed significantly over time. How weather is communicated to the everyday person impacts the ability to respond appropriately. Figure 4 depicts the weather conditions at the national level.

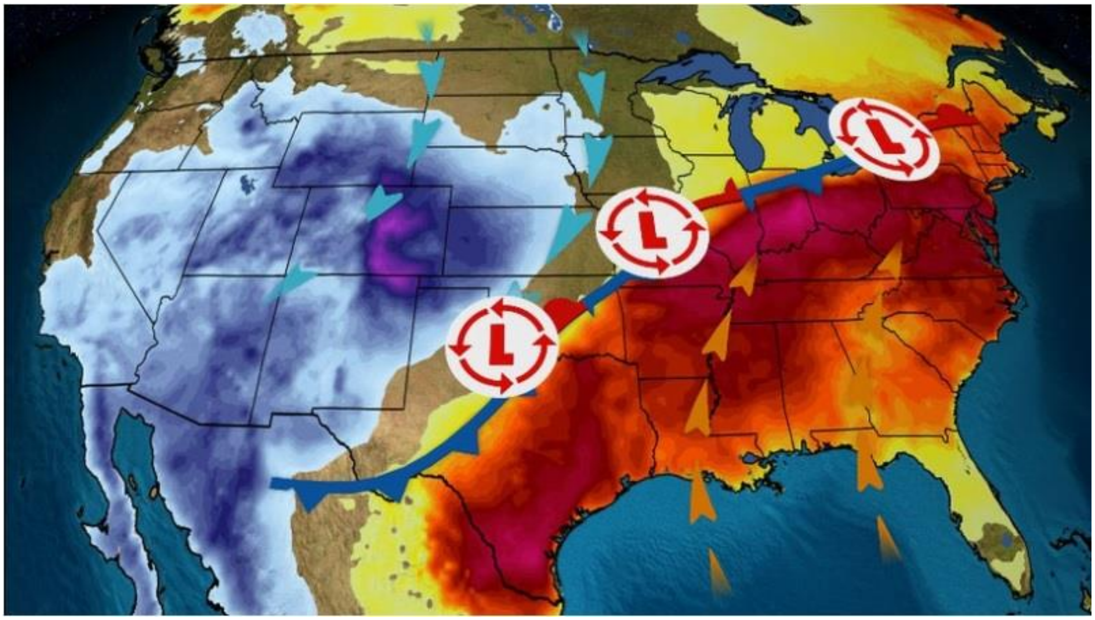

Figure 4. US National Weather View. Copyright 2020, The Weather Channel

The forecast shows low pressure systems, fronts along with blue arrows and red pips indicating the difference between cold air and warm air flow. If you look at a specific location, the forecast becomes more detailed. In this case, the top portion of Figure 5 depicts the current weather observation for Pittsburgh International Airport, PA. Weather information is provided in both visual and written formats and correspondingly varies in scale. The public can use the weather forecasts to assess the impact on their daily life and act accordingly.

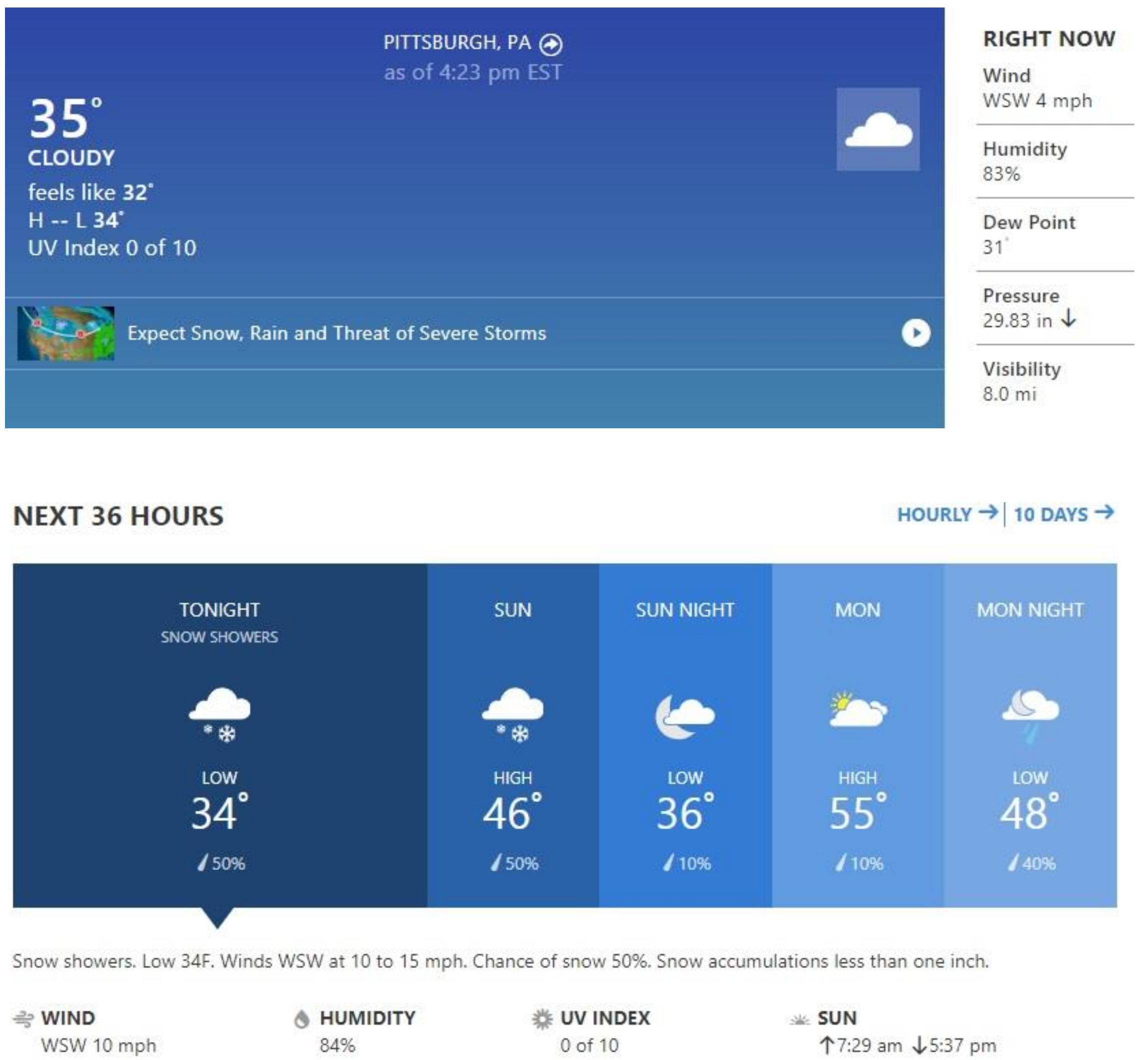

Figure 5. Pittsburgh, PA current observation and 36-hour forecast.
© 2020, The Weather Channel

Weather also affects the economy of companies/corporations and industries, as well. For example, agriculture, construction, and logistics industries are all impacted by weather. Commercial users/consumers of weather information have more specific requirements than the public users. Of note, all flying operations, to include commercial operations, use the Zulu clock. The bottom portion of Figure 6 shows an example of a 36-hour forecast for Pittsburgh, PA. Instead of reporting cloudy conditions as depicted in the top portion of Figure 5 for Pittsburgh, PA, the current sky condition in the weather observation, highlighted in yellow in Figure 6, is reported as “BKN013” for broken clouds or “ceiling” of clouds at 1,300’. The specificity of cloud height is important for air operations as it tells the aircrew the actual height of the clouds over the Pittsburgh runway. The height of the clouds will determine whether the aircrew can take off or land at the airfield using visual flight rules (VFR) or instrument flight rules (IFR).

Figure 6. Pittsburgh, PA current observation and 30-hour TAF.
© 2020, The Weather Channel

For example, the current visibility at Pittsburgh is 10 statute miles (SM) as shown in the current observation, outlined in yellow, in Figure 6. However, unlike the 36-hour forecast depicted in Figure 5, the 30-hour Terminal Aerodrome Forecast (TAF) for Pittsburgh, identified by the International Civil Aviation Organization (ICAO) code as KPIT, is depicted and outlined in red. The TAF, highlighted in red in Figure 6, provides much more specificity in terms of cloud heights, visibility, and winds. In this example, the KPIT TAF shows the visibility being reduced to 2 statute miles (2SM) with light snow (-SN) and a cloud height/ceiling of 800' overcast (OVC008) beginning on the 2^{nd} of February at 02:00 Zulu (FM020200). It is vitally important for the pilots to know the specifics of visibility, weather phenomena, clouds/ceiling, wind, and temperatures to operate their aircraft safely.

Military Weather

Many military operations require additional weather information to accomplish their missions. Information like providing altitude variation data for low-level flight operations or drop-zone forecasts for obscure locations are examples of weather-specific requirements that are common to the military operating environment but not needed for commercial air operations. More acute specificity and application of weather data are the main differences that the military weather forecaster must be able to provide to his or her military operator.

The main weather differences include weather specificity and application of weather data. For example, data required by military operations in support of missions include altitude variation data for jet aircraft flying low-level missions; drop-zone forecasts to support para-operations of personnel/equipment; and space weather impacts on satellite systems and ground station operations. Additionally, the support to different airframes often requires different weather support. These different forecasting requirements illuminate the importance and need for selecting qualified individuals who can provide weather support to military missions.

The United States Military All-Volunteer Force

Unfortunately, war and conflict are interwoven into the fabric of world history. One's nation cannot survive without some form of military capability, to protect its citizens, sovereign state, and national interests. Although cliché, philosopher George Santayana's statements of, “Those who do not remember the past are doomed to repeat it” and “Only the dead have seen the end of war” are responses to H.G. Wells’ and US President Woodrow Wilson’s proclamation that World War I would be the “War to end all wars” and still ring true (Santayana, 1905) (Paice, 2013). The quotes continue to remain very relevant in today’s turbulent world where the potential for conflict or response to a national or international emergency/catastrophe remains a constant concern.

Since the end of the Vietnam War and the revocation of mandatory conscription (i.e., “the Draft”) in 1973, the US has used the mandated Selective Service Program as a registering capability for national emergencies for all men 18-25. “The law currently requires that only men register with Selective Service. In the event that the law is changed to include registering women, Selective Service is prepared to expand registration” (US Government, 2021). Since that time, the US military’s human capital, including AFW, has been totally comprised of volunteer personnel who are both men and women. And given that the complexities creating a secure environment of the world of the future are more complex and volatile than any we have experienced in recent memory (Government, 2018). It is imperative that the all-volunteer military has the right people are available to fill specialty positions, like USAF weather personnel.

Recently, the military has identified a potential problem with future recruiting of young Americans to the different branches of the US military. This concern involves having the right people who are capable to fill the right jobs being available to enlist but due to personal-history issues (health/overweight, illicit drug use/involvement, etc.) they cannot enlist. A recent study conducted by The Heritage Institute identified 71 percent of eligible recruits between the age of 17 and 24 as being ineligible to join the military due to four main issues that have the potential to impact prospective recruits in the future: lack of basic education; physically unfit—obesity; drug use; and criminal records (Spoehr & Handy, 2018).

In mid-March 2018, then Secretary of the Air Force, Heather Wilson, made it clear that when it comes to recruiting, “the service's doors need to be open to all to attract, develop and retain the best young men and women possible.” (Spoehr & Handy, 2018). Wilson continued by talking about how the government and Congress stating, “There’s always a lot of focus on the next piece of equipment in this town but not a lot of focus on how we’re going to develop the next generation of leaders. And, how do we attract great young Americans to service and develop them and encourage them to stay?” (Bipartisan Policy Center, 2018). How do we ensure we are selecting and investing in the right people for the right jobs in the US military from a smaller pool of eligible recruits? The issue of whether enough capable young men and women will be available to fill its ranks along with putting the right people in the right jobs in the future will become vital.

In terms of the USAF and future manpower, it is very important that capable recruits who enlist from this limited commodity of personnel also meet specific criteria applicable to a job. As in the case of the Air Force, an Air Force Specialty Code (AFSC), like the 1W0X1 Weather Technician specialty, the recruit must meet job criteria to ensure mission success.

As the air component of the US military, the US Air Force (USAF), needs accurate and insightful selection requirements as part of the hiring process to acquire the right volunteer force of personnel to fill all career-fields. Historically, like the Army, Navy and Marines, the Air Force (AF) utilizes the Armed Services Vocational Aptitude Battery (ASVAB) of test scores to select its incoming volunteer force in an effort to match the right person for the right job or career field. AF Career fields are categorized using AF Specialty Codes (AFSCs). An AFSC is specific to a position—a career field—in the AF and determines what job a person accomplishes while filling that position. The different array of AFSCs ensure the Air Force produces a synergistic group of personnel who work together to support and produce mission success.

USAF Meteorological Technician Career Field and Spatial Visualization Skills

As stated in the Headquarters Air Force Weather (AFW) Flight Plan, "Air Force Weather (AFW) operations exploit weather information to maximize the application of military instruments of power" (Air Force Weather Directorate, 2016). The 1W0X1 career field—Weather Technician Air Force Specialty Code (AFSC)—plays a behind-the-scenes but very important part supporting military operations and engagements. The 1W0X1 AFSC identifies the Weather career field used to select and create meteorologists to forecast the weather in support of military operations and missions. Encoded as "1W0X1," the "1" identifies the "Operations" field and the "W" identifies the "Weather" career field. The final three digits, the "0X1" portion of the code, identifies the "skill level" of the person. A 1W031 is a "3-level" or new recruit, a 1W051, a "5-level" is a more seasoned recruit (e.g., 2-6 years of experience), a 1W071 is a "7-level" (e.g., 7-15 years of experience), and finally a 1W091 is a "9-level" (e.g., greater than 15 years of experience).

Current Mandatory Requirements used for AFW selection:

How does the USAF select its weather career field personnel? Currently, ASVAB specific test batteries are used to determine who is qualified to be classified as a Weather Technician candidate in the USAF. Present AFSC personnel selection criteria are based upon scores achieved in the ASVAB. Specifically, in the Weather ASFC career field, emphasis is based upon scores from the General and Electronic ASVAB batteries. Yet, research has shown that having spatial visualization skills as being advantageous for those who work in scientific fields, to include meteorology (Hegarty, Crookes, & Shipley, 2010).

Additionally, the Air Force weather technician utilizes aspects of spatial visualization to accomplish their job throughout his or her career. This capability is not currently assessed as an entry requirement for this specialty. Recent research indicates that it would be beneficial for the USAF to modify the Armed Services Vocational Aptitude Battery (ASVAB) criteria for selecting the right people to enter the US Air Force (USAF) in the right job; the meteorological career field—the 1W0X1—specialty. As described in the 2019 Air Force Enlisted Classification Directory (AFECD—located in Appendix 2), "individuals in the Weather career field forecast atmospheric and space weather conditions based on observations, terrestrial and space sensing instruments, weather radars, data and imagery from geostationary and polar orbiting satellites."

Brief History of the ASVAB

Although the ASVAB was introduced in 1968, its history can be traced back to World War I (WWI). Initially, the Army used two versions of the test to determine what occupations recruits would be best suited for. The alpha-test version was a written exam while the beta-test version was a non-verbal exam given to recruits who were illiterate, unschooled or foreign-speaking. Evolving over time, the ASVAB has gone through many iterations and subsequent studies by both the US military and higher education establishments. To this day, the purpose of the ASVAB is to assist military branches with determining the best qualifications for specific jobs that reside within their service. Additionally, the ASVAB serves as the initial delineator for the US military to determine minimal entrance qualification requirements (The Armed Services Vocational Aptitude Battery (ASVAB), 2017).

The nine batteries in the ASVAB are:

- General Science (GS)
- Arithmetic Reasoning (AR)
- Word Knowledge (WK)
- Paragraph Comprehension (PC)
- Mathematics Knowledge (MK)
- Electronics Information (EI)
- Auto and Shop Information (AS)
- Mechanical Comprehension (MC)
- Assembling Objects (AO)*

*Note, the Assembling Objects (AO) score is currently only used by the US Navy for military occupation selection (Held & Carretta, 2014).

The AFQT entry test score is a compilation of battery scores and is used to determine a candidate's eligibility for entry into the AF. Several batteries are used within the ASVAB to compute AF entry scores: Arithmetic Reasoning (AR), Word Knowledge (WK), Paragraph Comprehension (PC) and Mathematics Knowledge (MK). The formula used for entry in the Air Force is 2VE + AR + MK = AFQT RAW SCORE, where VE is the abbreviated form of Verbal Expression and is a combination of WK + PC. A minimum score of 36 is required for entry into the AF (Kaplan, 2016).[1] If a minimum score of 36 has been met, selection to enter the AF has been achieved and then a combination of specific and additional ASVAB subtests are required for entry into the AFW career field.

The ASVAB current composite of batteries used to select potential enlistee candidates for entry into the AF Weather (1WX01) career field are the General (G) and Electronic (E) composite test batteries, where G = VE + AR and E = AR + MK + EI + GS. Currently, the AFW requires prospective enlistees to score at least a 66 on the G composite battery and a 50 on the E composite battery. Although the Air Force currently tests personnel for spatial visualization capabilities using Assembling Objects (AO) and is already a part of the ASVAB, the scores are masked and are not used to classify any of the USAF AFSCs or US Army and US Marine Military Occupational Specialties (MOSs). Only the US Navy is currently using the AO test battery as a selection determinant for a small percentage of Navy ratings.

Personal Reflection

The lyrics from The Who's 1967 song, "I Can See For Miles" or the lead character, Emmet Brickowoski, from "The Lego Movie" exclaiming, "I can see everything!"—both infer visualizing and visualization concepts. Working in the field as an operational forecaster and being associated with AFW as an active-member and civilian weather program analyst for over 30 years, it is my belief that visualization conceptualization skills often separate the mediocre forecasters from good forecasters. Is the weather system associated with the jetstream? Is there divergence/diffluence aloft? What are the temperatures at the 500-mb level? Is there a short-wave trough aloft? What is the surface dew-point temperature? Does the current and forecast Skew-t diagrams for that location display severe-weather-pattern soundings? What are the stability indices? All of the answers to these meteorological questions assist the forecaster in "seeing" the weather structure of the atmosphere and provide assistance in determining the forecast and the probability of severe weather.

Weather forecast models can graphically show the future state of the atmosphere and they continue to get better over time. However, reliance on weather models to produce a forecast without understanding what is causing the current weather and checking to see if the model is initializing the meteorological conditions acceptably can lead to incorrect forecasts.

Additionally, the resolution (or grid size) of the model can also significantly impact the forecast output. Ingleby (2021) states, “All observing systems (surface-based observations and data from various satellite instruments) provide significant positive impact for at least some aspects of the numerical weather prediction (NWP) system.” This is especially true in data-sparse regions like those experienced by the US military in Iraq and Afghanistan during conflicts, in addition to other data-sparse locations like small islands. Having the capability to adjust the forecast model output by mentally visualizing and applying the outcome of these alterations to the forecast allows a meteorologist to produce a more accurate predictions. One only has to remember recent computer produced hurricane forecast tracks (e.g., Katrina, Harvey, and Irma, etc.) to gain an understanding of the difficulty of predicting the atmospheric state of the future. Each adjustment of the forecast weather track created a ripple effect of public panic throughout the potentially impacted areas.

In the military sector, blindly accepting model-run forecasts without checking the accuracy of the data and applying mental adjustments when needed can result in devastating mission-impact issues and can produce second- and third-order effects, as well. For example, using bad model data without correcting and mentally adjusting the forecast for aircraft operations to provide close-air support (CAS) to Army personnel on the ground could mean the difference between mission success or mission failure. In extreme cases, it could also have life-or-death implications, as well. Regardless of the supported agency, it is important for a meteorologist to be able to:

- Discern when initialization of the model indicates that erroneous-model output is occurring.
- Use weather forecasting techniques and make mental adjustments to the model.
- Visualize the weather forecast output and its impact on future operations.

From 1991 to 1995, as a Master Instructor at the Keesler AFB Weather School in Biloxi, MS, I taught a portion of the Weather Forecaster Technician curriculum that required students to apply forecast rules to move and modify the make-up of weather systems from their current state to 24 hours into the future. Two courses, Synoptic-System Forecasting (SSF) and Forecast Lab Evaluation (FLE), were based upon analyzing and forecasting the major synoptic or large-scale weather systems at levels of the atmosphere from the surface to the top of the troposphere (300-mb; ~ 36,000 feet) over the Continental United States (CONUS). The SSF course was designed to initially teach forecasting rules-of-thumb at specific levels of the atmosphere and applying those rules in FLE to draw, adjust (e.g., intensify/weaken, increase/decrease moisture, increase/decrease wind speeds, etc.), move, and visualize weather systems into the future on a map background of the CONUS on a piece of paper. Computer technology and modeling, in terms of graphics and output, was relatively basic during this time. Although weather computer modeling has improved substantially over the past twenty-five years, these forecasting rules of thumb can still be used today when weather-model data is sparse or unavailable.

One of the SSF rules used required moving a major short-wave trough (MSWT)—an upper-level weather producing feature—at 500-mb by using 50% of the windspeed behind trough on the current weather analysis. For example, if a MSWT had 50 knots of wind located behind it at 500-mb on the actual data analysis then one would forecast the trough to move at 25 knots (50% of 50 knots) of speed over the next 24 hours. This would result in moving the MSWT a total of 10 degrees of latitude downstream or approximately 600 nautical miles (25 knots X 24 hours) using the projected windflow direction as a steering mechanism. Drawing and placing the MSWT 600 miles downstream on paper (using the direction of the windflow) was a way the forecaster visualized where the trough and associated weather would be in the next 24 hours.

Occasionally, some individuals struggled with depicting the trough (and other weather features) into the future. Interestingly, when their student records were reviewed, many of these individuals who were having difficulty moving systems into the future had high General and Electrical ASVAB scores, as required for selection into the career field, but lower Mechanical aptitude scores. These individuals also did very well in the knowledge portion (i.e., written tests and exams) of the course where application of the weather knowledge and information were not required. Conversely, my experience also indicated that students who had average scores in the G and E batteries and high scores in the Mechanical (M) or Administrative (A) batteries, often displayed average scores in the knowledge portion of the school but flourished in the forecast application/visualization performance checks of the course. Of note, the Mechanical (M) score is calculated as: (AR) Arithmetic Reasoning + 2 (VE) Verbal Expression + (MC) Mechanical Comprehension (MC) + Auto and Shop Information (AS) while the Administrative (A) score is calculated as: Verbal Expression (VE) + Mathematics Knowledge (MK).

On the surface, these observations may provide an indication that those students who had average scores (or higher) in the G and E batteries but had high scores in the M or A batteries may be more capable of visualizing and 'seeing' the future state of the atmosphere than someone who has high G and E scores but low scores in the M or A batteries. This calls into question whether the ASVAB scores being used for entry into the AF Weather career field are the most appropriate. A study conducted by Wieand (2008) indicated that high M battery scores did not indicate a statistical correlation to producing successful forecasting students. Instead, Wieand's study (2008) indicated a possible correlation between the A battery and success in graduating from the school. Perhaps a focus on other ASVAB battery scores or, a combination of other ASVAB scores, could better assist in identifying potential AF Weather candidates.

Gaps in Air Force Weather Selection Criteria

Worried that increasing US military attrition rates were due to the seemingly reliance on high school credentials and high school diplomas, the National Defense Authorization Act for 2012 stated that noncognitive measures like spatial visualization testing could be used to recruit individuals into the military. The use of non-verbal tests and scores like Assembling Objects (AO)—already tested in the ASVAB but not used—along with other personality tests, could assist in remedying this issue (White, Mullins, Rumsey, & Nye, 2014). In 2015, the National Research Council of the National Academies stated, "A recent upsurge of empirical evidence suggests spatial abilities are an important predictor of performance, especially in scientific and technical fields" (National Research Council of the National Academies, 2015). In 2011, the Army published Technical Report 1282, "Assessment of Assembling Objects (AO) for Improving Predictive Performance of the Armed Forces Qualification Test." The study was conducted in an effort to determine whether adding AO as an applicant screening tool (Anderson, et al., 2011). The authors found that adding AO into the AFQT could be beneficial when screening for certain types of jobs. Specifically, "the jobs whose tasks require spatial aptitude (e.g., Light Wheel Vehicle Mechanic [91B]" (Anderson, et al., 2011).

Development of the Assembling Objects Test Battery

Held and Caretta (2014) state that the development of the Assembling Objects (AO) Spatial Visualization battery was originally established in the 1980s. The National Research Council's (2015) goal of the AO spatial visualization test was to improve "selection, classification, and utilization" of enlisted personnel and research data indicates that AO will have a positive impact on military job classifications. The AO 25-question battery contains a subset of puzzle questions (AO questions 1-12) and a subset of point-to-point questions (AO questions 13-25) as shown in Figures 7 and 8, respectively. It should be noted that the Puzzle tests utilize embedded shape analysis while the Point-to-Point tests utilize point linkage. These multiple-choice items are constructed at several difficulty levels, from easy to difficult. Both AO tests include rotation and translation aspects of spatial visualization (Kaplan, 2016).

AO Test Question Examples (36 Seconds/Question)

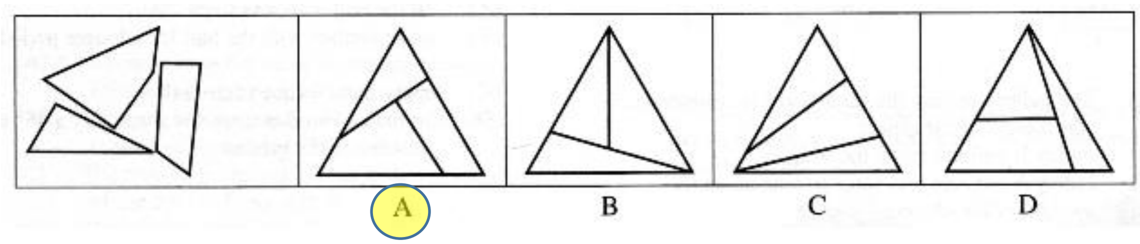

Figure 7. ASVAB AO Puzzle Example
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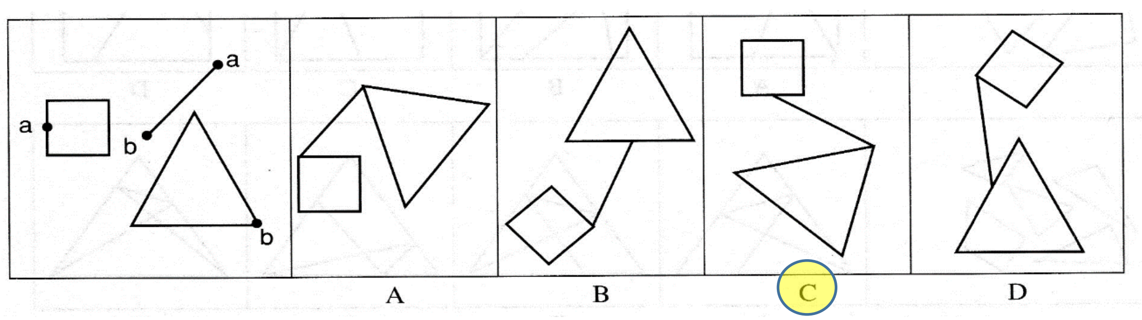

Figure 8. ASVAB AO Point-to-Point Example
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Development of Santa Barbara Sense of Direction (SBSOD) Spatial Visualization Survey

The Santa Barbara Sense of Direction (SBSOD) spatial visualization survey was originally developed in 2002 by Hegarty, Richardson, Lovelace and Subbiah (2002) as a standardized self-report scale of situational spatial ability. The resultant scale proved internally consistent and was considered to have good retest reliability. Example questions are shown in Figure 9. The survey design was based upon four validity studies that examined the: 1) relation to measures of spatial updating; 2) acquisition of spatial knowledge at different scales; 3) application to different learning experiences; and 4) ability to determine spatial visualization skills (Hegarty, et al., 2002). Specifically, Hegarty, Crookes, and Shipley (2010) state that the SBSOD scale shows promise in determining spatial visualization skills for personnel interested in entering Earth science fields, like meteorology.

The SBSOD scores are calculated by reverse scoring all positively worded items and computing the average score across the 15 items. The word "agree" means you think you are good at something; these questions are 1, 3, 4, 5, 7, 9 and 14. Reverse scoring these questions is accomplished by recording 1 as 7, 2 as 6, 3 as 5, 5 as 3, 6 as 2 and 7 as 1. Once reverse scoring is complete, then computing the average score across the 15 items (using the reverse scores for the positively stated items and the original scores for the other items) is calculated. The score will be a number between 1 and 7 where 1 means a poor sense of direction and 7 means a good sense of direction. Some example questions include:

1. I am very good at giving directions.
   strongly agree 1 2 3 4 5 6 7 strongly disagree

2. I have a poor memory for where I left things.
   strongly agree 1 2 3 4 5 6 7 strongly disagree

Figure 9. SBSOD Example Questions
© 2002, Hegarty et al.

Addressing the Selection Gaps

The current AFW selection criteria fails to consider modern AFW operations and technologies such as the lack of information, manipulated data or loss of data flow—the adversary creates a Contested and Degraded Operational (CDO) environment requiring adaptive basing concepts like the Agile Combat Employment (ACE) construct. These adaptive basing environments may limit access to weather information to include model, satellite, radar, and alpha-numeric data. The data may not be available or limited due to connectivity or data-latency issues. The result requires the use of manual forecasting techniques to create and issue weather forecasts in support of operations.

To address the data gaps and ensure weather forecasting capabilities, McNeal's (2017) research indicates that spatial visualization skills are critical for weather forecasters. The use of spatial visualization tests for AFW selection has the potential to assist in identifying recruits with the spatial visualization skills required to support AF missions. It is also believed that mental model formation is an important component of weather forecasting reasoning, as well (Hoffman, LaDue, Mogil, Roebber, & Trafton, 2017). In terms of mental model use with forecasting, Liu and Stasko (2010) state that spatial visualization skills interact with an individual's mental models. In addition, the National Research Council of the National Academies (2015) states that empirical evidence reveals that spatial visualization skills are important performance predictors in scientific and technological fields.

AFW support is highly technical and weather forecasting is enhanced by the use of spatial visualization skills. This capability assists forecasters when weather data is unavailable or unreliable, when encountering Contested, Degraded Operational (CDO) environments, and when an Agile Combat Employment (ACE) concept is required. As a result, it would be advantageous that AFW prepare for these lack-of-weather-data contingencies. The ASVAB AFW battery selection criteria would need to change to include spatial visualization testing as a determining factor. Based upon this information, it is possible that the ASVAB AFW selection criteria could be better designed to include consideration of spatial visualization data to select AF Weather technicians. Modifying the ASVAB AFW battery selection criteria to include the

Assembling Objects (AO) and Santa Barbara Sense of Direction survey (SBSOD) will assist the USAF by identifying recruits who have spatial visualization skills.

Chapter 2

Literature Review: Mental Models and Spatial Visualization

One needs to understand the meaning of spatial visualization and if this trait is important to the field of meteorology. A correlation between mental models, spatial visualization and meteorology needs to be confirmed, as well. Gaining an understanding of what mental models and spatial visualization are and the correlation of these functions in the field or meteorology will support the importance of identifying and selecting individuals who enter the USAF meteorological technician specialty with these intrinsic capabilities.

To gain a full understanding of the application of spatial abilities to AF weather forecasting, it is helpful to discuss previous research explaining the differences between mental models and spatial visualization, how these concepts interact, and how the brain supports these theories. A study by Ben-Chaim, Lappan and Houang (1988) stipulates that spatial perception is important for its relationship to most technical-science occupations, to include meteorology. Additionally, Humphreys, Lubinski, and Yao (1993) also describe non-verbal spatial ability assets as being just as important, if not more so, to entering engineering and the physical sciences. As such, one must first understand how the brain learns and the differences between visualization and mental models.

Understanding the differences between spatial visualization and mental models is a function of how our brains learn to interpret information along with understanding their importance and implications on science-based cognitive comprehension and learning processes. In conjunction with this thinking, some past studies have focused on whether a person's capability to learn and understand something was based on whether they were right- or left-brained people. Stereotypically, left-brained people were categorized as having more of an analytical way of perceiving things while right-brained people were considered more artistic.

Based upon this perception, it would reason that the best personnel to enter science-related fields would be left-brained. However, studies by Jensen (2008) have now determined that it is more likely that people are "whole-brained" and understanding and learning are not based solely on which hemisphere of the brain is considered dominant. Rather, it is the combination of the hemispheres of the brain that ultimately determines what is being understood or learned. Jensen's (2008) study also indicates that while the left side of the brain process focuses on parts sequentially, the right side of the brain focuses on wholes randomly, but both functions occur simultaneously.

Mental Models

Jensen (2008) provided research from a study by Drake (1996) that implied that some people may require or use "mental warm ups" and mental models while visualizing a scene to assist in the learning process. Additionally, a study by Hoffman (1991) on weather forecasters indicated that meteorologists develop mental models as they are compiling and reviewing the weather data prior to making a forecast. Hoffman (1991) continue by saying that, "forecasters develop initial mental models based on the information presented to them on their various displays."

Although mental models and visualization often work hand-in-hand, one must gain an understanding of what mental models are and if the ability to form accurate mental models is important to the field of meteorology. Due to its ambiguous nature, many varied definitions of what a mental models exist. Princeton's Mental Models and Reasoning website describes mental models as "psychological representations of real, hypothetical, or imaginary situations" (The Mental Models Global Laboratory, 2017). In terms of mental models and its relationship to forecasting the weather, Hoffman, et al. (1991) go onto say that "the concept has been in the literature of meteorology for decades." Rapp (2007) defines mental models as "internal representations of information and experiences from the outside world." As an example, Trafton et al. (2005) report that "scientists perform many mental operations including spatial transformations on their own mental models as well as external scientific visualizations."

A study by Liu and Stasko (2010) discusses the concept of Human Computer Interaction (HCI) as the cognitive process that connect internal representations or, mental models, and external visualizations. Liu and Stasko reference Larkin and Simon's (1987) claim that diagrams and other picture-like representations can be "internally stored in an individual's memory to assist in solving problems, similar to using external pictures or diagrams." Continuing with the theme of internal representations, Liu and Stasko (2010) go on to say that "mental models are more internal representations of visualizations as tools and must be functional." They propose that visualizing is focused on interaction between internal and external transformations and that people take internal mental models as structural, behavioral, and functional equivalents of our external visualization arrangements. They go onto say that our mental models preserve graphical, logical, or object-level information about data and this data can be represented in different formats. For example, a collage format could be used to overlay different types of information in an effort to ascertain similarities or differences in the array of data (Liu & Stasko, 2010). As such people can use their mental models in an effort to produce external reasoning support (Liu & Stasko, 2010).

Theorists Jones, et al. (2011) state that mental models are formed through analogical thinking and are constructed in one's working memory. They state that mental models can be run like a computer simulation and allow individuals to explore/test different possibilities mentally before acting and they provide a mechanism through which new information can be filtered and stored (Jones, Ross, Lynam, Perez, & Leitch, 2011).

Pliske et al. (1997) describe how expert forecasters attempt to understand the current weather situation by constructing a mental representation of the physical cause and effect relations in the atmosphere. If they realize they are missing pieces of information, they return to the diagnosis step. Wieand (2008) proposes that many forecasters create a mental forecast using the forecast funnel from the large scale (synoptic) to small scale (meso/micro) concept of how the weather should develop over the next several hours or days using a three-dimensional (3D) visual mental model. Wieand continues on by stating that today's forecaster creates a mental model using pattern recognition with reasonable scientific rationale and letting the data guide the forecast.

Mental Models and Meteorology

Gentner and Stevens (1983) state that mental models help create an understanding of the world. Chatterjee (2011) describes the use of mental models in the medical profession to aid in understanding the human anatomy. Chatterjee (2011) explains that the processes result in the formation of models that are used as frameworks to interpret new information. Morgan et al. (2002) state that people's judgments, decision making, and behavior about how to adopt a new innovation, accept a medical procedure, or support a power plant or natural gas transmission line, are all influenced by their mental models. A study by Thorne, Butte, Kovacs and Wood (2017) found that mental models provide a solid foundation for science informed, evidence-based strategies and communications.

In terms of mental models and the relationship to meteorology, Hoffman, et al. (2017) breakdown mental models into specific areas as mental model formations, reasoning models, and computational models. The researchers posit that there is a correlation between mental models and forecasting the weather, particularly, that forecasters develop mental models in addition to compiling and reviewing the weather data prior to issuing a forecast. Hoffman (1991) also goes on to say that the forecaster's initial mental models are based on information presented to him or her on various computer software displays. The combination of mental models and meteorology is important because it allows for the mental animation of static pictures to make forecast predictions as stated by Hoffman (2017).

With reference to meteorology, Hahn, Rall, and Klinger (2003) state that mental models are "associated with incorporating a strong understanding of weather patterns that are based on the region and time of the year." Of equal importance is having an understanding for identifying incorrect weather conceptual mental models, as well. One must not assume his or her mental model implies perfection or absolute correctness. On the contrary. A person's mental model can be flawed depending upon that person's understanding of knowledge or experience with a situation. Like GIGO, if the person's knowledge or experience is flawed then their derived output will likely be flawed as well (Hoffman, LaDue, Mogil, Roebber, & Trafton, 2017). For example, in AFW if one incorrectly understands the ingredients needed for a thunderstorm to develop, the result can lead to an incorrect forecast that may directly impact the success and safety of an aircraft mission. Having the capability to use mental models is significant in the process of developing a weather forecast while the importance of applying correct mental models during this process cannot be understated.

Davenport, Wohlwend, and Koehler (2015) accomplished a study of US Air Force Academy (USAFA) meteorological class students by initiating the use of a Fundamentals in Meteorology Inventory (FMI). The FMI was used to test students to see if they maintained meteorological concepts throughout the course of instruction. The authors determined that some students may have a previous misconception about a topic that can lead to incorrect applications of meteorological information. Davenport, Wohlwend, and Koehler (2015) say that these misconceptions are a result of gaps in their current conceptual models. The authors continue to say that to correct these misconceptions, students must be confronted with these gaps in their current model and presented with an understandable and logical new model (Davenport, Wohlwend, & Koehler, 2015). The application of the FMI allows students to see their misconceptions in their understanding and are presented with correct information that allows them to adjust and fill in their mental model gaps.

Trafton (2004) explains that mental models are utilized in meteorology by "being a mix of images and propositions, relying on qualitative and spatial relationships, allowing dynamic, runnable results to be mentally inspected, resulting in an inference, and almost always requiring a great deal of domain knowledge." As an example, a forecaster may be attempting to forecast the location of a surface cold front and associated weather. He or she can look at a static satellite picture to see where the front is located. They could then utilize their mental model of the clouds and weather a cold front creates, mentally animate the progression and movement of the front based on its previous history, and decide its future location based on their understanding of the current weather situation.

Uttal and Cohen (2012) go onto say that having increased spatial abilities may actually enhance the integration of STEM-related concepts into mental models that are undeveloped. Mental models can inform weather forecasting and get better with more experience. According to Trafton (2004), meteorology requires a lot of critical solving knowledge and mental models are created with a great deal of domain knowledge. According to Godske, Bergeron, Bjerkes, and Bundgaard (1957), meteorologists should have the capability to "combine a large number of observations into a logical three-dimensional mental picture." This three-dimensional picture, enhanced by adding the fourth dimension of time, produces a conceptual mental model.

Spatial Visualization—Seeing the Weather

McGee (1979) states that, spatial visualization is "the ability to mentally manipulate, rotate, twist, or invert pictorially presented visual stimuli." Johns Hopkins University (JHU) (2018) defines spatial ability as a unique type of intelligence; the capacity to understand and remember the spatial relations among objects. JHU (2018) goes onto say that spatial ability is a combination of other abilities such as verbal ability, reasoning ability, and memory skills.

A study by Humphreys and Lubinski (1996) describes spatial visualization as an unappreciated ability. A study by Webb, Lubinski, and Benbow (2007) also alludes to this as well. They state that the results of their 3-phase study determined that math-science career fields should include spatial-ability data as a degree selection criteria, potentially uncovering a previously unidentified group of math and science talent. (Webb, Lubinski, & Benbow, 2007).

In terms of applicability, JHU (2018) states that the occupational fields of mathematics, natural sciences, engineering, economic forecasting, meteorology, and architecture all involve the use of spatial skills. In an Oxford study conducted by Drake (1996), visualizations were found to have increased learning capability in people when introduced during classroom instruction. Lubinski (2010) also states that "a recent upsurge of empirical evidence suggests spatial abilities are an important predictor of performance, especially in scientific and technical fields." Some experts in the field also reference the terms "spatial visualization" and "spatial ability" and considered them synonymous when studying visualization capabilities of individuals.

In terms of predicting performance, The National Research Council of the Academies (2015) states that scientific and technical fields like meteorology can be enhanced by selecting personnel with high spatial visualization skills. In 2003, University of Oklahoma Professor Charles "Chuck" Doswell alluded to the importance of visualization skills when asked what factors were most important to become a meteorologist. While attending a weather conference in Victoria, British Columbia and sitting on a panel of meteorological experts, attendees asked Doswell what traits are required by individuals to become successful meteorologists. Doswell (2003) identified the capability to visualize the weather as one of the 12 characteristics he believes is important to becoming a successful meteorologist. Doswell explained that a person who forecasts the weather must be able to "see" the atmosphere in three dimensions, understand how weather works and how it will evolve and change over time—the fourth dimension (Doswell C. , 2003).

Additionally, Cohen and Hegarty (2014) maintain that it is important for Science, Technology, Engineering and Mathematic (STEM) related career-seeking personnel to have capability to be able to determine external and internal aspects of 3-dimensional objects—to have spatial visualization skills. In meteorology, it is not only important to understand atmospheric physics and dynamics, the how and why of weather, one also needs to be able to incorporate weather theory and predict how the weather systems will change over time, as well. Spatial visualization skills are critical to the extrapolation of current weather data. Weather models can assist meteorologists with forecasting the weather but they are not a panacea.

Doswell's visualization explanation infers the need for the human—the forecaster—to be able to understand the biases of the model and adjust it using the laws of physics, thermodynamics and the capability to visualize and understand what the atmosphere will look like in the future and be able to 'see' the atmosphere of the future. As stated by Trafton and Hoffman (2007), "No one can be a really good weather forecaster by relying on the computer model outputs unless she or he can forecast the weather without using the computer model outputs." After all, "computer models are not infallible" (Trafton & Hoffman, 2007). Doswell's assertion of being able to visualize the weather allows the forecaster to fill-in the gaps and adjust the forecast where and when the model is inaccurate.

A study by Rapp (2007), focuses on the interaction of mental models and visualizations and how they enhance scientific learning. As described by Rapp (2007), "Visualizations provide one method for describing how particular components in a complex system interact." Rapp (2007) goes on to explain that "The underlying imagistic nature of mental models suggests that although they are certainly not mental pictures, they are both useful and necessary for considering the visuospatial characteristics of a concept or system." Rapp (2007) summarizes the goal of his study by stating that the critical evaluation of visualizations should be to build mental models in an effort to increase student scientific comprehension capabilities. To then make an adjustment to the incorrect weather model output requires a different vision capability of the meteorologist—the capability to utilize mental models.

In many ways, the atmosphere and weather systems can be viewed as structures that can be dissected in the mind's eye and seen as parts or pieces of a structure. For example, when analyzing thunderstorms to determine severity, a forecaster looks at the pieces of the atmosphere to assist in making a determination. Using the data to visualize the atmosphere, the forecaster answers a multitude of questions, relative to the data that is available, to gain an understanding of whether severe thunderstorms will occur or not. Similar to mental models, Deno (1994) goes on to say that "The possession of spatial visualization abilities is a critical attribute for people in professions employing the areas of engineering and technology." Uttal and Cohen (2012) also support this concept and go onto say that having increased spatial abilities may actually enhance the integration of STEM-related concepts into mental models that are undeveloped.

Spatial Visualization and Meteorology

McNeal, Petcovi and Ellis (2017) state that there is a significant correlation between meteorology and spatial thinking tests. Doswell (2004) states that visualization skills are one of the most important factors in becoming a meteorologist. While Hegarty and Cohen (2014) state that spatial visualization skills are important in geosciences like meteorology. It is believed that spatial abilities are important to geosciences because they are more real-world grounded and include experiences of spatial structure and processes, such as a thunderstorm (Hegarty, Crookes, & Shipley, 2010). Cohen and Hegarty (2007) also state that spatial visualization skills increase the ability to deduce and interpret 3-D object cross-sections. For example, many forecasters can look at a severe thunderstorm and visualize the internal interworking of the storm. They can determine the location of the rear flank downdraft, the forward flank downdraft, where a wall cloud may form, and where the heaviest rain and largest hail will occur with reference to the storm's movement.

Spatial Visualization and STEM

Scientific studies also indicate that spatial abilities may be an important predictor of job performance, specifically in the scientific and technical fields (National Research Council of the National Academies, 2015). As discussed by Lubinski (2010), using spatial ability scores will assist in determining learning opportunities, uncover an under-utilized pool of talent, and might be overlooked to meet needs of a technologically-based world. Lubinski's (2010) study states that selecting students for STEM based opportunities relies and focuses too much on SAT/GRE standardized testing. He posits that overlooking spatial ability may actually reduce capability to produce the right students for the right curriculum (Lubinski, 2010).

Lubinski (2010) continues with this sentiment and reasoning by saying that meeting today's requirements of an ever-evolving and complex technological world requires identification of people who have good spatial abilities. Lubinski (2010) alludes to Flanagan's et al. (1962) seminal Project Talent as a foundational longitudinal study. The project launched numerous other studies and is based on the value of testing for student spatial abilities and its applicability to STEM occupations. In one such derivative longitudinal study, Wai, Lubinski, and Benbow (2009) provided highly consistent findings for combined students in grades 9–12 which indicated that high general intelligence and intellectual orientation were dominated by high mathematical and spatial abilities when compared to verbal abilities. Figure 10 represents the findings by Wai, Lubinski, and Benbow (2009). The study concentrated on those students who went on to receive Bachelors, Masters and PhD degrees. The figure depicts average z-scores of participants on verbal (V), spatial (S), and math (M) ability for bachelor's degrees, master's degrees, and PhDs and are plotted by field (Lubinski, 2010). From left to right, as the spatial ability scores increase, so do the science-based degrees. As a follow up, Lubinski (2010) stated that, "It is interesting that these and other longitudinal findings on spatial ability, replicated over multiple decades and multiple sets have not resulted in exploiting the psychological significance of this powerful construct in educational and occupational settings."

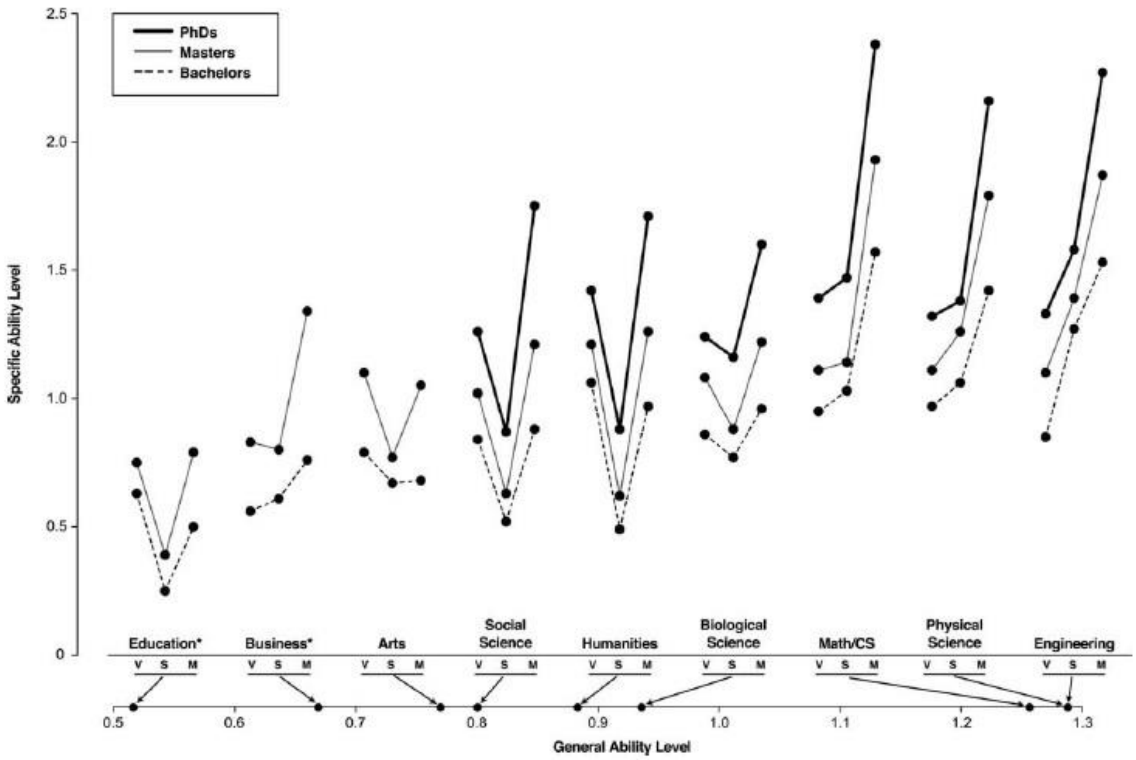


Figure 10. Average z-scores of participants on verbal (V), spatial (S), and math (M) ability for bachelor's degrees, master's degrees, and PhDs are plotted by field. © 2009 Jonathan Wai, David Lubinski, and Camilla P. Benbow

Lubinski (2010) also adapted Shea, Lubinski, and Benbow's (2001) longitudinal study data that resulted in the excerpt data output displayed in Figure 11. Verbal, math, and spatial ability Scholastic Assessment Test (SAT) scores were examined using the categories of college majors and occupations. To highlight a consistent pattern across the two data points, dashed lines are used to group the STEM items. In Figure 11, the SAT-Math scores are scaled on the x-axis, SAT-Verbal on the y-axis, while Spatial Ability levels are indicated on the z-axis. With reference to the z-axis, arrows to the right indicate a positive z-axis value and higher spatial ability while arrows to the left indicate a negative z-axis value and lower spatial ability (Shea, Lubinski, & Benbow, 2001). As can be seen, the scientific college majors and occupations are associated with rightward-pointing positive z-axis value arrows indicating higher levels of spatial ability while non-scientific fields are associated with leftward-pointing negative z-axis value arrows indicating lower spatial ability. From this information, Lubinski's (2010) derived study culminated with this empirical generalization: "Individual differences in spatial ability contribute to learning, the development of expertise, and securing advanced educational and occupational credentials in STEM." Lubinski (2010) continues by stating that testing for spatial visualization skills would go a long way towards filling this growing and important educational gap. Of note, these patterns also build upon those observed in Project Talent, a comprehensive longitudinal study conducted by Flanagan et al. (1962). Project Talent data are among the most compelling for illustrating the role that spatial ability plays in developing expertise in STEM. Project Talent participant's 11-year longitudinal follow-up study was conducted before the Study of Mathematically Precocious Youth (SMPY) participants* were identified in the late 1970s at age 13 (Wai, Lubinski, & Benbow, 2009). Using this data, considering spatial visualization testing for specific US military technical STEM-like specialties, like meteorology, would also be advantageous, as well.

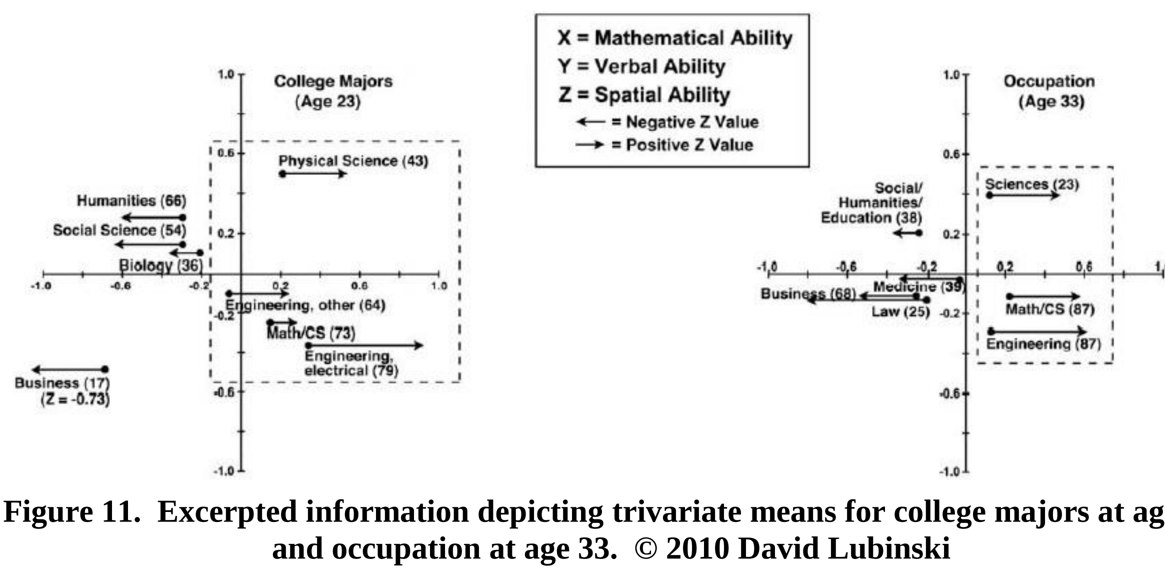
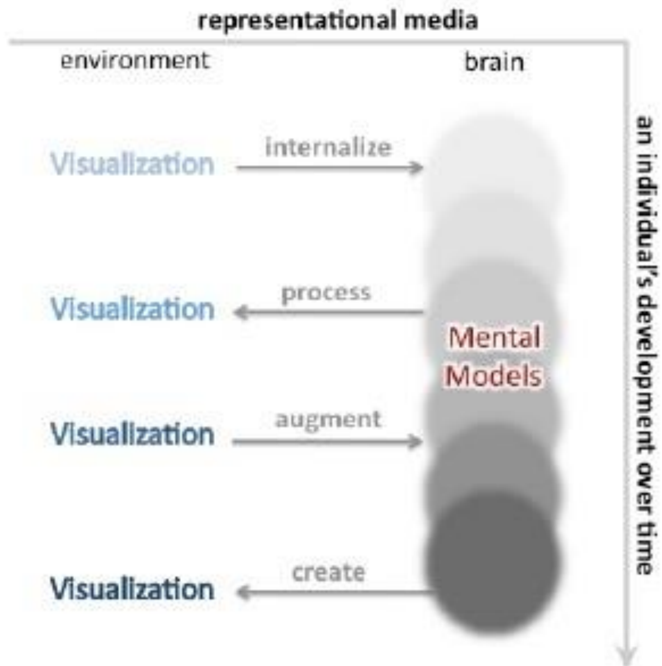


Figure 11. Excerpted information depicting trivariate means for college majors at age 23 and occupation at age 33. © 2010 David Lubinski

Mental Models and Spatial Visualization

A study by Rapp (2007), focuses on the interaction of mental models and visualizations and how they enhance scientific learning. As described by Rapp (2007), "Visualizations provide one method for describing how particular components in a complex system interact." Rapp (2007) goes on to explain that "The underlying imagistic nature of mental models suggests that although they are certainly not mental pictures, they are both useful and necessary for considering the visuospatial characteristics of a concept or system." Rapp (2007) summarizes the goal of his study by stating that the critical evaluation of visualizations should be to build mental models in an effort to increase student scientific comprehension capabilities. To then make an adjustment to the incorrect weather model output requires a different vision capability of the meteorologist—the capability to utilize mental models.

A study conducted by Liu and Stasko (2010) discusses how mental models may provide useful theoretical concepts when related to spatial visualization. Liu and Stasko (2010) state that "the mental model framework in cognitive science and Human Computer Interaction (HCI) may provide a useful theoretical concept" between internal representations, or mental models, and external visualizations. They continue by stating that "mental models are internal, structural, behavioral and functional analogues of external visualization systems" (Liu & Stasko, 2010). Figure 12 represents Liu and Stasko's high-level dynamic interactions of internalizing, processing, augmenting, and creating visualizations between mental models and external visualizations (Liu & Stasko, 2010). What begins as an internalized external representation that develops into a nascent mental model, the interaction continues as a process into an external visualization. The external visualization then augments the maturing mental model. This maturing mental model can then create a new external visualization.



Visualization as an interactive process across representational media: a developmental perspective

Figure 12. Mental model and visualization interaction. © 2010 Liu/Stasko

Building upon this premise, a study by Paivio (1969), discusses how one goes from mental models to spatial visualization using concrete ideas (e.g., a pyramid) as they are easier to visualize than abstract ideas (e.g., freedom). Similarly, a study by Collins and Gentner (1987) also describe a concept of how an individual cognitively understands an unfamiliar domain by drawing on a familiar domain or a domain perceived as similar. Whether identifying with Paivio's concrete representations or Collins and Gentner's familiar domains, both are used in support of spatial visualization methods. Figure 13 depicts examples of the similar aspects of Paivio and Collins and Gentner by using cold frontal familiar domains and warm frontal concrete representations. When these domains and representations are used with the knowledge of weather to include the general circulation of the atmosphere and cloud types, a forecaster can combine the information into a mental model going from the known to the unknown. In this case, the unknown visualized output would be the forecast produced for a specific location.

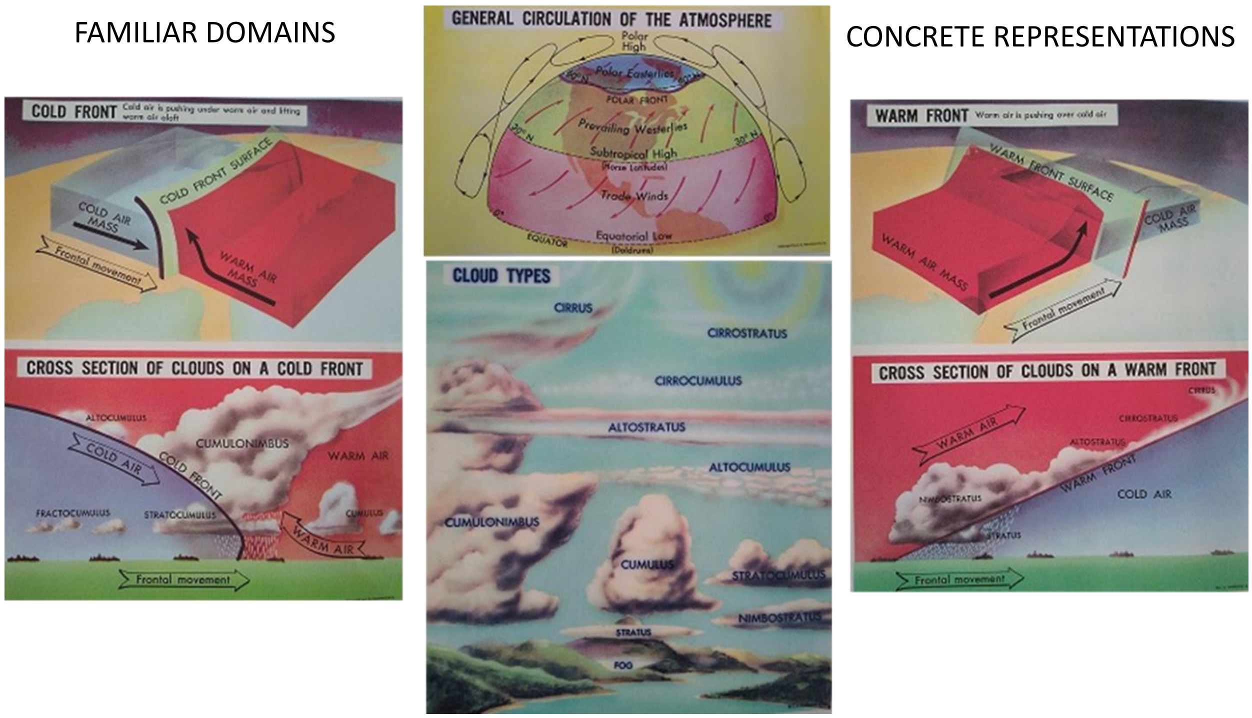


Figure 13. Know to unknown visualization development. © Hubbard Press

Figure 14 depicts the process of going from a mental model to creating a visualized forecast. A forecasting student learns the typical weather associated with a low pressure frontal system using the left picture of the cold frontal known-process mental model. An experienced forecaster looks at the current external satellite (center picture) and is able to converge the model and satellite to produce the visualized forecast on the right. First, the forecaster internalizes the mental model using the information he or she learned for the typical weather associated with a low pressure frontal system. Then, they would take the external representation (satellite picture) and process a new spatial visualization of the associated clouds and weather. Finally, the forecaster would then take the newly visualized weather system and apply it at their location, creating the final visualized local weather forecast.

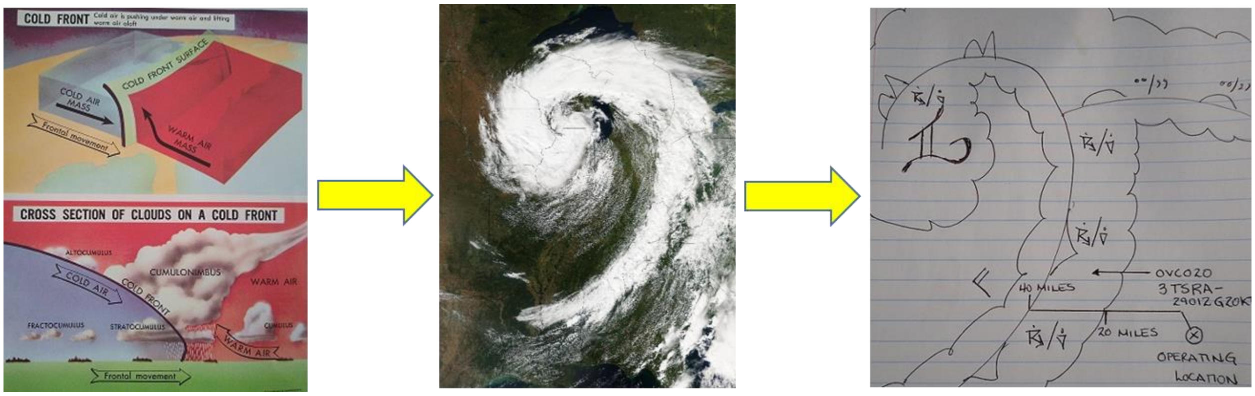


Figure 14. The meteorological visualization process. © Hubbard Press

Newcombe (2015) discussed how high spatial learners are better equipped to process dynamic visualizations. Newcombe and Shipley (2015) described meteorology as highly spatial, requiring students to "master complex spatial reasoning processes to interpret data, visualize invisible fluids, project future scenarios, and perceive motion within a frame of reference." Hegarty and Sims' (1994) enhancer hypothesis; Hegarty and Waller (2005); Huk (2006); and Höffler (2010) echoes Newcombe by stating that high spatial learners are better equipped to process dynamic visualizations because they have remaining cognitive capabilities to build an adequate mental model of the content to be learned. According to this hypothesis, learning with dynamic visualization leads to high spatial learners performing better. The interaction between spatial abilities and performance suggests that high and low spatial learners differ in their processing of instructional materials containing dynamic visualizations.

The Spatial Visualization Testing Gap

As stated by the National Research Council (2015), there are significant implications for using spatial visualization testing on new technologies used in the USAF. For example, current and future duties/tasks will demand and require spatial visualization abilities. Additionally, the use of spatial visualization capabilities will have impact on in human-computer systems interactions, virtual interfaces, graphical-data representations, and other digital-age technologies (National Research Council of the National Academies, 2015). Spatial visualization has the potential to be individually determined by using test result data from an exam already administered to Air Force recruits but that is not used, the Assembling Objects (AO) battery. Including AO testing as a selection requirement has the potential to increase the ability to achieve career excellence in physical sciences and may also identify enlistees who are more likely to remain committed to the USAF. This research will be beneficial for AFW if ASVAB selection criteria can be modified.

Research Questions and Hypotheses:

RQ1: Can spatial visualization skills (represented by AO and SBSOD test/survey scores) be an important determinant for selecting Air Force Weather (AFW) personnel?

RQ2: Does ASVAB sufficiently measure spatial visualization skills or do supplemental tests of spatial visualization (i.e., AO and SBSOD) provide additional information?

The hypotheses were examined using three different tests: (A) the examination of weather (WX) experience on AO and SBSOD, (B) the examination of the relationship between AO and SBSOD, and (C) the examination of AO on SBSOD and ASVAB.

Hypothesis A: Examine the influence of WX experience on spatial visualization

H_0: WX Experience is not related to AO
H_1: WX Experience is related to AO

H_0: WX Experience is not related to SBSOD
H_1: WX Experience is related to SBSOD

If H_0 cannot be rejected, then it suggests that spatial visualization measures may be a stable characteristic that could be reliably assessed for AF weather technician selection.

Hypothesis B: Examine the relationship between AO and SBSOD

H_0: AO is not related to SBSOD

H_1: AO is related to SBSOD

If H_0 cannot be rejected, then it suggests that AO and SBSOD assess different constructs of spatial visualization measures.

Hypothesis C: Examine the relationship between spatial visualization and ASVAB

H_0: AO is not related to ASVAB
H_1: AO is related to the ASVAB

H_0: SBSOD is not related to ASVAB
H_1: SBSOD is related to the ASVAB

If H_0 cannot be rejected, then it suggests that neither the AO nor SBSOD duplicates the information provided by ASVAB and thus would provide useful assessments of spatial visualization measures.

Chapter 3

Operationalizing the Research Question—Pathway to Data

This research examines the role of spatial visualization assessments in improving the capability to select the right people to enter the USAF in the right job—the weather technician/meteorological career field specialty. As previously discussed, AFW does not currently utilize visualization testing for selecting individuals for entry into the USAF and the Weather career field. Thus, the question remains as to how the AF will make certain it selects the most-qualified people to fill these positions to work in situations where weather data may be limited or unavailable. The expectation of operating in Contested Degraded Operational (CDO) environs, the need to support adaptive basing concepts like Agile Combat Employment (ACE), and the need for the capability to visualize the weather provide strong evidence for the need to recruit AFW technicians with spatial visualization skills. It is proposed that selecting capable individuals who have mental model/visualization skills will assist the USAF with mission accomplishment.

Methodology

This study was accomplished using survey-based research methodology with a participant pool of current and previous USAF Weather Technicians. The goal was to examine forecaster spatial visualization abilities using Assembling Objects (AO) testing, the Santa Barbara Sense of Direction (SBSOD) questionnaire, and by asking personal and weather experience questions. This approach was used in an effort to evaluate participant spatial visualization skills.

An integrated 5-part survey was created for this study and included 58 questions. The visualization batteries were administered in two parts of the survey and included the 25-question

Assembling Objects (AO) battery and the 15-question Santa Barbara Sense of Direction (SBSOD) survey. Personal ASVAB self-reported data were also requested in the survey, comprised of 4 personal score questions for the General, Mechanical, Electrical and Administrative batteries measured at the time the participant entered the AFW career field. Out of the remaining 15 questions, 9 were related to the participant's military weather experience. Additionally, one self-reported question was related to using Legos, building models, playing with blocks, and drawing 3-D pictures. Deno's (1994) Special Experience Inventory (SEI) incorporates cultural variables and includes spatial activities, enjoyment of spatial activities requiring spatial skills, and the subjects' self-perceptions of spatial abilities. Using specific areas of the SEI, 3 questions asked participants about playing a musical instrument, playing video games, and about the types of courses taken in high school, respectively. Data collection was accomplished using The University of Oklahoma's Qualtrics website survey tool and the full survey is in Appendix A.

The survey was active for 71 days, from March 23, 2019 through June 1, 2019. Two pools of participants were used to obtain the data. The initially contacted population, Pool 1, was a private group of members from the Facebook "USAF Weather" page who were contacted using the message depicted in Figure 16. Pool 1 was comprised of current and past AFW personnel. Due to low participation and lack of responses (<30), a second pool of participants were contacted in an effort to increase the sample size of the population. A subsequent recruitment private event, as depicted in Figure 14, was sent via Facebook Messenger to friends of the researcher who had/have AFW experience. As a result, a total of 105 responses were received.

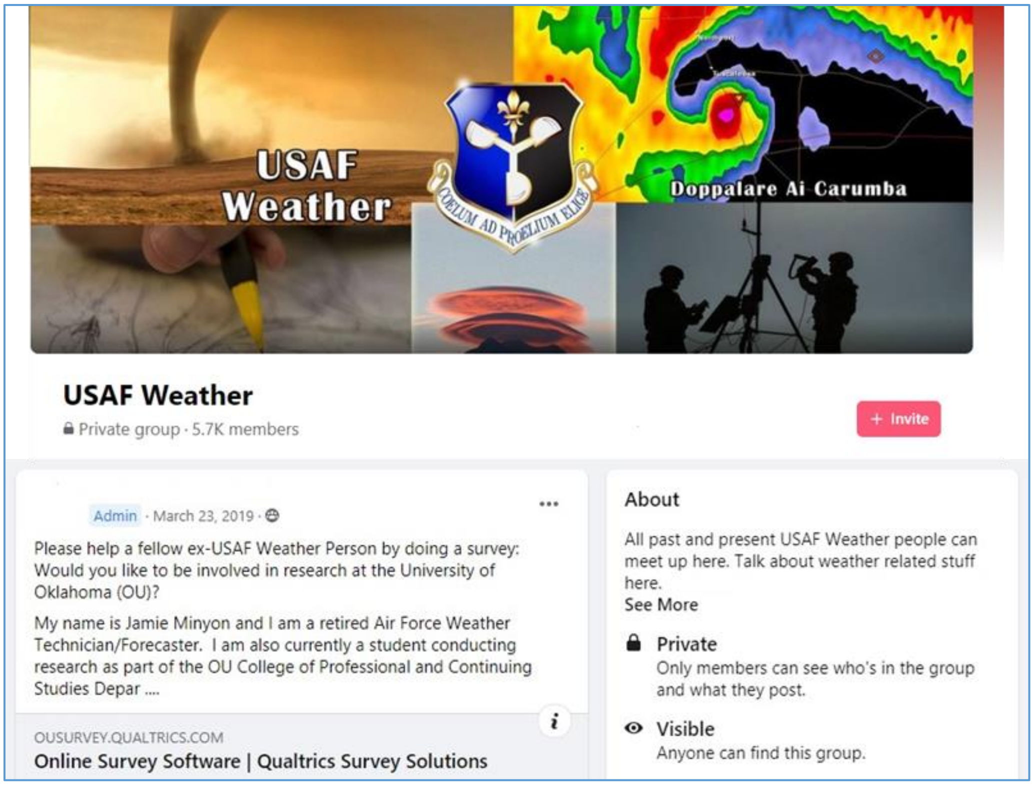


Figure 15. Facebook USAF Weather Page Recruitment Message

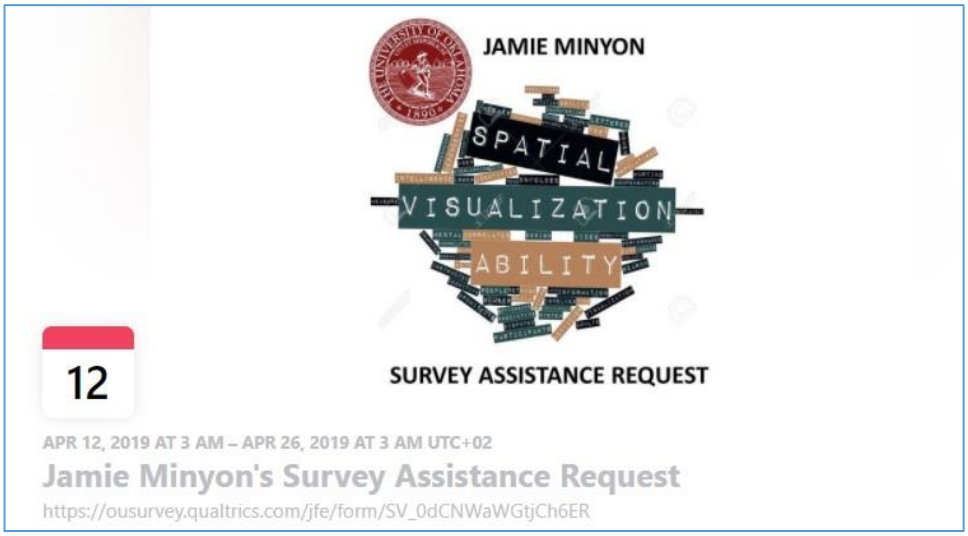
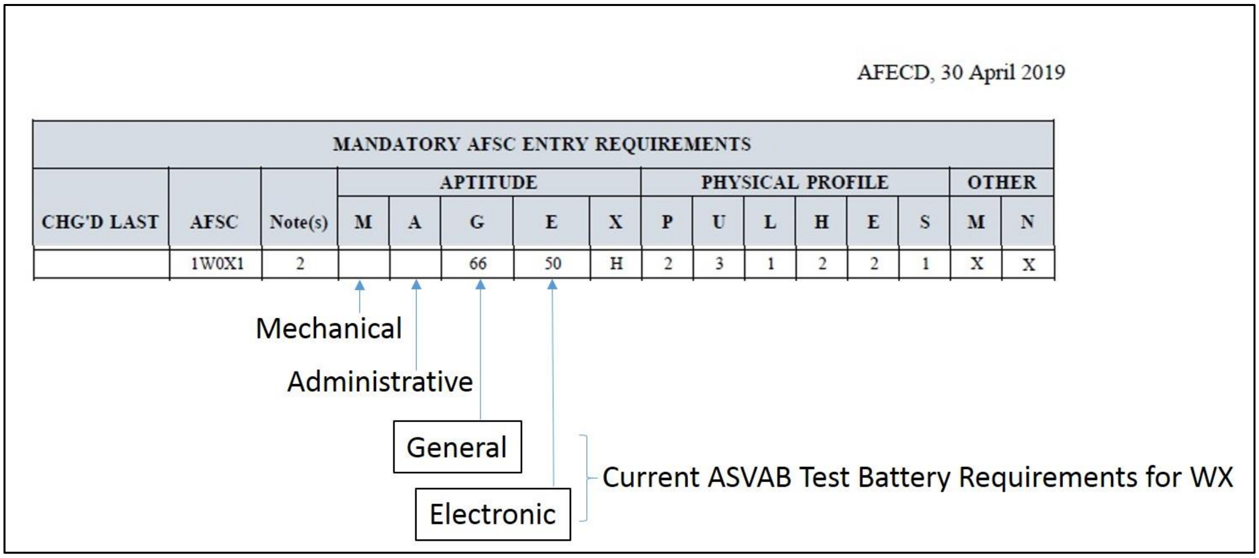


Figure 16. Facebook Private Recruitment Event

Data Collection

Out of the 105 responses received, only 62 were considered eligible/available for data use. Forty-three participants did not fully complete the surveys and were not included in the analysis. The primary focus for the exclusion of participants was lack of completion of the AO battery. If the participant did not complete the AO battery (had greater than nine missing responses), or the battery scores were excessively low (<30%), suggesting the use of random selection for answers, the data were removed. Data from two additional participants were eliminated as outliers after the surrogate age metrics was statistically scrutinized and these participants were much older than the expected age of the typical participant.

Of the eligible participants, some were current AFW Officers who were not required to take the ASVAB upon entry into the AF, and thus had incomplete data. Figure 17 is an excerpt from the AF Enlisted Classification Directory (2019) that determines what criteria are needed to enter a specific career field. Figure 17 depicts the current General (G) and Electronic (E) ASVAB minimum scores required for entry into the 1W0X1 Weather career field. For this study and to impute values, the AFW Officer missing data were baselined at the current lowest ASVAB acceptable entry levels into AFW for the General (i.e., 66) and Electronics (i.e., 50) battery scores. Baselining in this method allowed the current AFW officer's participation data in the survey to be retained while permitting inclusion of their spatial visualization capabilities using a conservative minimum score as opposed to using median scores. This method of baselining was also used for those individuals who could not recall their ASVAB scores. Finally, those questions that participants skipped/did not answer while taking the AO battery individual (less than 5) were coded as incorrect.



MANDATORY AFSC ENTRY REQUIREMENTS															
			APTITUDE					PHYSICAL PROFILE						OTHER	
CHG'D LAST	AFSC	Note(s)	M	A	G	E	X	P	U	L	H	E	S	M	N
	1W0X1	2			66	50	H	2	3	1	2	2	1	X	X

Figure 17. Current Minimum General and Electronic ASVAB Scores for Entry into the AFW 1W0X1 Career Field. ©2019 United States Air Force.

Participant data were analyzed to determine if there was a correlation between years of experience and age. Although age was not requested in the survey, surrogate ages of the participants were determined using an average age of 22-years old upon enlistment. The participants' responses to the question of the year they entered the USAF was then used to calculate a surrogate age. Some of the respondents answering the survey are no longer active-duty members and their current age skewed the surrogate age determination based upon the year they entered the Air Force. The average surrogate age of the 1- to 5-year experienced respondents was 32.5 years and the respondent's age continued on an increased trend as experience levels increased. As a result, the average respondent's surrogate age correlated to increased experience level, as well. Figure 18 shows the expected ages and surrogate average ages that were calculated for the survey participants. The preponderance of participants were from the 1 to 5 years, 16 to 20 years, and greater than 20 years age groups.

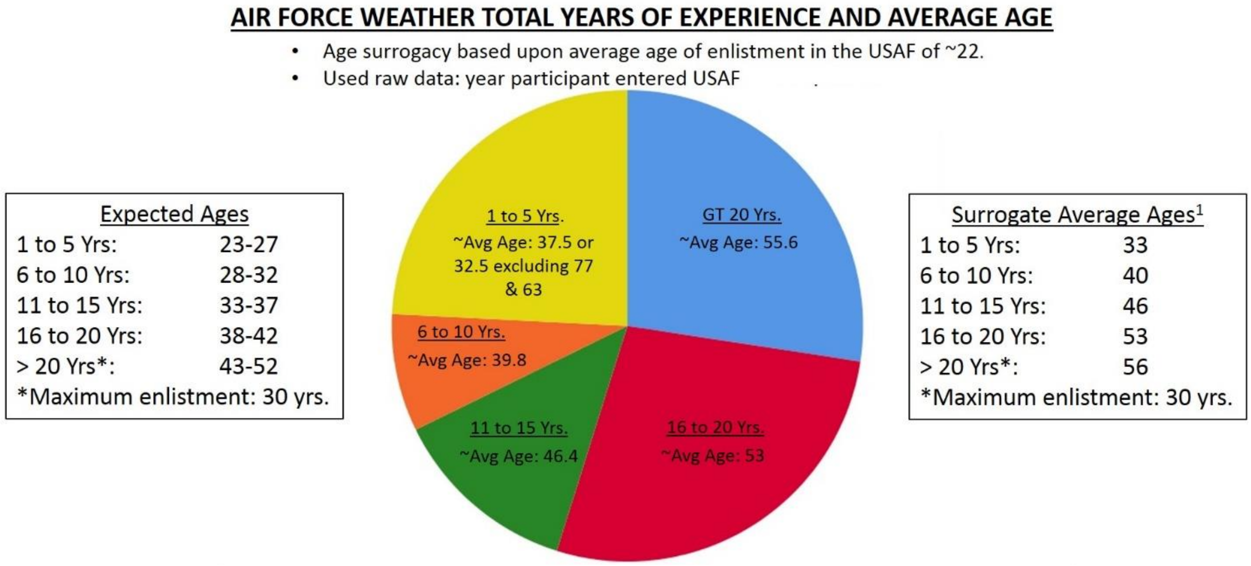


Figure 18. Age Surrogacy Based Upon Average Age of Enlistment in the USAF of ~22.

The scatter plot in Figure 19 was developed to examine the relationship between age and experience. Two outliers in the 1-5 year experience group were removed, a 77-year-old and a 63-year-old respondent who had 4 years of active-duty AFW experience. They entered the Air Force in the mid-60s and late 70s, respectively. With the outliers removed from the 1-5 year group, the fit of line for the sample of 60 participants has a fairly strong linear relationship (R^2 = 0.464) with years of experience in AF Weather. Of note, the 6-10-year experience group represent a smaller number of study participants. Typically, people who depart the AF if they are not interested in achieving a 20-year retirement often do so in this range of service years. This is often a critical time in a recruit's career because once a decision is made to re-enlist past 10 years, most recruits will stay with the AF through the 20-year retirement point.

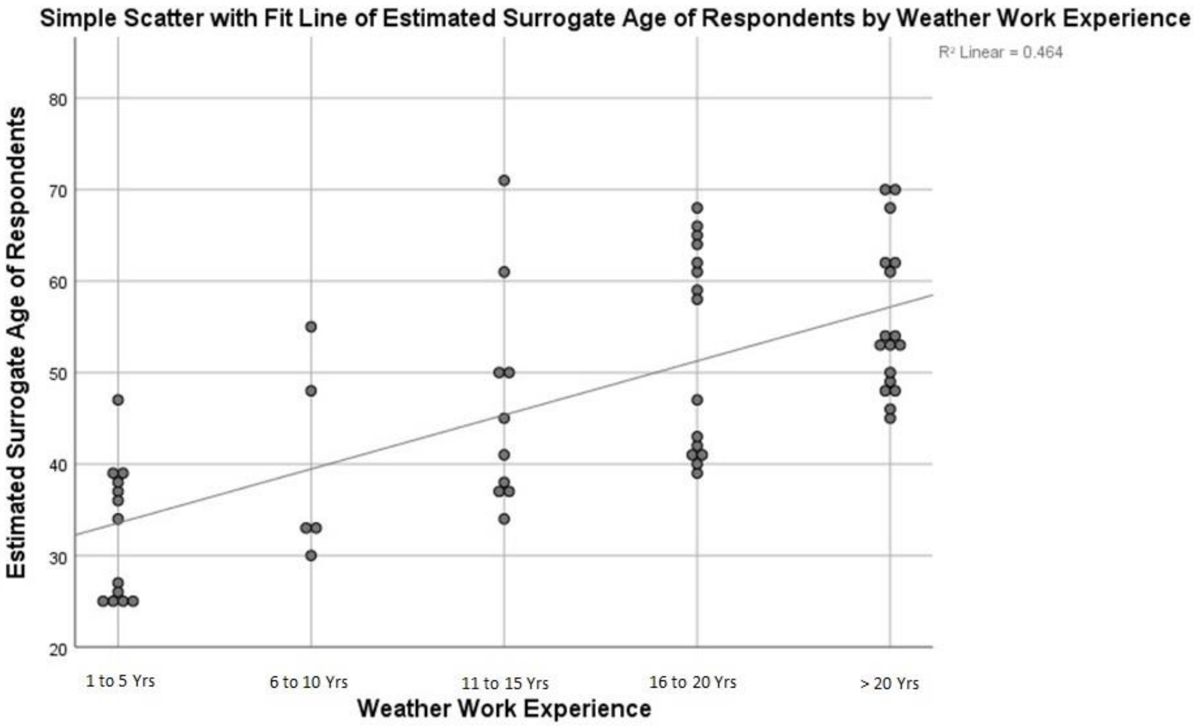


Figure 19. Estimated Age Surrogacy Scatter Plot.

Table 1 provides a table that crosses AO scores with various experience questions posed in the survey. It displays the proportion of participants within each AO score category that report agreement with each survey question. The survey categories represent selected responses and are not all inclusive to the questions asked in the survey tool. The overall average proportion of participants who reported video game playing was 90% and was the highest average across the experience questions. Although Spence and Feng (2010) state that video game playing could be a contributor for eventually revolutionizing the teaching of spatial skills and concepts to children, it was not further researched in this study. 80% of the participants found the job of weather forecasting challenging, 50% were interested in weather and voluntarily selected weather while only 30% enjoyed working in the career field working as a weather technician. Of note, a study conducted by Hoffman, Coffey, and Ford (2000) for the US Navy found that 50% of personnel were highly interested in weather, science, biology, or oceanography prior to entering the weather career field. The highlighted area on Table 1 depicts those personnel who were interested and voluntarily selected the weather career field. Participants with AO scores between 77% and 96% reported the highest level of interest and selection. Participants with lower AO scores showed less interest/motivation as did those with higher scores.

SURVEY CATEGORY	ASSEMBLING OBJECTS (A/O) SCORE				AVERAGE
	66-76% (Total: 18 or 29%)	77-86% (Total: 9 or 15%)	87-96% (Total: 25 or 40%)	>96% (Total: 10 or 16%)	Total=62
PLAYED VIDEO GAMES	0.8	0.9	0.7	1.0	0.9
INTEREST IN WEATHER	0.3	0.6	0.6	0.4	0.5
VOLUNTARILY SELECTED WX	0.4	0.7	0.5	0.4	0.5
VOLUNTARILY RETRAINED INTO WX	0.1	0.1	0.2	0.3	0.2
ENJOYMENT	0.4	0.3	0.3	0.2	0.3
CHALLENGE	0.8	0.8	0.9	0.8	0.8

Table 1. Proportion of Participants in Each AO Score Category that Reported Agreement with Each Survey Question

Chapter 4

Quantitative Results

Assembling Objects (AO) Normality Examination

The Assembling Objects 25-question battery consists of two different sections. The first section is comprised of 12 puzzle questions while the second section is comprised of 13 point-to-point questions. The puzzle type items have participants translate and rotate 4 to 5 pieces into a whole. The point-to-point items have a marked point and participants must rotate and translate the shapes to find the connection for the joining line. The puzzle makes a cohesive shape while the point-to-point connection questions are more abstract. Both question types elucidate spatial visualization skills. With reference to recruits, a study by the National Research Council of the National Academies (2015) states that using the Assembling Objects (AO) battery of the ASVAB would benefit the military for the initial selection of recruits, determine their initial occupations and classifications, their long-term retention, and their performance in an occupation. In terms of the AO battery, a Defense Manpower Data Center (DMDC) report (2009) states that "connection test items were consistently more difficult than puzzle items." Yet, this study's participants statistically scored higher on point-to-point items when compared to puzzle items.

Table 2 lists participant responses divided into two columns, one column for the AO 1-12 (Puzzle) scores and the second column for AO 13-25 (Point-to-Point) scores. Each side-by-side AO 1-12 and AO 13-25 score pairing in the two-column table represents one individual's responses. Out of the 62 responses, only three participant's scores for the AO 1-12 questions were higher than their AO 13-25 questions score (5% total and highlighted in yellow/bold). Six other participants had identical scores (10% total and highlighted in bold) in both sections of the

AO battery. In summary, 55 of the 62 participants (89% total) scored higher on AO 13-25 (Point-to-Point) section of the battery than the AO 1-12 (Puzzle) section.

Individual Scores			**Individual Scores**	
AO 1-12	**AO 13-25**		**AO 1-12**	**AO 13-25**
58%	**46%**		75%	85%
42%	54%		58%	100%
25%	69%		58%	100%
33%	69%		58%	100%
58%	**54%**		67%	92%
67%	**54%**		75%	92%
50%	77%		67%	100%
50%	77%		67%	100%
33%	92%		67%	100%
58%	77%		67%	100%
42%	92%		67%	100%
67%	69%		83%	85%
42%	92%		83%	92%
42%	92%		83%	92%
42%	92%		83%	92%
67%	69%		75%	100%
50%	85%		83%	92%
50%	92%		83%	100%
58%	85%		83%	100%
58%	85%		83%	100%
42%	100%		83%	100%
58%	85%		**92%**	**92%**
58%	85%		**92%**	**92%**
67%	85%		83%	100%
50%	100%		83%	100%
58%	92%		**92%**	**92%**
75%	77%		**92%**	**92%**
67%	92%		92%	100%
67%	92%		92%	100%
75%	85%		**100%**	**100%**
58%	100%		**100%**	**100%**

Table 2. Participant AO Scores for Puzzle (1-12) and Point-to-Point (13-25) Scores

Given the start difference in performance on the two question subsets, the question of which data set to use for this study was examined. The AO responses were reviewed as subsets for questions 1-12, 13-25, and 1-25. The three panels of Figure 18, Figure 19, and Figure 20 depict normality data frequencies for AO questions 1-12, 13-25, and 1-25, respectively. In Figure 20 and Figure 22, both AO subsets 1-12 and 1-25 have a fairly normal distribution. However, in Figure 21, the AO subset 13-25 distribution is not normal and shows a skewed representation towards the higher scores as was indicated in Table 2.

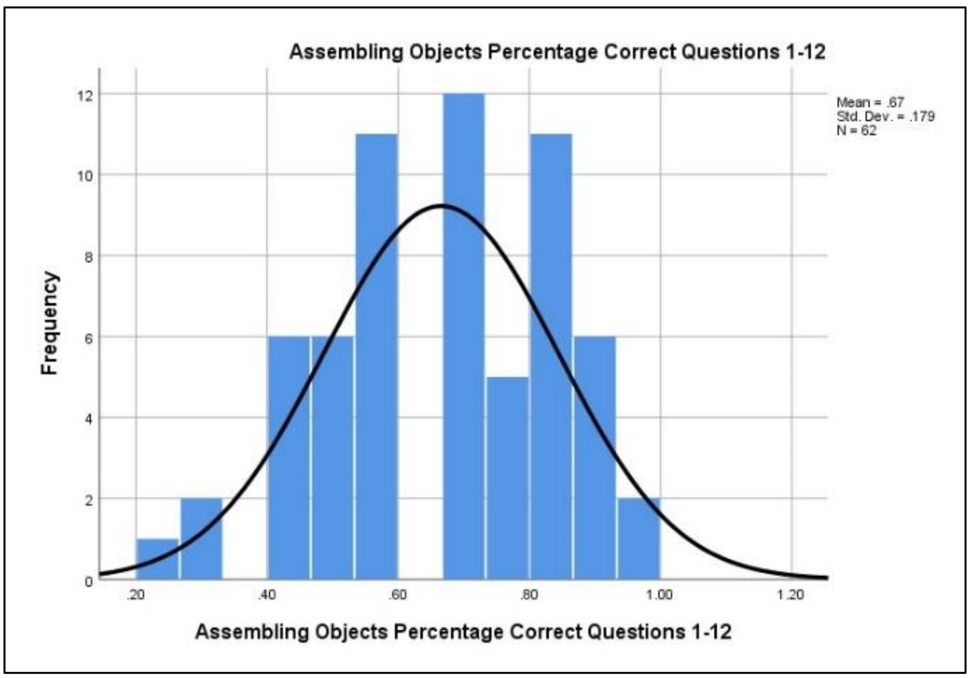


Figure 20. Normality Data: Frequencies for AO Questions 1-12

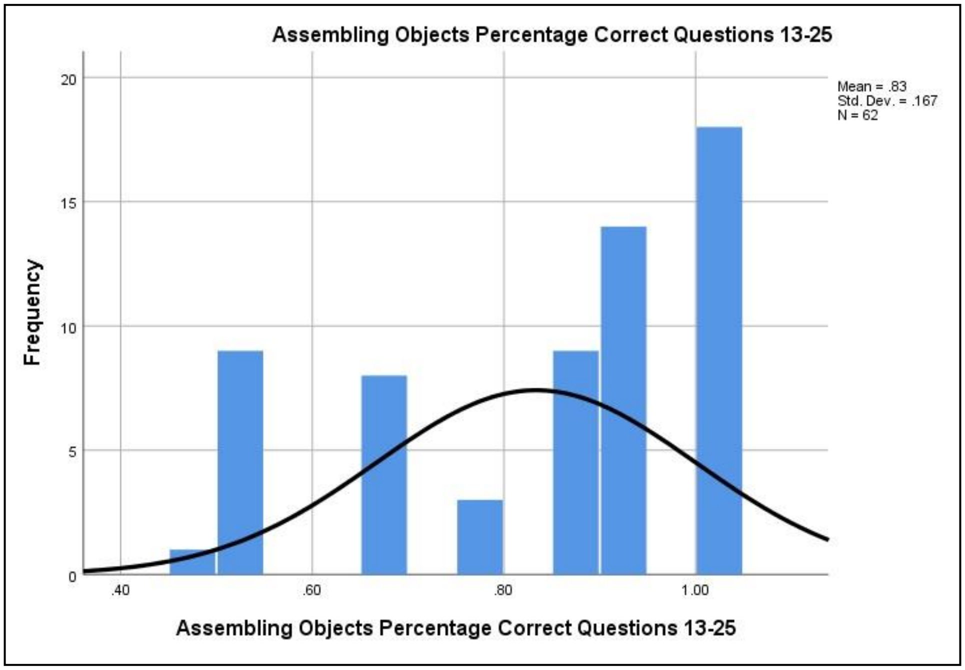


Figure 21. Normality Data: Frequencies for AO Questions 13-25

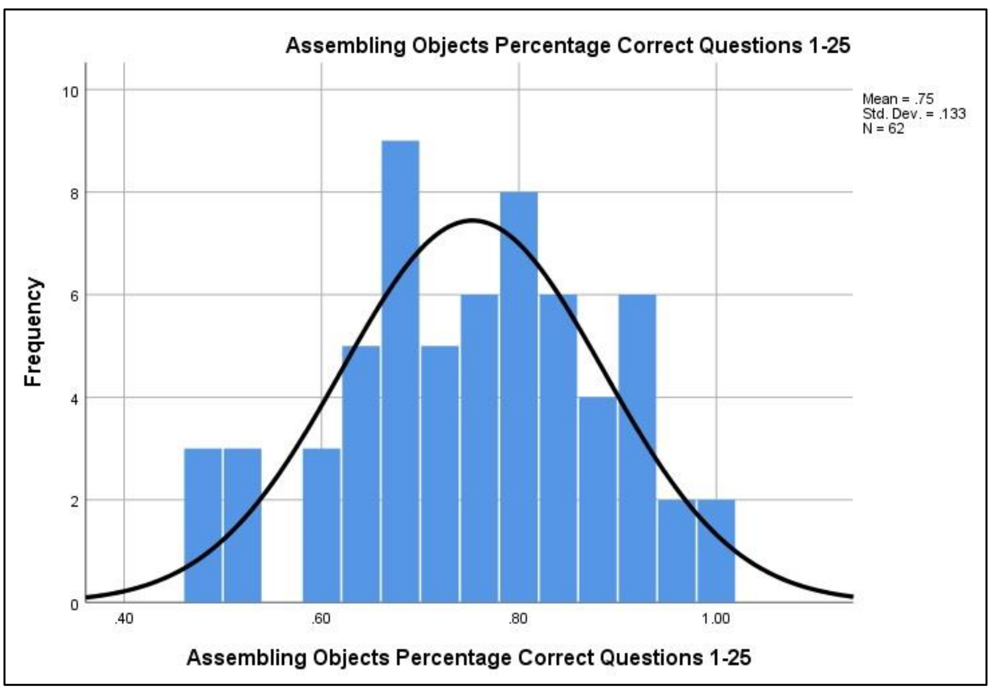


Figure 22. Normality Data: Frequencies for AO Questions 1-25

Figure 23, Figure 24, and Figure 25 depict the means boxplots for AO questions 1-12, 13-25, and 1-25, respectively. In Figure 23, the AO 1-12 boxplot indicates a somewhat normal range with a slight skewness towards lower values. In Figure 24, the AO 13-25 boxplot does not indicate normality and shows significant skewness towards higher scores. Whereas, in Figure 25, the AO 1-25 boxplot indicates normality in addition to indicating an equal range between high- and low-score outliers, as well. After completing the normality review of statistical data (Figures 18-23), it is apparent that the Assembling Objects (AO) data subsets 1-12 and 1-25 are closer to a normal distribution than questions 13-25.

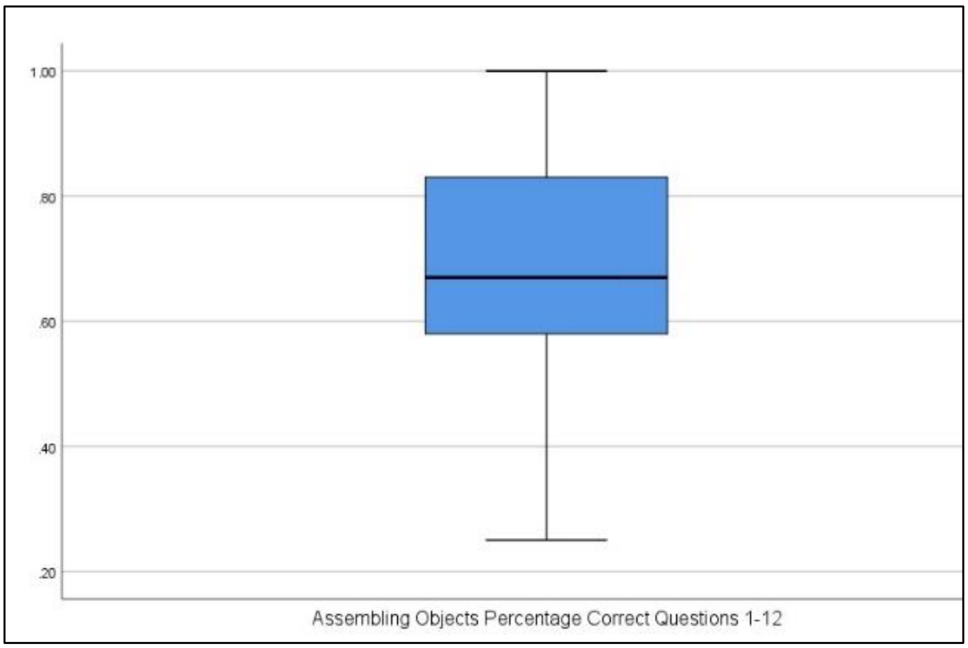


Figure 23. Means Boxplots for AO Questions 1-12

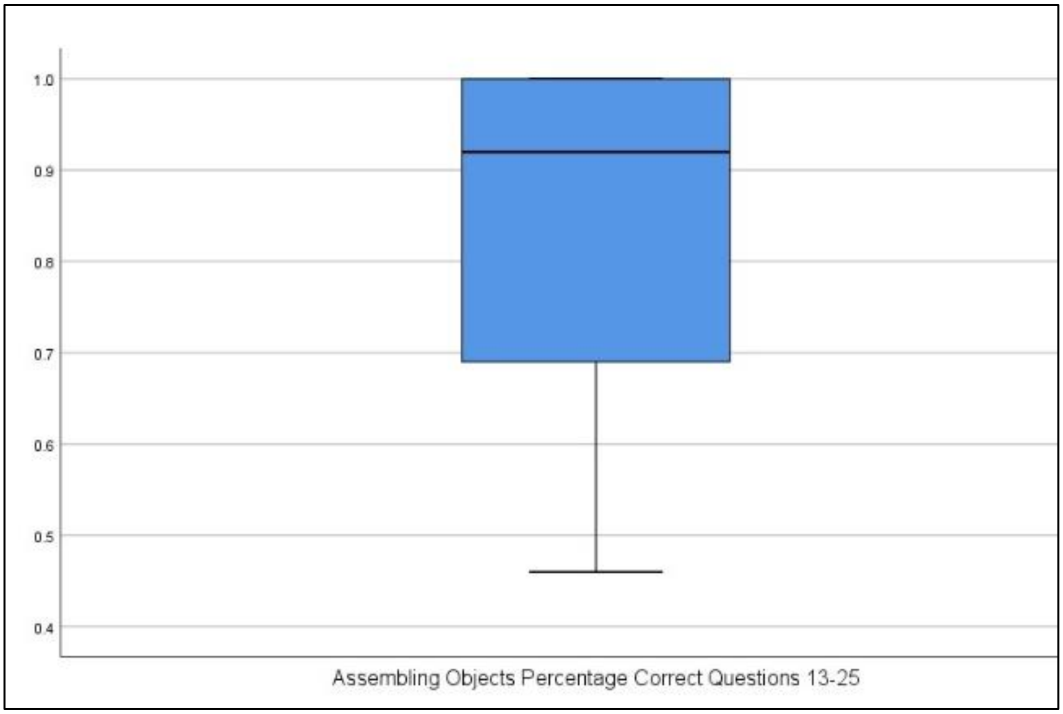


Figure 24. Means Boxplots for AO Questions 13-25

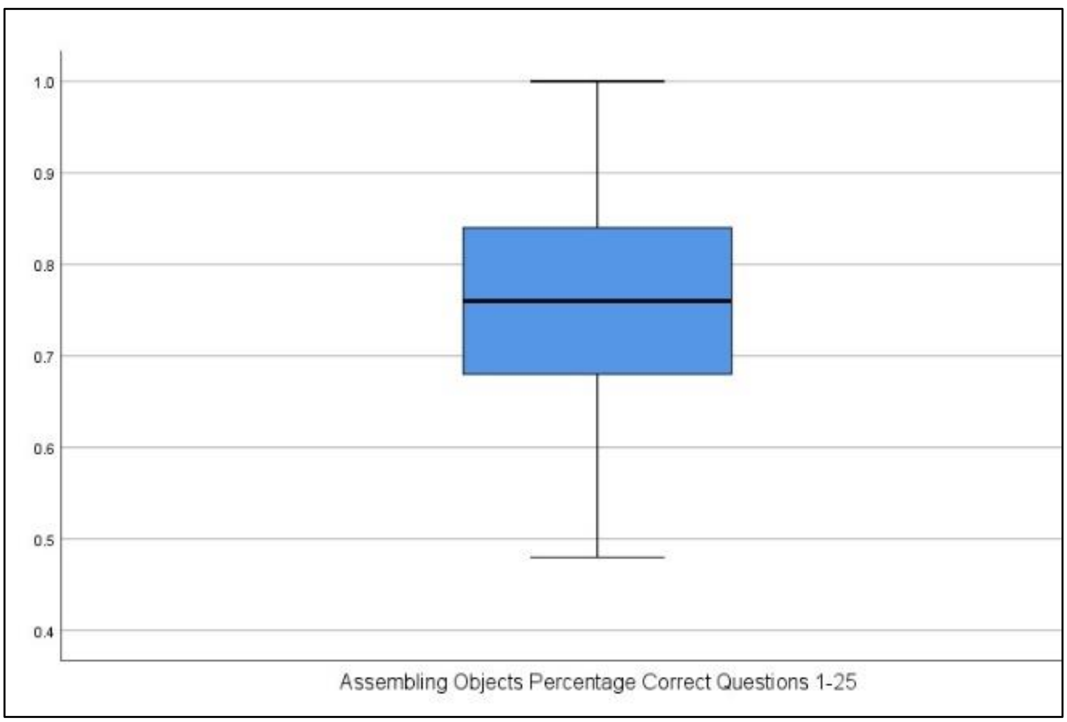


Figure 25. Means Boxplots for AO Questions 1-25

Table 3 shows the statistical evaluation of normality using indices of skewness and kurtosis and the Shapiro/Wilk statistic. The Skewness and Kurtosis z-values for AO questions 1-12 (-.42 and -1.11, respectively) and 1-25 (-.75 and -.86, respectively) are small and indicate that the data sets each do not differ significantly from normality. The Skewness and Kurtosis z-values for AO Questions 13-25 (-2.28 and -1.20, respectively) are larger, showing that the data are skewed (outside +/-1.96 acceptable limit range) and somewhat Kurtotic, indicating that this data subset is not normally distributed.

Shapiro/Wilk statistics are also shown in Table 3. This *p*-value statistic is used to test the hypothesis that the data are normally distributed. If the test *p*-value is < 0.05, then the hypothesis of normality is rejected. The statistics indicate that the distributions for AO 1-12 and 1-25 (.084 and .149, respectively) are not significant and the hypothesis was not rejected. However, the Shapiro/Wilk statistic for AO 13-25 indicates that the rejection of the H_0 is warranted based upon the calculated *p*-value of .000. Given that both data subsets 1-12 and 1-25 were found to be normally distributed, either would provide a valid dataset for further analysis. The AO 1-25 questions were selected for further analysis since the data provide a more comprehensive set of normality—both *p*-value and boxplot central tendency—measurements of spatial visualization.

	Shapiro/Wilk P-Value	Skewness Z-Value	Kurtosis Z-Value
AO Questions 1-12	.084	-.42	-1.11
AO Questions 13-25	.000	-2.28	-1.20
AO Questions 1-25	.149	-.75	-.86

Table 3. Normality Data: Skewness for AO Questions 1-12, 13-25, and 1-25

Santa Barbara Sense of Direction (SBSOD) Normality Examination

A test of normality was also conducted on the SBSOD responses. The histogram and boxplots in Figures 26 and 27, respectively, indicate normality. The Wilks/Shapiro, kurtosis and skewness tests are located in Table 4. The Shapiro/Wilk *p*-value of .973 in Table 4 is greater than .05, thus the hypothesis of normality cannot be rejected. The skewness z-value of -.349 falls between +0.5 and -0.5 suggesting approximate symmetry, and the kurtosis z-value of -.477 falls between the accepted limit values of +1.96 and -1.96 which is indicative of normality, as well. After reviewing the histogram, boxplot, and the normality test output, it was determined that the hypothesis, that the data are normally distributed, could not be rejected and the SBSOD data are normally distributed.

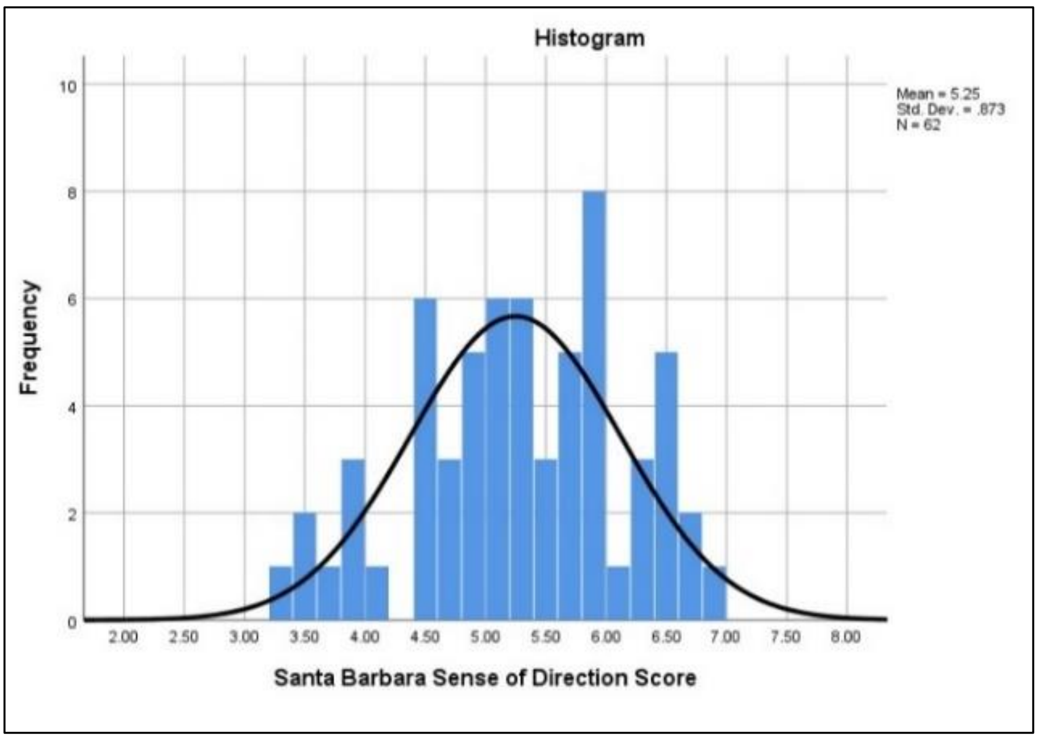


Figure 26. SBSOD Histogram

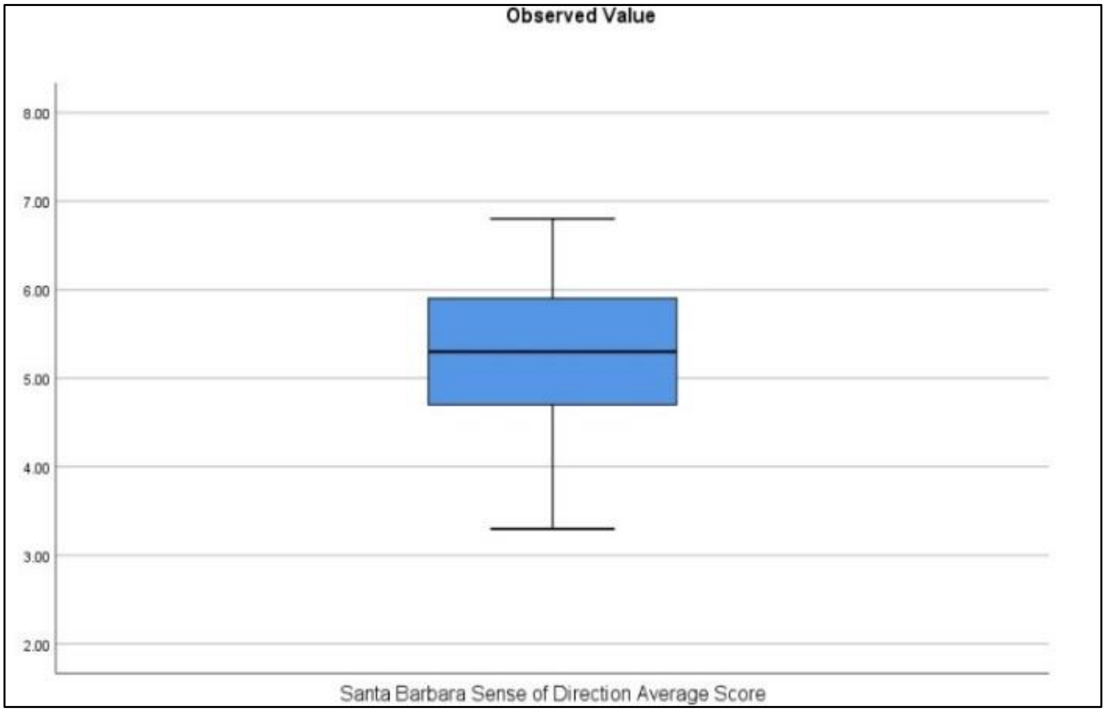


Figure 27. SBSOD Boxplot

	Shapiro/Wilk	Skewness Z-Value	Kurtosis Z-Value
SBSOD Responses	.973	-.349	-.477

Table 4. SBSOD Normality Values

Inferential Statistics

Relationship between Weather Experience and Assembling Objects (AO)

This section will use inferential statistics to examine the correlation of the dependent variables of AO and SBSOD and the independent variables of weather experience and ASVAB scores. The first correlation examined was the effect of the experience of the participants on AO score. To reiterate Hypothesis A: Examine the influence of WX experience on spatial visualization measures.

H_0: WX Experience is not related to AO
H_1: WX Experience is related to AO

H_0: WX Experience is not related to SBSOD
H_1: WX Experience is related to SBSOD

If H_0 cannot be rejected, then it suggests that the more weather experience one has does not contribute to allowing a person to develop their spatial visualization skills. Therefore, there is no effect of years of weather experience on developing spatial visualization skills as indicated by AO and SBSOD scores. Figure 28 presents a scatter plot of weather experience compared to AO scores. The linear relationship between the two variables yields an R^2 value of .042, indicating the linear model describes very little of the variation in the dataset. Table 5 shows the ANOVA for this linear regression that has a *p*-value of .108 therefore there is no effect of weather experience on AO.

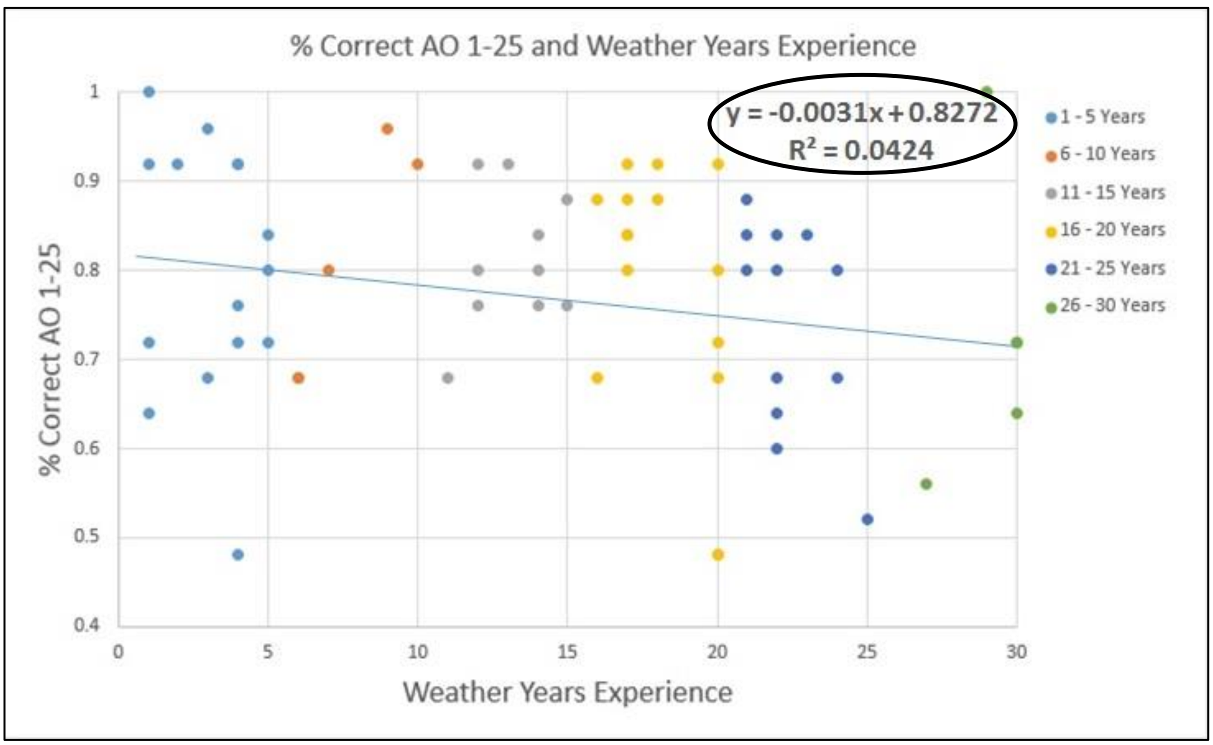


Figure 28. Scatter Plot of AO Questions 1-25 and Weather Experience

Model Summary

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	.206[a]	.042	.026	.12738

a. Predictors: (Constant), Years of WX Experience

ANOVA[a]

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	.043	1	.043	2.658	.108[b]
	Residual	.974	60	.016		
	Total	1.017	61			

a. Dependent Variable: Assembling Objects Percentage Correct Questions 1-25

b. Predictors: (Constant), Years of WX Experience

Table 5. Model Summary for AO and Weather Experience

The second correlation examined was the experience of the participants and their relationship to SBSOD. This analysis provides an alternative way to examine experience with weather and spatial visualization skills. Figure 29 depicts the analysis of weather experience and SBSOD. The test for regression coefficient of .0283 and the *p*-value (p=.031< 0.05) shown in Table 6 indicate that the coefficient is non-zero and also indicates a significant relationship between weather experience and SBSOD. The R^2 value of .075 reveals that the variability in SBSOD explained by weather experience is about 7%. Therefore, there is an effect of weather experience on SBSOD and I reject H_0. However, while the data indicates a significant effect and cannot be dismissed, it does not provide much information and is not an important effect pertaining the relationship between SBSOD and weather experience.

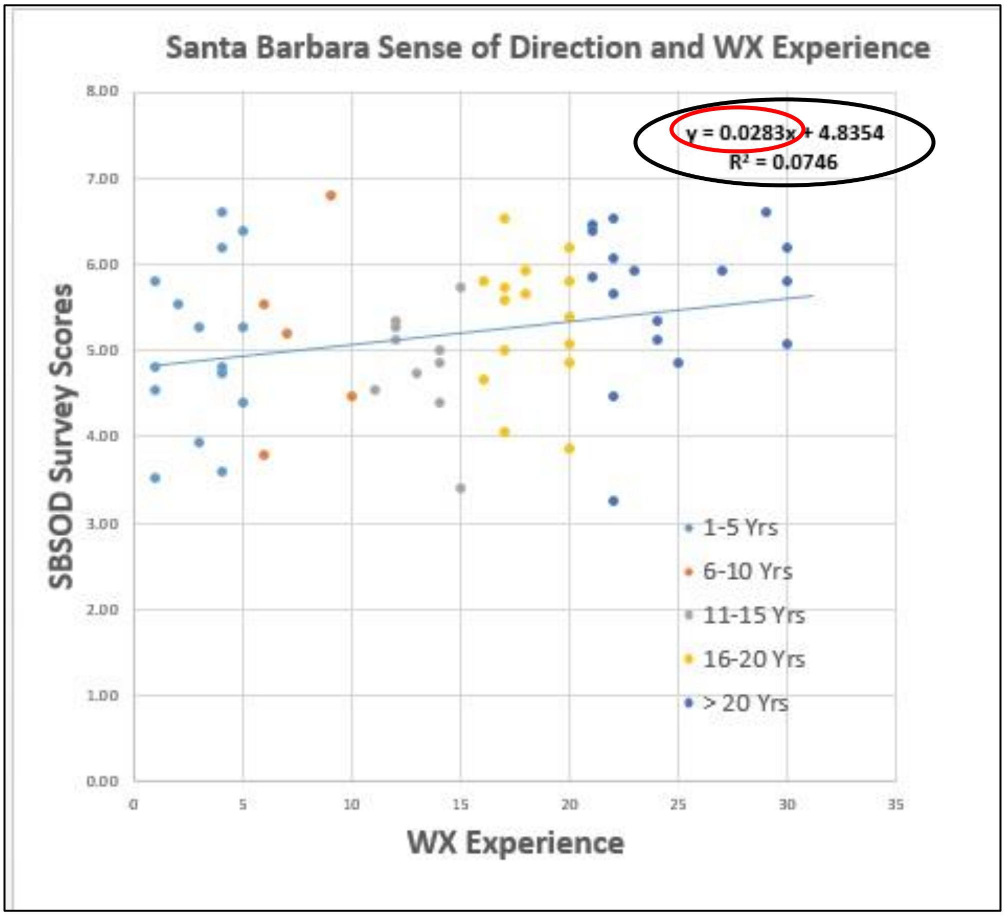


Figure 29. Scatter Plot of SBSOD and Weather Experience

Model Summary

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	.274[a]	.075	.060	.84896

a. Predictors: (Constant), Years of WX Experience

ANOVA[a]

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	3.505	1	3.505	4.863	.031[b]
	Residual	43.244	60	.721		
	Total	46.749	61			

a. Dependent Variable: Santa Barbara Sense of Direction Average Score

b. Predictors: (Constant), Years of WX Experience

Table 6. Model Summary of SBSOD and Weather Experience

The next step taken was to determine if there was a correlation between AO and SBSOD. Both AO and SBSOD are indicative of spatial visualization capabilities. To reiterate Hypothesis B:

H_0: AO is not related to SBSOD
H_1: AO is related to SBSOD

The analyses that follow were accomplished to determine the strength of the relationship between AO and SBSOD. Looking at the scatter plot in Figure 30, you can see that for the various values of AO questions percent correct, typically there was a range of SBSOD scores for each range of AO scores. However, the three data points that are circled (AO = .52, .56, and .60), only had one SBSOD score for each. Therefore, those one-time occurrences were removed from the data and Table 7 displays this descriptive information (highlighted in yellow). Figure 30, Figure 31, and Table 7 show the data prior to removing the one-time occurrences.

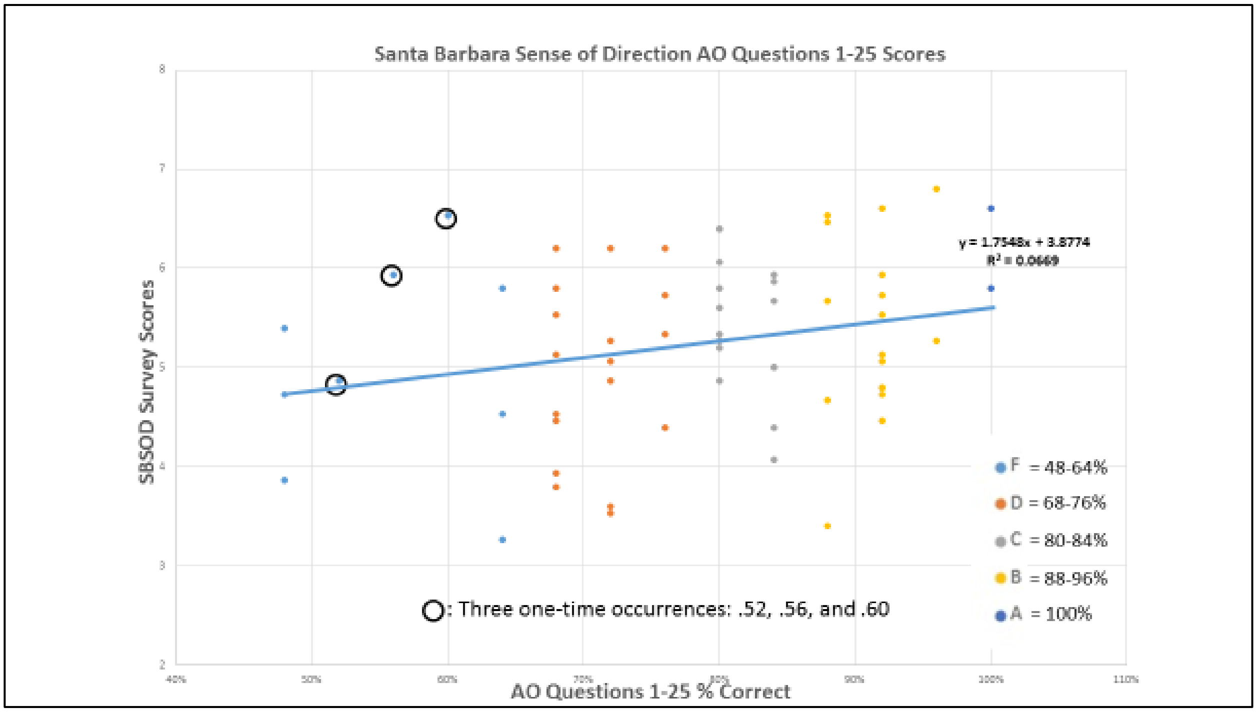


Figure 30. Scatter Plot with Three One-Time Occurrences

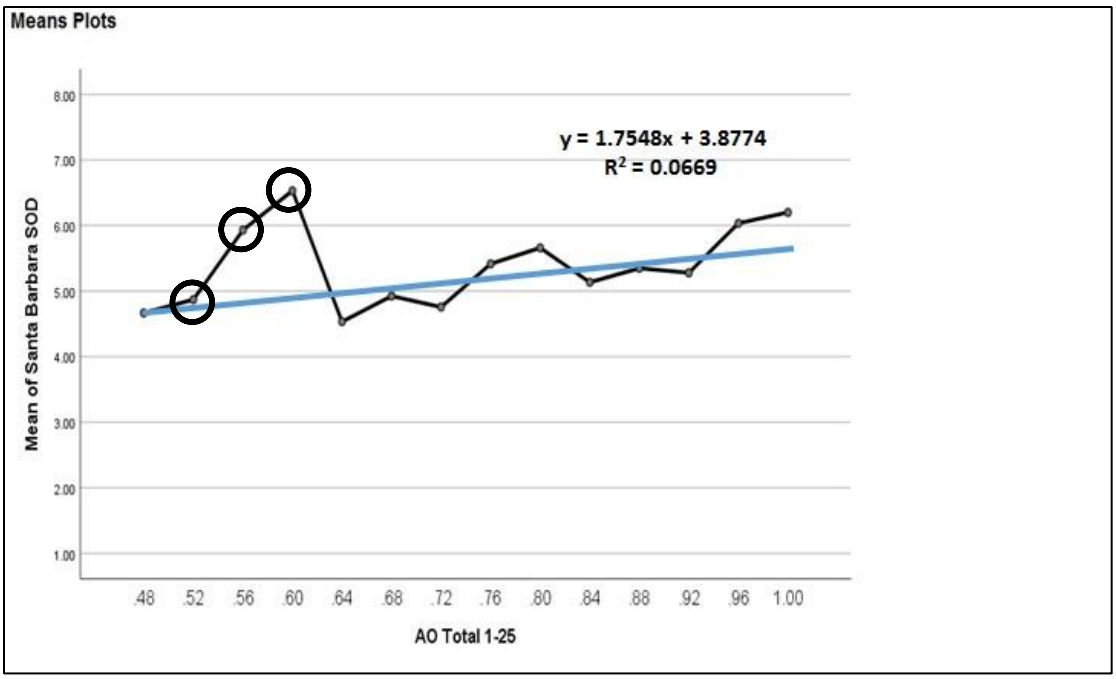


Figure 31. Means Plot SBSOD and AO 1-25 with Three One-Time Occurrences

Descriptives

Santa Barbara SOD

	N	Mean	Std. Deviation	Std. Error	95% Confidence Interval for Mean		Minimum	Maximum
					Lower Bound	Upper Bound		
.48	3	4.6667	.76696	.44281	2.7614	6.5719	3.87	5.40
.52	1	4.8700	.	.	.	.	4.87	4.87
.56	1	5.9300	.	.	.	.	5.93	5.93
.60	1	6.5300	.	.	.	.	6.53	6.53
.64	3	4.5333	1.26500	.73035	1.3909	7.6758	3.27	5.80
.68	8	4.9238	.87977	.31105	4.1882	5.6593	3.80	6.20
.72	6	4.7567	1.02960	.42033	3.6762	5.8372	3.53	6.20
.76	4	5.4150	.76440	.38220	4.1987	6.6313	4.40	6.20
.80	9	5.6600	.54580	.18193	5.2405	6.0795	4.87	6.40
.84	7	5.1343	.72679	.27470	4.4621	5.8065	4.07	5.93
.88	5	5.3480	1.32421	.59220	3.7038	6.9922	3.40	6.53
.92	10	5.2790	.65962	.20859	4.8071	5.7509	4.47	6.60
.96	2	6.0350	1.08187	.76500	-3.6852	15.7552	5.27	6.80
1.00	2	6.2000	.56569	.40000	1.1175	11.2825	5.80	6.60
Total	62	5.2484	.87543	.11118	5.0261	5.4707	3.27	6.80

Table 7. Descriptives Table of SBSOD and AO 1-25 with Three One-Time Occurrences

Figures 32 and 33 show a scatter plot and a means plot after the three one-time occurrences have been removed. Additionally, Table 8 depicts a correlation table with the three one-time occurrences removed, as well. The sample size is reduced to 59 participants but shows an improved fit of the line. The correlation between AO and SBSOD improved to R^2=0.114, indicating the proportion of variability that is explained between the SBSOD and AO model. The *p*-value of .009 for the relationship between the variables indicates that they are significantly related. As a result, there is an effect of AO on SBSOD and I would reject H_0. However, the previously mentioned R^2 of .114 reveals that the variability in SBSOD explained by AO is about 11%. Therefore, while the data indicates a significant effect and cannot be dismissed, it is does not provide much information and is not an important effect pertaining to the relationship between SBSOD and AO.

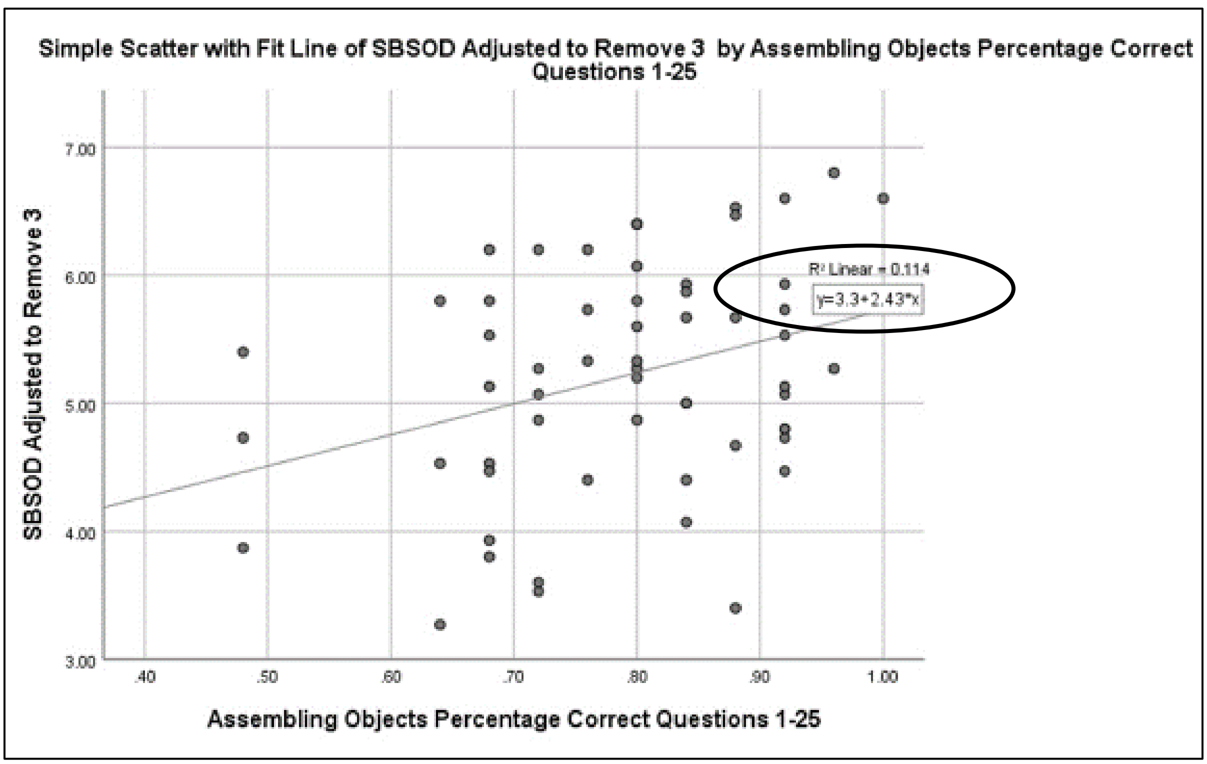


Figure 32. Scatter Plot of SBSOD and AO 1-25 with Three One-Time Occurrences Removed

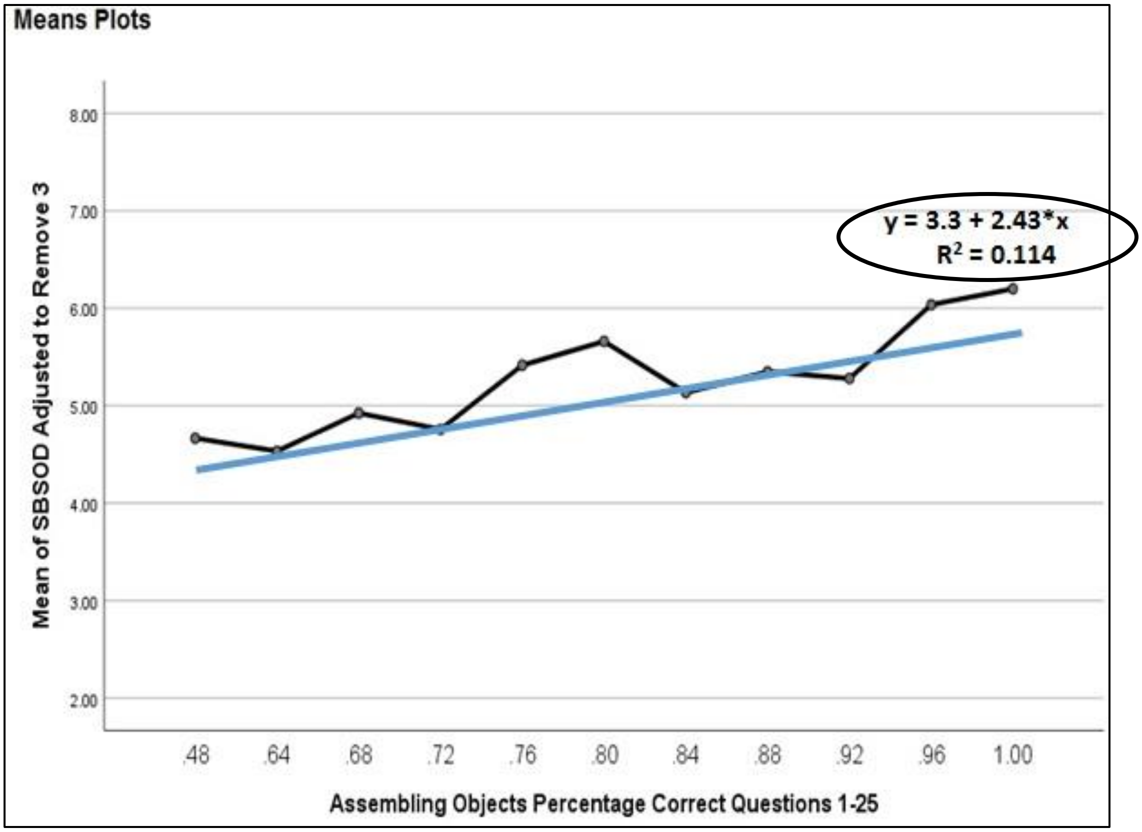


Figure 33. Means Plot of SBSOD and AO 1-25 with Three One-Time Occurrences Removed

Correlations

		Assembling Objects Percentage Correct Questions 1-25	SBSOD Adjusted to Remove 3
Assembling Objects Percentage Correct Questions 1-25	Pearson Correlation	1	.338**
	Sig. (2-tailed)		.009
	N	59	59
SBSOD Adjusted to Remove 3	Pearson Correlation	.338**	1
	Sig. (2-tailed)	.009	
	N	59	59

**. Correlation is significant at the 0.01 level (2-tailed).

Table 8. Correlations Table of SBSOD and AO 1-25 with Three One-Time Occurrences Removed

The next analysis was to examine the correlation between AO and ASVAB scores to determine if the AO spatial visualization evaluation adds unique value to the ASVAB assessment.

To reiterate Hypothesis C:

H_0: AO is not related to ASVAB	H_0: SBSOD is not related to ASVAB
H_1: AO is related to the ASVAB	H_1: SBSOD is related to the ASVAB

Scatter plots with best fit lines are provided to examine the strength of the relationship between AO and ASVAB scores. Figures 34 and 35 depict plots of the General, Mechanical, Electronic, and Administrative ASVAB scores and AO scores. All R^2 values are very weak indicating poor goodness of fit. Additionally, Table 9 depicts the *p*-values ranging from .865 to .910 (highlighted in yellow) indicating very weak positive/negative correlations between AO and ASVAB, as well. As a result of this data, H_0: no relationship between AO and ASVAB scores was not rejected, and thus AO may serve to provide some value with determining spatial visual capabilities.

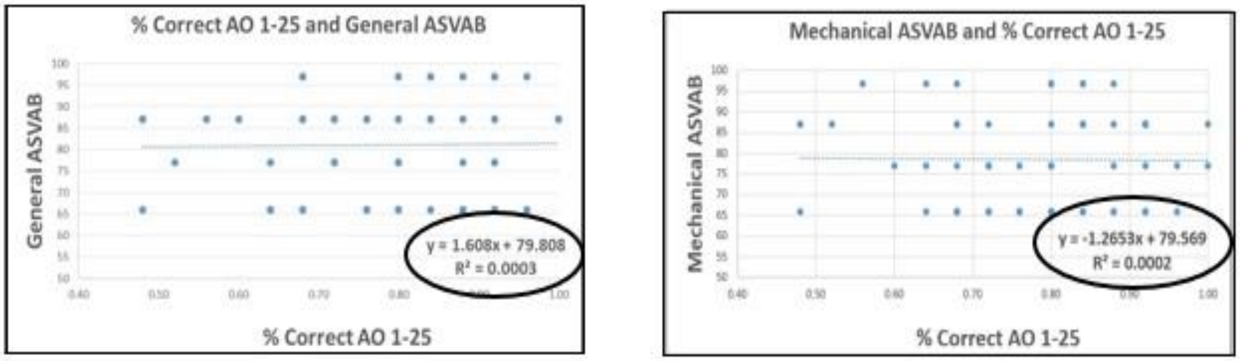


Figure 34. General/Mechanical ASVAB and AO Scatter Plots

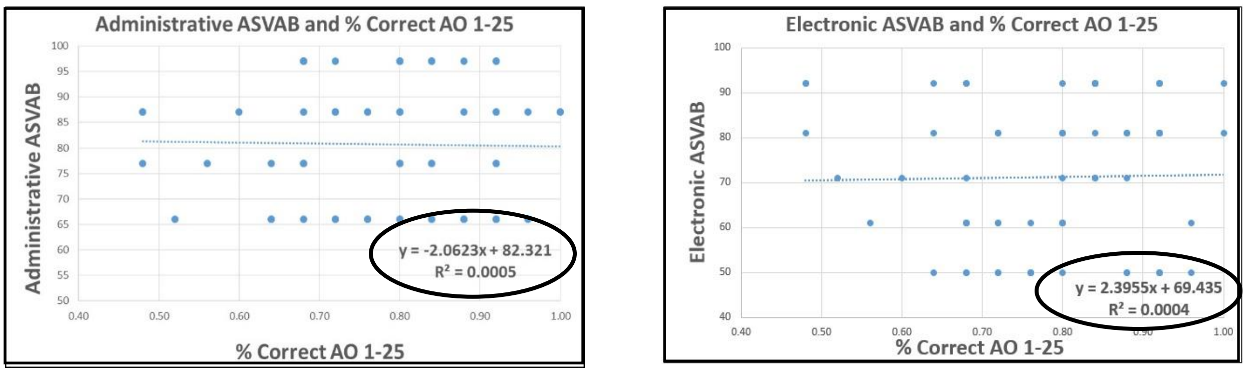


Figure 35. Administrative/Electronic ASVAB and AO Scatter Plots

Correlations

		General ASVAB Score	Mechanical ASVAB Score	Administrative ASVAB Score	Electronics ASVAB Score	Assembling Objects Percentage Correct Questions 1-25
General ASVAB Score	Pearson Correlation	1	.399**	.676**	.404**	.019
	Sig. (2-tailed)		.001	.000	.001	.886
	N	62	62	62	62	62
Mechanical ASVAB Score	Pearson Correlation	.399**	1	.185	.669**	-.015
	Sig. (2-tailed)	.001		.151	.000	.910
	N	62	62	62	62	62
Administrative ASVAB Score	Pearson Correlation	.676**	.185	1	.254*	-.022
	Sig. (2-tailed)	.000	.151		.046	.865
	N	62	62	62	62	62
Electronics ASVAB Score	Pearson Correlation	.404**	.669**	.254*	1	.020
	Sig. (2-tailed)	.001	.000	.046		.875
	N	62	62	62	62	62
Assembling Objects Percentage Correct Questions 1-25	Pearson Correlation	.019	-.015	-.022	.020	1
	Sig. (2-tailed)	.886	.910	.865	.875	
	N	62	62	62	62	62

**. Correlation is significant at the 0.01 level (2-tailed).

*. Correlation is significant at the 0.05 level (2-tailed).

Table 9. ASVAB and AO Correlations

The final statistical review was to determine if there was a correlation between SBSOD and ASVAB scores. This data will determine the strength of relationship between SBSOD and ASVAB scores where H_0: No relationship between ASVAB Scores and SBSOD. Figures 36 and 37 show the ASVAB and SBSOD scatter plots. R^2 data does not indicate goodness of fit for any of the ASVAB batteries. Tables 10-13 depict *p*-values ranging from .202 to .916 and indicates very weak positive/negative correlations between SBSOD and ASVAB. Therefore, the H_0 was not rejected. Similar to AO, SBSOD does not duplicate information provided by ASVAB and it may provide relevant spatial visualization information to the screening/selection process.

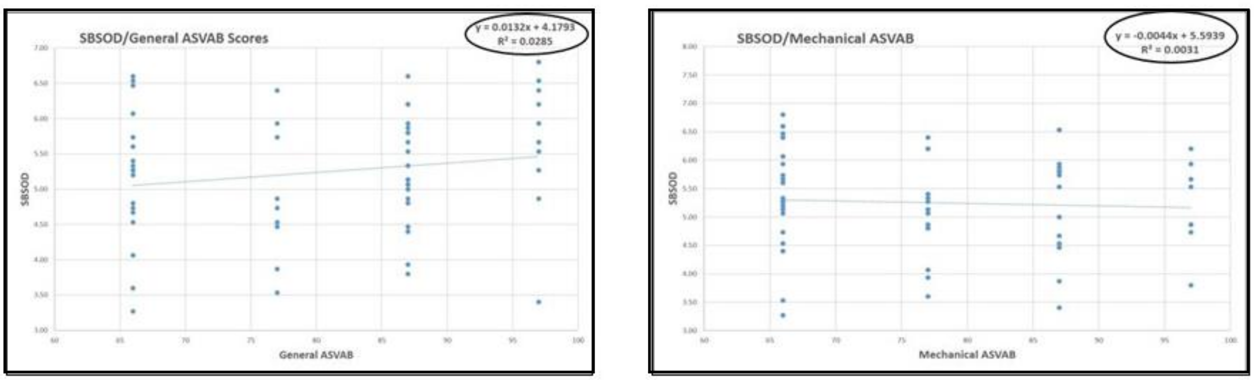


Figure 36. General/Mechanical ASVAB and SBSOD Scatter Plots

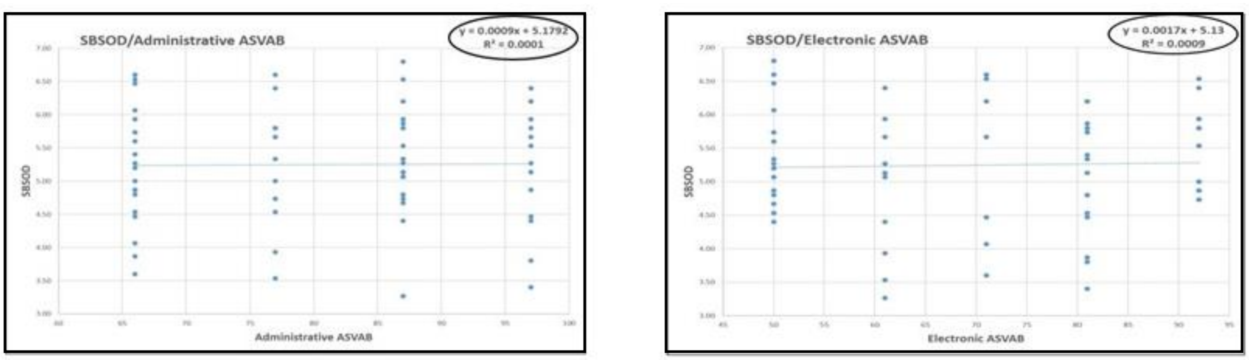


Figure 37. Administrative/Electronic ASVAB and SBSOD Scatter Plots

Correlations

Descriptive Statistics

	Mean	Std. Deviation	N
General ASVAB Score	81.06	11.201	62
Santa Barbara Sense of Direction Average Score	5.2484	.87543	62

Correlations

		General ASVAB Score	Santa Barbara Sense of Direction Average Score
General ASVAB Score	Pearson Correlation	1	.164
	Sig. (2-tailed)		.202
	N	62	62
Santa Barbara Sense of Direction Average Score	Pearson Correlation	.164	1
	Sig. (2-tailed)	.202	
	N	62	62

Table 10. General ASVAB and SBSOD Correlations, and Descriptive Statistics

Correlations

Descriptive Statistics

	Mean	Std. Deviation	N
Mechanical ASVAB Score	78.58	11.094	62
Santa Barbara Sense of Direction Average Score	5.2484	.87543	62

Correlations

		Mechanical ASVAB Score	Santa Barbara Sense of Direction Average Score
Mechanical ASVAB Score	Pearson Correlation	1	.014
	Sig. (2-tailed)		.916
	N	62	62
Santa Barbara Sense of Direction Average Score	Pearson Correlation	.014	1
	Sig. (2-tailed)	.916	
	N	62	62

Table 11. Mechanical ASVAB and SBSOD Correlations, and Descriptive Statistics

Correlations

Descriptive Statistics

	Mean	Std. Deviation	N
Administrative ASVAB Score	80.71	12.056	62
Santa Barbara Sense of Direction Average Score	5.2484	.87543	62

Correlations

		Administrative ASVAB Score	Santa Barbara Sense of Direction Average Score
Administrative ASVAB Score	Pearson Correlation	1	-.031
	Sig. (2-tailed)		.812
	N	62	62
Santa Barbara Sense of Direction Average Score	Pearson Correlation	-.031	1
	Sig. (2-tailed)	.812	
	N	62	62

Table 12. Administrative ASVAB and SBSOD Correlations, and Descriptive Statistics

Correlations

Descriptive Statistics

	Mean	Std. Deviation	N
Electronic ASVAB Score	71.08	15.584	62
Santa Barbara Sense of Direction Average Score	5.2484	.87543	62

Correlations

		Electronic ASVAB Score	Santa Barbara Sense of Direction Average Score
Electronic ASVAB Score	Pearson Correlation	1	-.063
	Sig. (2-tailed)		.626
	N	62	62
Santa Barbara Sense of Direction Average Score	Pearson Correlation	-.063	1
	Sig. (2-tailed)	.626	
	N	62	62

Table 13. Electronic ASVAB and SBSOD Correlations, and Descriptive Statistics

Qualitative Statistics—Mental Adjustment Word Cloud Analysis

With a focus on Trafton's (2017) mental models and spatial visualization theory associated with weather forecasting, a word cloud analysis was accomplished using survey question nine. The question specifically asks, "How do/did you approach a forecast when you determine/determined the forecast model is/was not handling the meso-/micro-scale situation very well for your location?" Figure 38 shows the results provided by 59 participants for question nine where "mentally making adjustments" comprised 40% of the results. The second highest response to question nine were those participants who use/used a combination of methods (24%). The question was then dissected further by examining what combination methods were used to make a forecast when the model is wrong. An additional 10 personnel stated that they use mental adjustments increasing the percentage using mental adjustments to 56%. As a result, mental adjustments were the number one method used when the model was determined to be incorrect.

Survey question 9—combination option clarified

How do/did you approach a forecast when you *determine/determined* the forecast model is/was not handling the meso-/micro-scale situation very well for your location?

9. How do/did you approach a forecast when model is wrong?	
a. Mentally made adjustments[1]	25 (40%)
b. Utilized constant movement method	9 (15%)
c. Utilized historical weather patterns and climo	9 (15%)
d. Utilized persistence forecast method	1 (2%)
e. Utilized a combination; please clarify	15 (24%)

9.e. Utilized a combination of forecast methods (clarify):	
- Mentally made adjustments[1]	10 + 25 = 35 (56%)
- Utilized constant movement method	6 + 9 = 15 (24%)
- Utilized historical weather patterns and climo	11 + 9 = 20 (32%)
- Utilized persistence forecast method	7 + 1 = 8 (13%)

[1] Trafton, et. al, Minding the Weather, MIT Press, Cambridge, MA, 2017.

Figure 38. Word Cloud Analysis When the Model is Incorrect

Chapter 5

Conclusion

Weather support will remain an important aspect of supporting US military operations in the future. Although weather computer modeling is becoming more accurate, humans will continue to be a part of the military weather forecasting decision process for the foreseeable future. Military engagements and tactics will continue to change thereby requiring weather support requirements, techniques, and procedures to also change, as well. Due to the importance of providing weather support, it has never been more essential to ensure the AF selects the right personnel to accomplish the right job at hand. When it comes to applying the military meteorologist's skill set in contested degraded operation (CDO) areas and during Agile Combat Employment (ACE) basing operation scenarios, the automation that we are so accustomed to use might not be available during conflict. If it is not, then AFW meteorologists will have to rely on basic skills and their understanding of the "science of weather." As a result, forecasters will have to go "beyond the model."

How will the AF make certain it selects the most-qualified people to fill these positions to work in situations where weather data may be limited or unavailable? Answering this question could assist in determining the right people to select for the 1W0X1 AFSC to work as Weather Technicians in the USAF. This thesis sought to assist in identifying the most qualified people by introducing a measure of spatial visualization capability as a selection criterion for entry into the AFW meteorological technician career field. With reference to the research question, this study attempted to answer the following specific question: Can spatial visualization skills (represented by AO and SBSOD test/survey scores) be an important determinant for selecting Air Force Weather (AFW) personnel? This research utilized 64 participants who either are currently or were previously AFW technicians. The survey tool used for this study acquired data that indicate the spatial visualization capabilities of the participants. To test the hypothesis, participants were provided with the 25-question AO battery and the 15-question SBSOD survey along with 9 additional experiential questions.

This study investigated if a correlation between weather experience and measures of spatial visualization exists. The study uncovered no relationship between participant experience in the weather career field and AO spatial visualization scores. Similarly, weather career field experience had no significant relationship to the SBSOD spatial visualization score. If a significant correlation would have been uncovered, it would suggest that spatial visualization is a learned skill and may not be appropriate as a selection criterion to enter the weather technician career field. The lack of relationships between the measured variables suggests that spatial visualization may be a stable characteristic that could be reliably assessed for AF weather technician selection. This study did not measure the stability of spatial visualization. But given that it is not tightly correlated with experience, it is safe to presume that it is a relatively stable trait, at least in this career field.

A second analysis accomplished in this study was to examine how spatial visualization metrics relate to the current ASVAB subscores in order to determine if any of those subscores reliably assessed spatial visualization skills. To investigate whether any of the ASVAB subscores measured spatial visualization, separate correlations of AO and SBSOD to each subscore were accomplished. None of these correlations were significant and therefore there were no redundant metrics of spatial visualization in the ASVAB subscores. ASVAB subscores are not picking up the spatial visualization traits that are measured with AO or SBSOD. Therefore, an independent metric of spatial visualization should be provided. Neither the AO nor SBSOD duplicates the information provided by ASVAB and thus would be useful measures of spatial visualization skills.

Another analysis was accomplished to validate the literature that suggests spatial visualization is important to STEM subjects and Earth science fields, like meteorology. Specifically, this part of the study examined how participants talk about using spatial visualization in their work. Based on text responses, mental adjustments (the language to describe spatial visualization traits) were reported to be an important factor in making weather model corrections by more than half (56%) of the participants. Therefore, the result provides additional evidence that supports the literature assertion that spatial visualization is an important trait for weather technicians.

In conclusion, these analyses support using an additional metric of spatial visualization for evaluation of AF weather candidates. This extends the literature recommendation that it is a critical factor and important component of the job and that the ASVAB does not provide a sufficient indication of spatial visualization skills as measured by AO and SBSOD.

Limitations

Additionally and similar to other studies, this research was not without limitations. The initial methodology concept included an attempt to access and obtain Department of Defense Manpower Center (DMDC) relevant ASVAB score statistical data along with the permission to use current USAF active-duty weather personnel as participants in this study. This research was self-sponsored, self-initiated, and self-funded. It was not directed, funded, or supported under the auspices of the USAF. As such, I was denied access to both the DMDC ASVAB-score data and denied permission to use current USAF active-duty weather personnel as participants in this study. It is believed that obtaining this information directly from the USAF may have assisted in providing more data and fidelity for supporting this study and its thesis. For example, the ASVAB scores provided by the participants in this study could not be verified. Finally, the methodology and use of a 58-question survey may have contributed to the lack of respondents that resulted in producing a small population and subsequent reduction in the amount of useable data to analyze.

Despite these limitations, it is hoped that the empirical data produced by this study fills a gap in spatial visualization research and its application on selecting future personnel for the USAF weather technician career field. It is also hoped that this information can provide some impetus for future researchers to consider continuing the study and efforts to ascertain whether spatial visualization skills can improve the selection of future AFW recruits. Selecting AFW Weather Technicians with spatial visualization skills will produce individuals who can apply their weather-forecast-skill aptitude that is relevant, accurate and timely in support of real-world military missions. The selection of AFW Technicians with spatial visualization skills in support of USAF military operations can provide the right people to apply meteorological information and techniques in support of USAF missions as Weather Technicians. The USAF should consider incorporating an individual's spatial visualization Assembling Objects (AO) test score in correlation with the ASVAB scores to select individuals for entering the AF Weather (AFW) Technician career field.

Appendix A: Survey Tool

Online Consent to Participate in Research

Would you like to be involved in research at the University of Oklahoma (OU)?

My name is Jamie Minyon and I am a retired Air Force Weather Technician/Forecaster. I am also currently a student conducting research as part of the OU College of Professional and Continuing Studies Department and I invite you to participate in my research project entitled "Using Spatial Visualization to Select Weather Recruits." This research is being conducted on the Facebook USAF Weather Page. You were asked to be a possible participant because you have AFW forecasting experience. You must be at least 18 years of age to participate in this study.

Please read this document and contact me to ask any questions that you may have BEFORE agreeing to take part in my research.

What is the purpose of this research? The purpose of this research is to look at the benefits of testing prospective Air Force Weather (AFW) weather technician recruits for spatial visualization skills—an ability that other research studies have indicated as being positively correlated with success in the field of meteorology.

How many participants will be in this research? Approximately a total of 360 AFW experienced people will take part in this research. The personnel will be a mix of participants that will include first- and second-term AFW airmen, honorably discharged AFW airmen and retired AFW airmen.

What will I be asked to do? If you agree to be in this research, you will take a survey that includes a 25 question spatial visualization test, a 15 question spatial visualization questionnaire along with demographic/affinity for weather questions.

How long will this take? Your participation will take approximately 40 minutes to complete.

What are the risks and/or benefits if I participate? There are no risks and no benefits from being in this research.

Will I be compensated for participating? You will not be reimbursed for your time and participation in this research.

Who will see my information? In research reports, there will be no information that will make it possible to identify you. Research records will be stored securely and only approved researchers and the OU Institutional Review Board will have access to the records.

Data are collected via an online survey system that has its own privacy and security policies for keeping your information confidential. However, no assurance can be made as to their use of the data you provide.

You have the right to access the research data that has been collected about you as a part of this research. However, you may not have access to this information until the entire research has completely finished and you consent to this temporary restriction.

Do I have to participate? No. If you do not participate, you will not be penalized or lose benefits or services unrelated to the research. If you decide to participate, you don't have to answer any question and can stop participating at any time.

Will my identity be anonymous or confidential? Your identity and name will remain anonymous and will not be retained or linked with your responses.

Will my personal records be accessed? If you approve, your confidential records will be used as data for this research but will only accessed and provided by you. The data that you will provide will be personal ASVAB test scores. These records will be used for the following purpose(s): to determine if personal Spatial Visualization scores show a correlation with personal ASVAB scores.

Who do I contact with questions, concerns or complaints? If you have questions, concerns or complaints about the research, please contact me via e-mail at: james.minyon.1@ou.edu or via phone at: (334) 782-3095. For additional questions, you may also contact my OU advisor, Dr. Randa Shehab, at e-mail: rlshehab@ou.edu or via phone at: (405) 325-4277.

You can also contact the University of Oklahoma – Norman Campus Institutional Review Board (OU-NC IRB) at (405) 325-8110 or irb@ou.edu if you have questions about your rights as a research participant, concerns, or complaints about the research and wish to talk to someone other than the researcher(s) or if you cannot reach the researcher(s).

Please print this document for your records. By providing information to the researcher(s), I am agreeing to participate in this research*.*

This research has been approved by the University of Oklahoma, Norman Campus IRB.

IRB Number:_______________ **Approval date:** ______________

I agree to participate.

I do not want to participate. Thank you for your consideration to complete this survey.

INTRODUCTION: This survey is associated with a study to determine if USAF (AF) Weather Forecasters (Weather Technicians) utilize spatial visualization skills to develop weather forecasts. According to Thurstone's definition, spatial visualization is the ability to hold an image of an object in mind and to twist, turn or rotate it to match another object.

Design of the Study:

Using spatial visualization skill scores and comparing them to specific ASVAB aptitude areas have the potential to assist the USAF in selecting future Weather Technician recruits. Your participation in this study will facilitate determining if spatial visualization skills show a correlation to AF Composite ASVAB scores. There are a total of 58 questions in this 5-part survey.

Part 1. The first 4 questions are related to your previous AF Composite Scores of the Armed Services Vocational Aptitude Battery (ASVAB) in the General, Mechanical, Electrical and Administrative aptitude areas. Prior to taking this survey, please check vMPF (or a previous saved personal file or memory) to obtain your ASVAB information to complete these four questions. These questions are self-paced.

Part 2. The next 5 questions are related to your enlistment in the AF and working in the AF Weather Technician (AFW) career field. These questions are self-paced.

Part 3. The Assembling Objects (A/O) spatial visualization diagram test is comprised of 25 questions that are timed. You'll compare a diagram on the left to four alternate diagram choices on the right to determine which choice includes the correct pieces or positions of the original diagram.

Part 4. The Santa Barbara Sense of Direction (SBSOD) scale has 15 questions to assist in determining environmental spatial skills. These questions are self-paced.

Part 5. The final 9 questions are related to demographics associated with spatial visualization skills, AFW Technician experience and affinity for weather. These questions are self-paced.

The survey should take approximately 40 minutes to complete.

I sincerely appreciate your participation in support of my study. Thank you!

If accessible, please enter your Virtual MPF (vMPF) ASVAB score range for the General (G) aptitude area. If you cannot access your score, please provide your best estimate based upon the range of scores listed below:

66-76

77-86

87-96

>96

I cannot access the data and do not have my personal ASVAB records--I have no recollection of my "G" score.

If accessible, please enter your vMPF ASVAB score range for the Mechanical (M) aptitude area. If you cannot access your score, please provide your best estimate based upon the range of scores listed below:

66-76

77-86

87-96

>96

I cannot access the data and do not have my personal ASVAB records--I have no recollection of my "M" score.

If accessible, please enter your Virtual MPF (vMPF) ASVAB score range for the Electrical (E) aptitude area. If you cannot access your score, please provide your best estimate based upon the range of scores listed below:

50-60

61-70

71-80

81-90

>91

I cannot access the data and do not have my personal ASVAB records--I have no recollection of my "E" score.

If accessible, please enter your vMPF ASVAB score range for the Administrative (A) aptitude area. If you cannot access your score, please provide your best estimate based upon the range of scores listed below:

66-76

77-86

87-96

>96

I cannot access the data and do not have my personal ASVAB records--I have no recollection of my "A" score.

How many years have you (had you previously) worked as an Air Force Weather (AFW) Technician (Air Force Specialty Code [AFSC] 1W0X1 or 25170)?

When you enlisted in the AF, you knew that the Weather Technician Air Force Specialty Code (AFSC) 1W0X1 or 251X0 existed. had no idea that a Weather Technician AFSC 1W0X1 or 251X0 existed.

If you are separated or retired, what were your years of service working as an AFW Technician? For example, if you were an AFW Technician from 1999 to 2004, enter "1999-2004" in the space below.

If you are currently an active duty AFW Technician, please enter "Currently active duty" and the year you became an AFW Technician in the space provided below. For example, if you are currently active duty and have been an AFW Technician since 2008 you would enter "Currently active duty-2008" in the space below.

What year did you enlist in the AF? Please enter the year in four digits. For example, if you entered the AF in 2002, enter "2002" in the space provided below.

Did you retrain into the AFW Technician career field?

No, I have been/was an AFW Technician since my first term of AF enlistment.

Yes, the AF mandated that I retrain and I volunteered to become an AFW Technician.

Yes, the AF mandated that I retrain and I was non-voluntarily selected to become an AFW Technician.

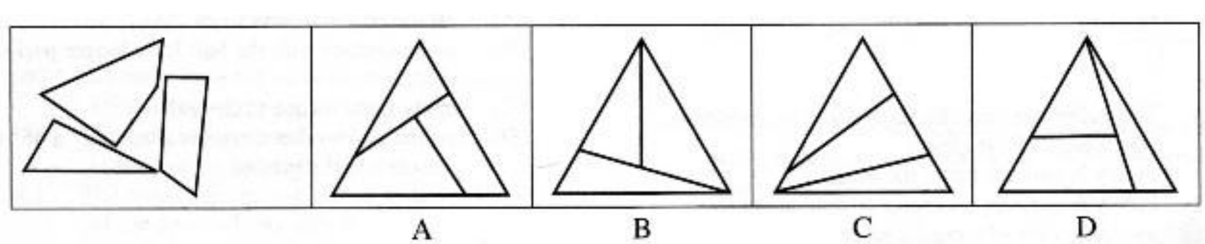
Yes, when I had the opportunity, I submitted a retraining package because I wanted the opportunity to become an AFW Technician.

INSTRUCTIONS:

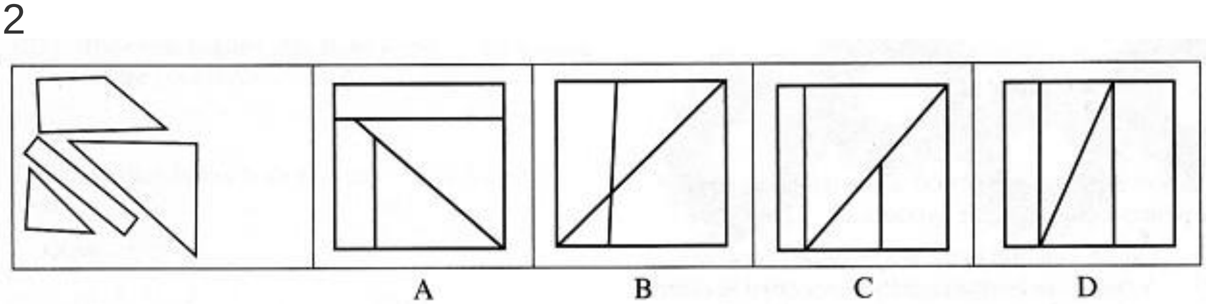
Assembling Objects (AO)--Parts Puzzle © 2019, Kaplan Publishing. For questions 1-12, determine how an object will look when its parts are put together. From the parts figure on the left, which figure (A, B, C, or D) to the right correctly shows how the parts will look when assembled?

For each question, determine the best answer and select the corresponding letter A, B, C, or D to answer. A total of 7 minutes and 12 seconds is allotted to complete questions 1 through 12. As a result, you will be afforded 36 seconds/question to answer before the next question is automatically displayed. Timing will not start for the first question until you click on the arrow below.

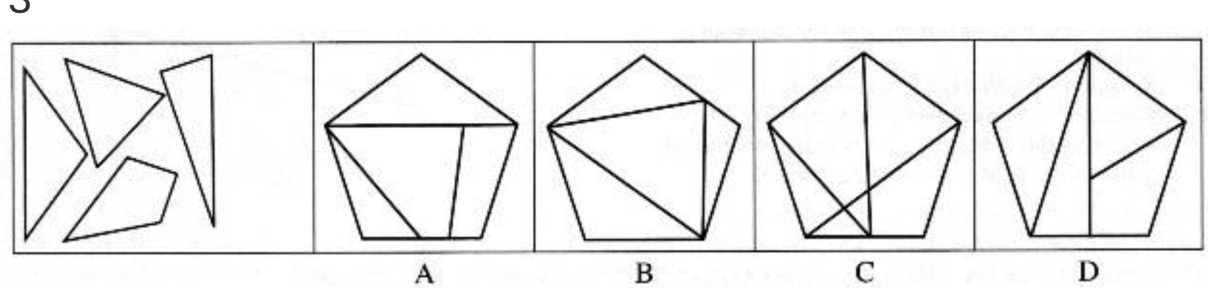
1



2



3



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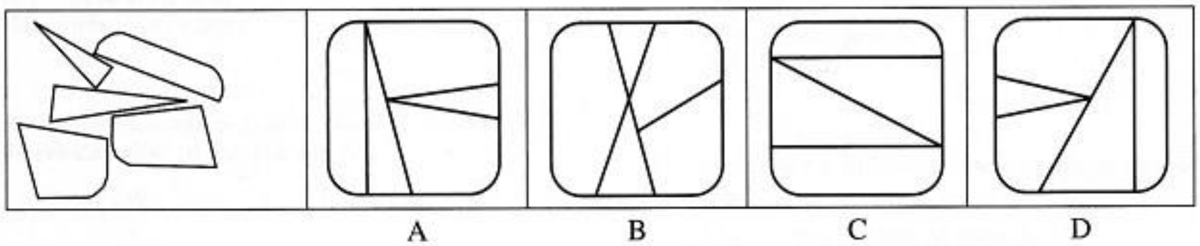

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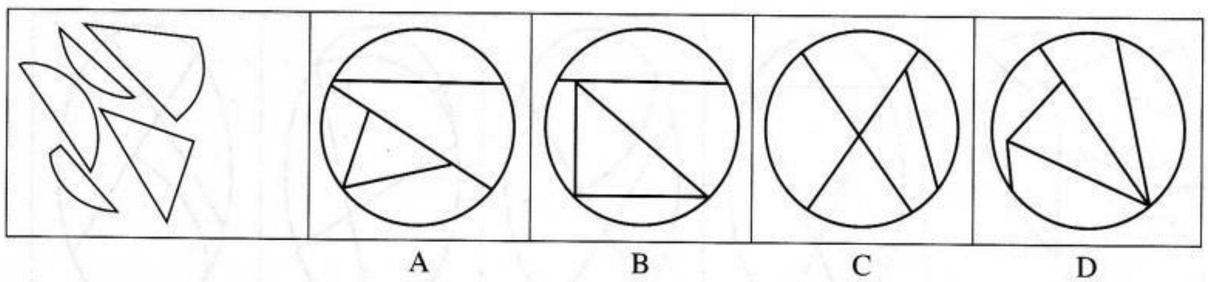

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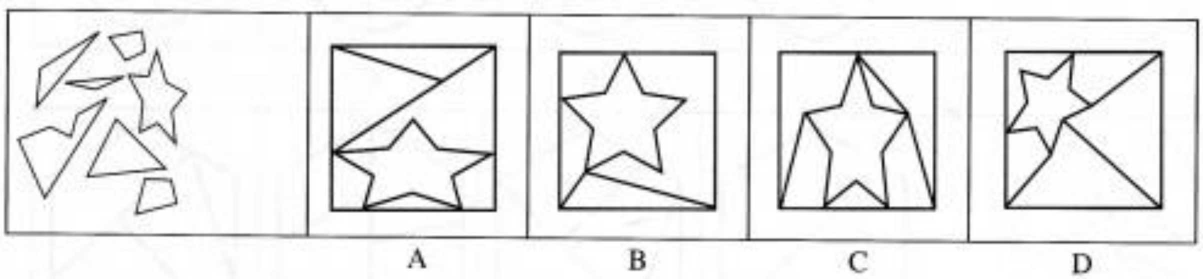

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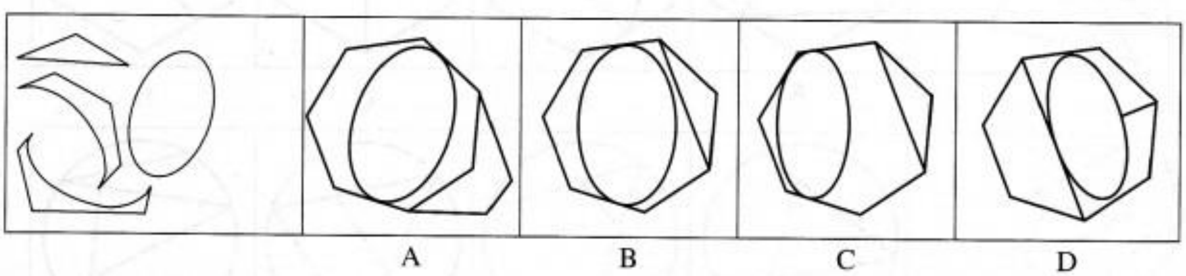

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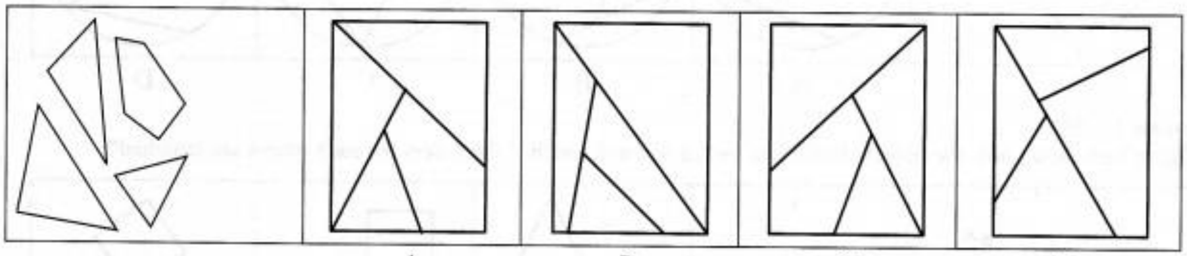

A B C D

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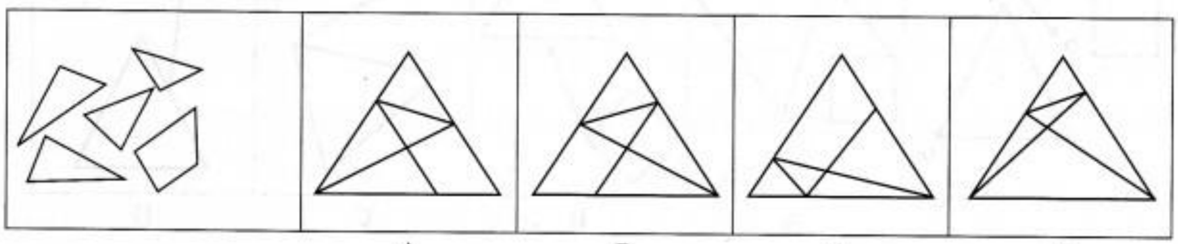

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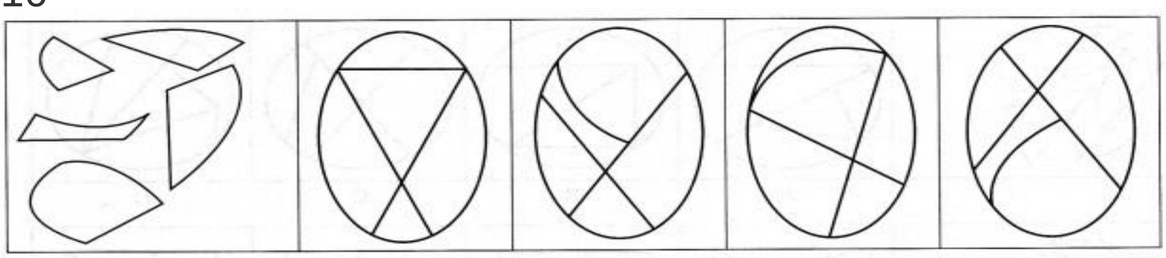

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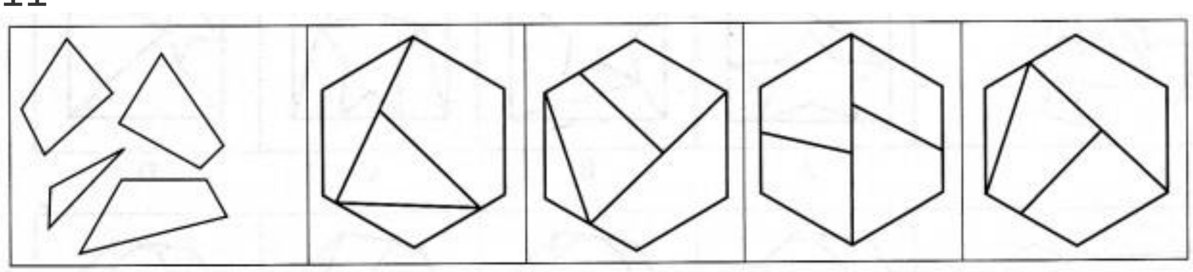

A B C D

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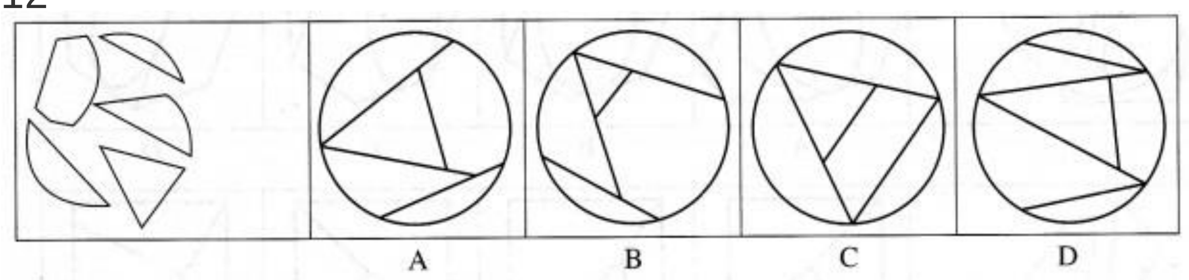
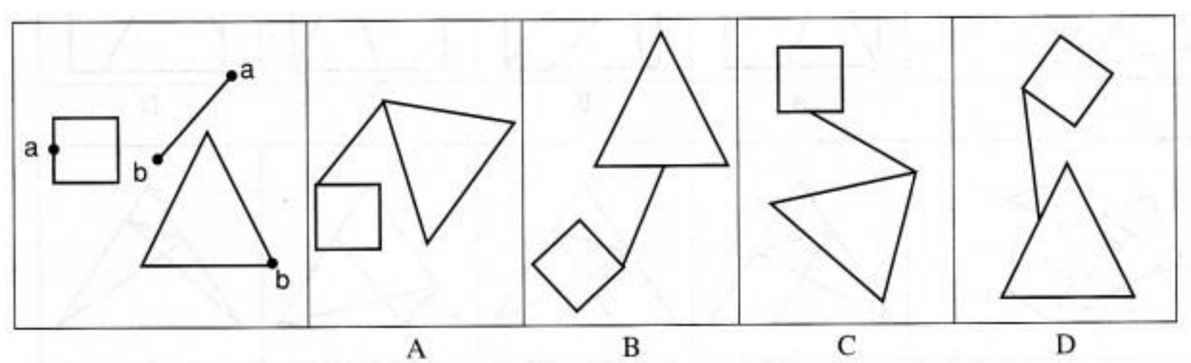


INSTRUCTIONS:

Assembling Objects--Point-Part Connections (AO--PPC) © 2019, Kaplan Publishing. For questions 13 through 25, you will determine how an object will look when its points connect and touch at the prescribed part locations. Which figure (A, B, C, or D) on the right correctly shows how the parts in the box on the left will appear when the parts are connected at their specific points?

A total of 7 minutes and 48 seconds is allotted to complete the AO--PPC questions. As a result, you will be afforded 36 seconds/question to answer before the next question is automatically displayed.

13



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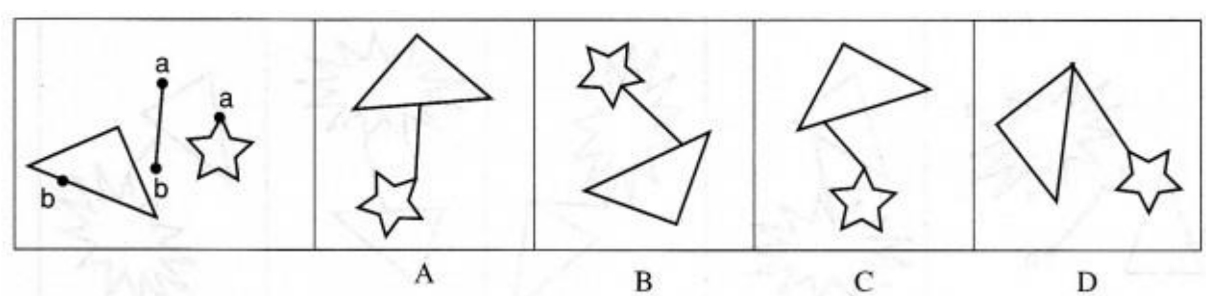

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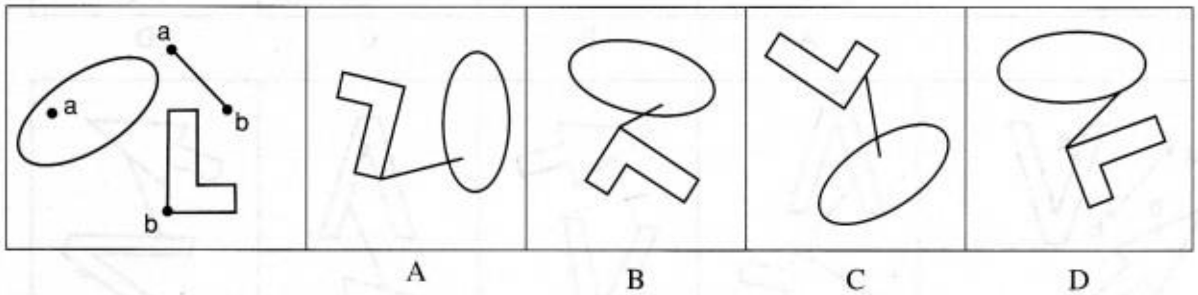

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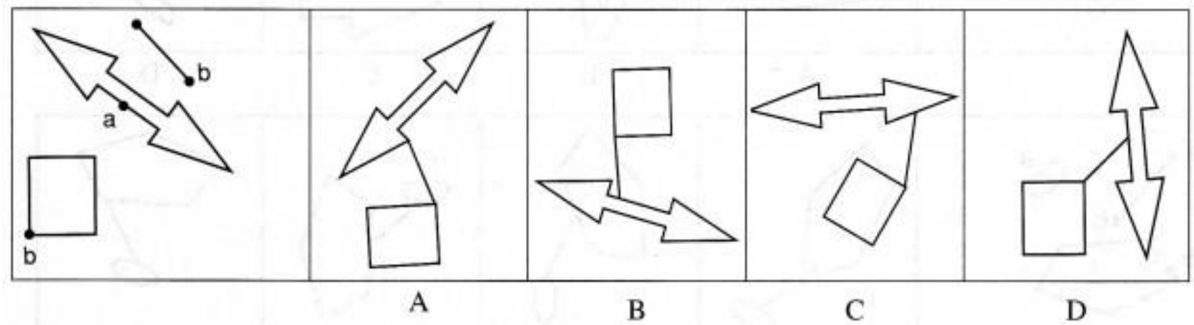

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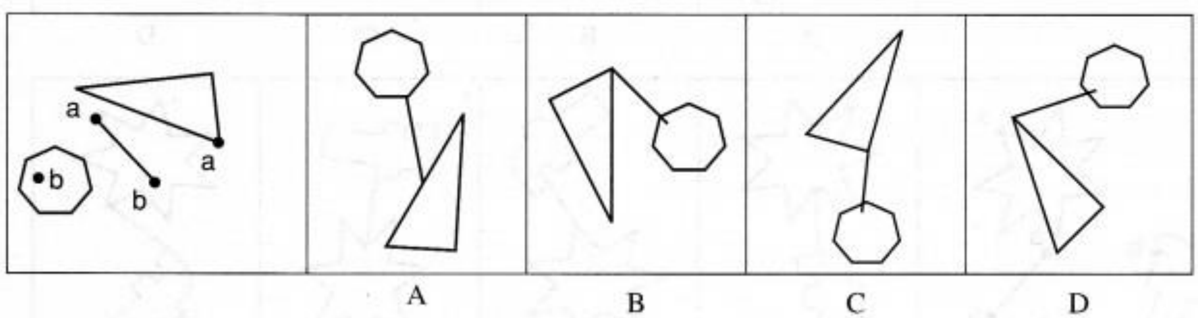

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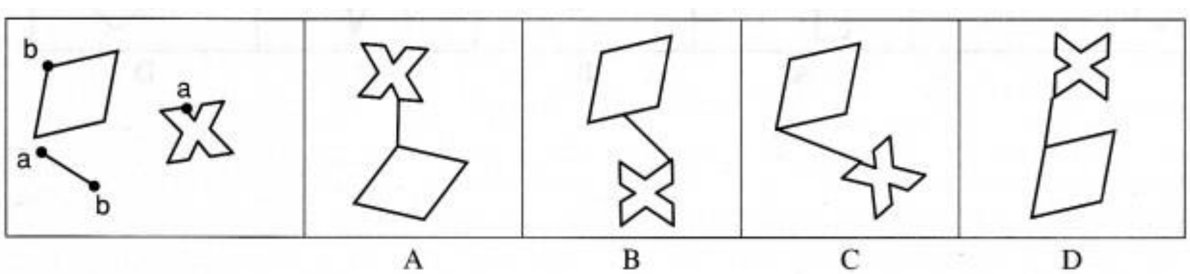

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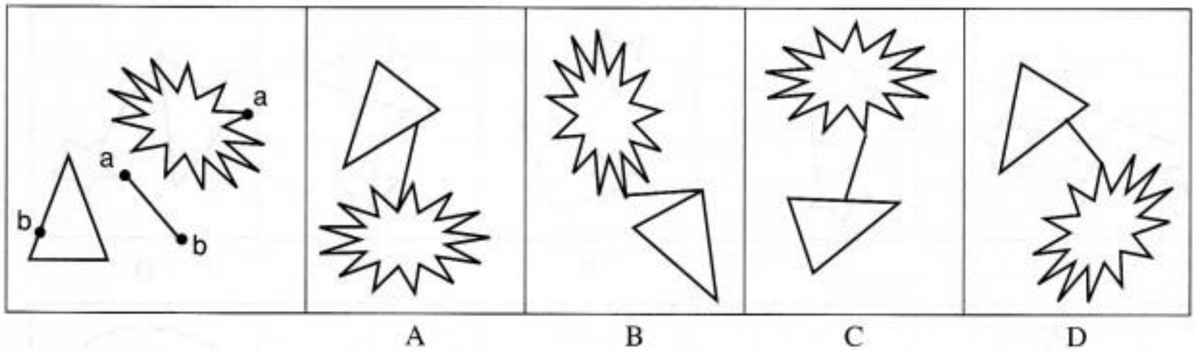

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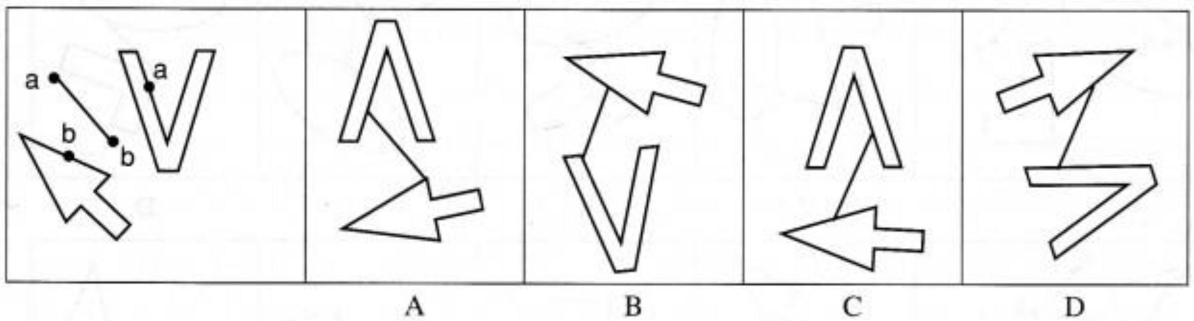

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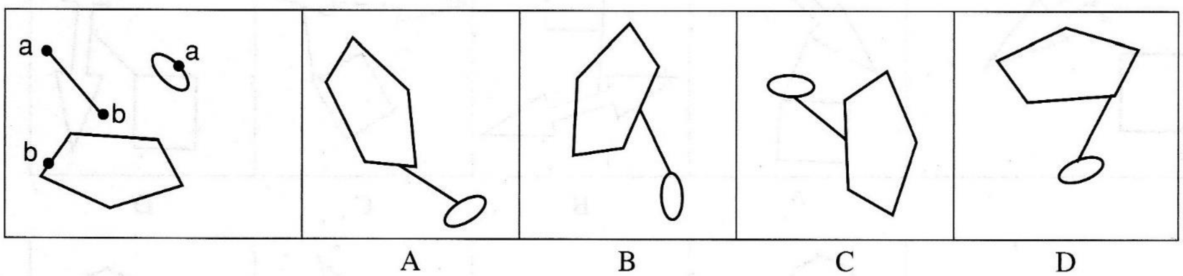

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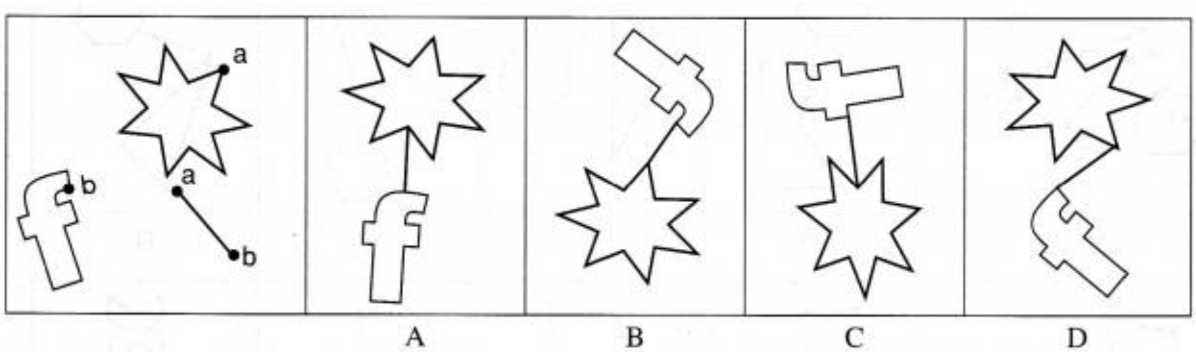

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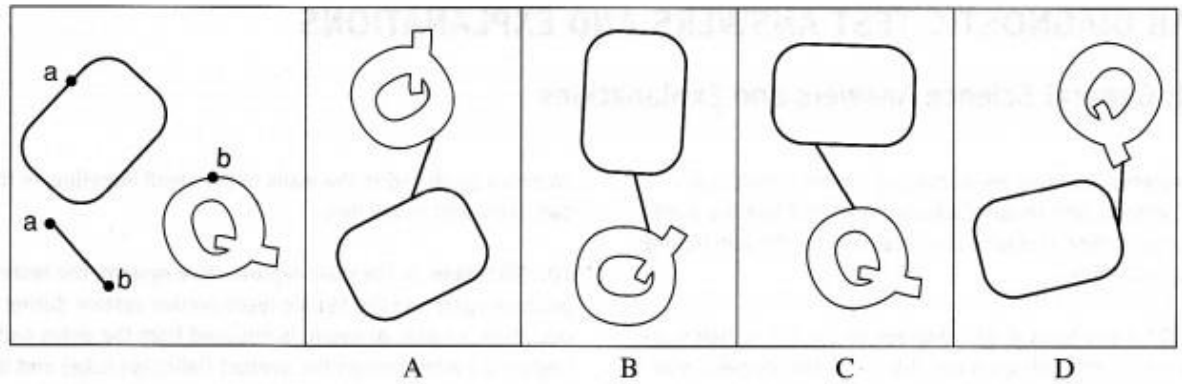

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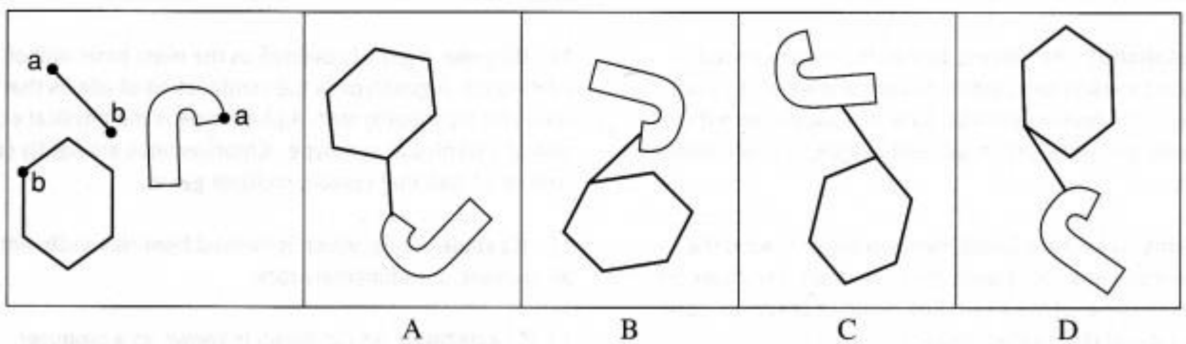

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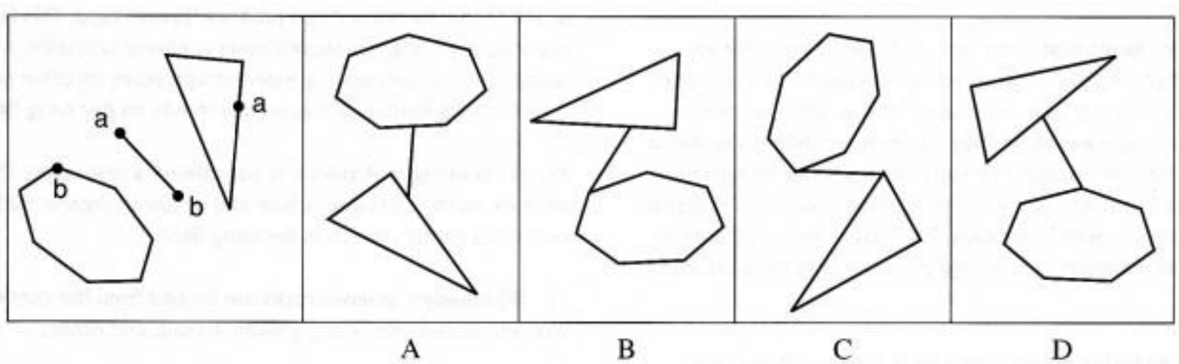

The Santa Barbara Sense-of-Direction (SBSOD) Survey*

The following 15 SBSDS questions consist of several statements about your spatial and navigational abilities, preferences, and experiences.

INSTRUCTIONS:

After each statement, select a number to indicate your level of agreement with the statement. Select "1" if you strongly agree the statement applies to you, "7" if you strongly disagree, or some number in between if your agreement is intermediate. Select "4" if you neither agree nor disagree.

There is no time limit for these 15 questions.

I am very good at giving directions.

strongly agree	2	3	neither agree nor disagree	5	6	strongly disagree
1			4			7

I have poor memory for where I left things.

strongly agree	2	3	neither agree nor disagree	5	6	strongly disagree
1			4			7

I am very good at judging distances.

strongly agree	2	3	neither agree nor disagree	5	6	strongly disagree
1			4			7

My "sense of direction" is very good.

strongly agree	2	3	neither agree nor disagree	5	6	strongly disagree
1			4			7

I tend to think of my environment in terms of cardinal directions (N, S, E, W).

strongly agree	2	3	neither agree nor disagree	5	6	strongly disagree
1			4			7

I very easily get lost in a new city.

strongly agree 1	2	3	neither agree nor disagree 4	5	6	strongly disagree 7

I enjoy reading maps.

strongly agree 1	2	3	neither agree nor disagree 4	5	6	strongly disagree 7

I have trouble understanding directions.

strongly agree 1	2	3	neither agree nor disagree 4	5	6	strongly disagree 7

I am very good at reading maps.

strongly agree 1	2	3	neither agree nor disagree 4	5	6	strongly disagree 7

I don't enjoy giving directions.

strongly agree 1	2	3	neither agree nor disagree 4	5	6	strongly disagree 7

It's not important to me to know where I am.

strongly agree 1	2	3	neither agree nor disagree 4	5	6	strongly disagree 7

I usually let someone else do the navigational planning for long trips.

strongly agree 1	2	3	neither agree nor disagree 4	5	6	strongly disagree 7

I can usually remember a new route after I have traveled it only once.

strongly agree 1	2	3	neither agree nor disagree 4	5	6	strongly disagree 7

I don't have a very good "mental map" of my environment.

strongly agree 1	2	3	neither agree nor disagree 4	5	6	strongly disagree 7

The following block of 9 survey questions relate to your personal experiences. There are no right or wrong answers.

INSTRUCTIONS:

For each question, determine the most-applicable selection(s) and/or enter the requested information that applies to your personal experiences.

There is no time limit for these 9 questions.

I like/liked to (select all that apply)

- play with Legos
- build models
- play with blocks
- draw three-dimensional objects
- None of the above

Prior to enlisting in the Air Force did you play a musical instrument?
Yes
No

Did you or do you enjoy playing any of the following video games? Please select all that apply.

- Platformer Action Games (e.g., Donkey Kong, Galaga and Super Mario Bros)
- First Person Shooter Action Games (e.g., Call of Duty, HALO, Battlefield and Half-Life)
- Top Down Shooter Action Games (e.g., Space Invaders and Raiden V: Director's Cut)
- Action/Adventure Games (e.g., Legend of Zelda, Resident Evil and Castlevania)
- Role Playing Games (e.g., Final Fantasy and Mass Effect)
- Simulator Games (e.g., The Sims)
- Sports Themed Games (e.g., Madden NFL, FIFA and Gran Turismo)

- Puzzle Video Games (e.g., Brain Age, Minecraft and Tetris)

- I did not/do not play video games

Prior to enlisting in the Air Force, which of the following courses did you take in high school or college? Please select all that apply.

Physics

Chemistry

Physical Science

Geography

Computer Programming

Meteorology Oceanography

Geometry

Algebra Trigonometry

Calculus

Having achieved the prerequisite ASVAB scores required for being selected to work in the AF as a Weather Technician (AFSC 1W0X1), you

- voluntarily selected the Weather Technician AFSC (1W0X1) upon your initial enlistment.

- were a non-volunteer selected to become a Weather Technician (AFSC 1W0X1) based on your General and Electronics Information (EI) ASVAB scores upon your initial enlistment.

- voluntarily applied to retrain to become a Weather Technician (AFSC 1W0X1) after your first term of enlistment.

- were in an AFSC overage and offered Weather Technician (AFSC 1W0X1) as a retraining option after your first term of enlistment.

- Other

Did you have an interest in weather/meteorology prior to enlisting in the Air Force?

Definitely yes

Might or might not have

Definitely not

Answer the following statement with the response that most identifies with you and working (previously working) as a Weather Technician in the Air Force. I...

- enjoy/enjoyed working as a Weather Technician because I have always been interested in weather.

- do/did not enjoy working as a Weather Technician even though I have always been interested in weather.

- enjoy/enjoyed working as a Weather Technician even though I did not have a previous interest in weather.

- do/did not enjoy working as a Weather Technician because I do/did not have an interest in weather.

Answer the following statement with the response that most identifies with you and working (previously working) as a Weather Technician in the Air Force. I...

- enjoy/enjoyed working as a Weather Technician because I do/did like the challenge of military weather forecasting.

- enjoy/enjoyed working as a Weather Technician even though I do/did not find military weather forecasting challenging.

- do/did not enjoy working as a Weather Technician because I find/found military weather forecasting too challenging.

- do/did not enjoy working as a Weather Technician because I do/did not find military weather forecasting challenging enough.

How do/did you approach a forecast when you determine/determined that the forecast model is/was not handling the meso-/micro-scale situation very well for your location? You

- mentally make/made adjustments to the model and then incorporate/incorporated the results into your forecast.

- utilize/utilized the constant-movement method based upon the current system impacting your area to forecast the weather from its current position into the future.

- utilize/utilized historical weather patterns and climatological data tables.

- utilize/utilized the persistence forecast method.

- utilize/utilized a combination of forecast methods listed above (please clarify).

- utilize/utilized another method not listed (please clarify).

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Appendix B: Santa Barbara Sense of Direction (SBSOD) Survey

SANTA BARBARA SENSE-OF-DIRECTION SCALE
Sex: F M Today's Date:________________
Age:_______ V. 2

This questionnaire consists of several statements about your spatial and navigational abilities, preferences, and experiences. After each statement, you should circle a number to indicate your level of agreement with the statement. Circle "1" if you strongly agree that the statement applies to you, "7" if you strongly disagree, or some number in between if your agreement is intermediate. Circle "4" if you neither agree nor disagree.

1. I am very good at giving directions.

strongly agree 1 2 3 4 5 6 7 strongly disagree

2. I have a poor memory for where I left things.

strongly agree 1 2 3 4 5 6 7 strongly disagree

3. I am very good at judging distances.

strongly agree 1 2 3 4 5 6 7 strongly disagree

4. My "sense of direction" is very good.

strongly agree 1 2 3 4 5 6 7 strongly disagree

5. I tend to think of my environment in terms of cardinal directions (N, S, E, W).

strongly agree 1 2 3 4 5 6 7 strongly disagree

6. I very easily get lost in a new city.

strongly agree 1 2 3 4 5 6 7 strongly disagree

7. I enjoy reading maps.

strongly agree 1 2 3 4 5 6 7 strongly disagree

8. I have trouble understanding directions.

strongly agree 1 2 3 4 5 6 7 strongly disagree

9. I am very good at reading maps.

strongly agree 1 2 3 4 5 6 7 strongly disagree

10. I don't remember routes very well while riding as a passenger in a car.

strongly agree 1 2 3 4 5 6 7 strongly disagree

11. I don't enjoy giving directions.

strongly agree 1 2 3 4 5 6 7 strongly disagree

12. It's not important to me to know where I am.

strongly agree 1 2 3 4 5 6 7 strongly disagree

13. I usually let someone else do the navigational planning for long trips.

strongly agree 1 2 3 4 5 6 7 strongly disagree

14. I can usually remember a new route after I have traveled it only once.

strongly agree 1 2 3 4 5 6 7 strongly disagree

15. I don't have a very good "mental map" of my environment.

strongly agree 1 2 3 4 5 6 7 strongly disagree

Appendix C: Air Force Enlisted Classification Directory Weather Excerpt

AFECD, 30 April 2019

WEATHER CAREER FIELD (1W)

Introduction

Individuals in the Weather career field collect, analyze, predict, tailor, and integrate weather and space environmental information, including forecasts of conditions, to provide decision-quality information on environmental impacts to Air Force, Army, Joint and Coalition operations. They operate meteorological equipment and employ computer workstations to interrogate current and forecast atmospheric and space weather conditions based on observations, terrestrial and space sensing instruments, weather radars, data and imagery from geostationary and polar orbiting satellites, and forecast data provided by military, national, and international weather centers. Air Force weather personnel are attached or assigned to Air Force, Army, Joint, or coalition conventional and special operations at garrison and expeditionary locations worldwide. Qualified volunteers may perform airborne and special operations duty in this career field. Weather is a Battlefield Airman (BA) career field according to AFPD 10-35, *Battlefield Airmen*.

AFECD, 30 April 2019

AFSC 1W091, Superintendent
AFSC 1W071, Craftsman
AFSC 1W051, Journeyman
AFSC 1W031, Apprentice
AFSC 1W011, Helper

WEATHER
(Changed 31 Jan 12)

1. Specialty Summary. Performs and manages the collection, analysis, and forecast of atmospheric weather and space environmental conditions to enable decision superiority and application of land, air, space and cyberspace power across the full spectrum of military operations. Related DoD Occupational Subgroup: 142000.

2. Duties and Responsibilities:

2.1. Collect, analyze and integrate atmospheric and space environmental information into military decision-making processes.

2.2. Observe, record, and transmit surface, upper air and space environment observations.

2.3. Operate atmospheric and space-sensing instruments and computer workstations to interrogate data from weather radars, meteorological satellites, and products provided by military, national, and international weather agencies.

2.4. Use a detailed understanding of the atmosphere and space environment to translate raw data into decision-quality environmental information.

2.5. Issue advisories, watches and warnings to alert users of dangerous, inclement, or operationally significant terrestrial and space weather events.

2.6. Understand war fighter tactics, techniques and procedures to maximize air, space, cyberspace combat power. Utilizes weather tactics, techniques, and procedures to integrate weather information into the decision-making process at all levels to mitigate and exploit weather impact on operations.

2.7. Manage weather operations, ensure quality, and adapt resources to meet mission requirements.

*AFECD; mandatory ASVAB requirements for entry into the 1W0X1 AFW career field:

3. Specialty Qualifications.

3.1. Knowledge. Knowledge of the following is mandatory: characteristics and principles of atmospheric weather and space environment; observation, analysis, prediction, and integration of weather and space environment information; operation and operator maintenance of fixed and deployable meteorological and space weather instruments and systems; operation and operator maintenance of communications and computer systems; use of weather products from operational and strategic centers; military weapons systems and decision-making processes; and combat field skills (ability to survive and operate on the battlefield and use of tactical equipment).

3.2. Education. For entry into this specialty, a high school diploma or equivalent is required. Courses in physics, chemistry, earth sciences, geography, computer sciences, and mathematics are desirable.

3.3. Training. For award of AFSC 1W031, completion of the weather initial skills course is mandatory.

3.4. Experience. The following experience is mandatory for award of the AFSC indicated:

3.4.1. 1W051. Qualification in and possession of AFSC 1W031. Also, experience in collecting and analyzing atmospheric data, performing meteorological watch, preparing forecast products, and issuing weather watches, warnings, and advisories.

3.4.2. 1W071. Qualification in and possession of AFSC 1W051. Also, experience in forecasting local area and mesoscale weather features, determining weather effects on weapons systems, and preparing and delivering weather briefings and mission execution forecasts.

3.4.3. 1W091. Qualification in and possession of AFSC 1W071. Also, experience in scheduling personnel, providing technical leadership and training, tailoring unit capabilities, and managing weather resources to meet mission requirements.

3.5. Other. The following are mandatory as indicated:

3.5.1. For entry into 1W0X1:

3.5.1.1. Ability to speak distinctly.

3.5.1.2. Visual acuity correctible to 20/20.

3.5.1.3. See attachment 4 for additional mandatory requirements for AFSC entry.

3.5.2. For award and retention of these AFSCs:

3.5.2.1. Requires routine access to Secret material or similar environment. Award and retention of AFSCs requires completion of a current National Agency Check, Local Agency Checks and Credit (NACLC) according to AFI 31-501, *Personnel Program Management*.

3.5.2.2. For award and retention of these AFSCs, must maintain local network access IAW AFI 17-130, *Cybersecurity Program Management* and AFMAN 17-1301, *Computer Security*.

AFECD, 30 April 2019

MANDATORY AFSC ENTRY REQUIREMENTS															
			APTITUDE					PHYSICAL PROFILE						OTHER	
CHG'D LAST	AFSC	Note(s)	M	A	G	E	X	P	U	L	H	E	S	M	N
	1W0X1	2			66	50	H	2	3	1	2	2	1	X	X

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