3.9 Relative Humidity: What do students know about it?

Sherman E. Fredrickson[1], Pamela L. Heinselman[2], Wilson J. Gonzalez-Espada[3], and Daphne Zaras[2]

[1]NOAA National Severe Storms Laboratory, Norman, Oklahoma
[2]Cooperative Institute for Mesoscale Meteorological Studies, University of Oklahoma Norman, Oklahoma
[3]Arkansas Tech University, Russellville, Arkansas

1. Introduction

It is well known that students reach our meteorology classroom with intuitive and possibly incorrect perceptions about the physical world. This scientific, pseudoscientific, and non-scientific information comes from a number of sources, including the students' daily experiences, their own environmental explorations, their social interactions, media, and formal instruction. As a consequence of their constant constructing, deconstructing, processing, and organizing of the received information, college students will have ideas that are not currently supported by the scientific community (Gonzalez-Espada 2002). The National Academy of Sciences has classified science misconceptions into five categories (National Research Council, 1997):

- Preconceived notions, defined as popular conceptions rooted in everyday experiences.
- Nonscientific beliefs, defined as views learned by students from sources other than scientific education, such as religious or mythical teachings.
- Conceptual misunderstandings, defined as student models that combine correctly taught scientific information with their own preconceived notions and nonscientific beliefs.
- Vernacular misconceptions, defined as confusion created when words have both an "every day" meaning and a scientific one.
- Factual misconceptions, defined as falsities learned at an early age and retained unchallenged into adulthood.

Unlike physics misconceptions, which have been studied extensively by physics education researchers (e.g., Clement 1982; Clement 1993; Dykstra 1992) and science educators (e.g., Wandersee, Mintzes, and Novak 1995) over the last two decades, earth science misconceptions, particularly weather misconceptions, have not been studied as extensively (Fraser 2005; Henriquez, 2000; Phillips 1991; Todaro 2003).

The misconception addressed in this paper is that of relative humidity. Interesting, the authors were unable to find a single article in the education literature addressing even a suggested misconception about relative humidity. Given, then, that no research has

Corresponding author address: Sherman Frederickson, NSSL, 1313 Halley Circle, Norman, OK, 73069. E-mail: Sherman. Frederickson@noaa.gov

investigated the characteristics, cause and extent of this topic, the authors of this paper aim to contribute to the science education literature in this important area.

The concept of relative humidity is currently viewed and informally and formally taught in a manner that has remained virtually unchanged for at least the last 150 years. The concept is based on the idea that the air can hold only so much water vapor. When this limit is reached, we say the air is saturated. Any action to increase this saturation results in condensation of the water vapor in the form of rain, fog, dew, etc. We call the relationship between the actual amount of water vapor in air, and the maximum amount possible, relative humidity.

The crux of the misconception is that the air has the capacity to “hold” water vapor; that at some point it reaches something called saturation. It does not. And it is not enough to say that there is some evidence to refute this concept. Rather, it is more accurate to say that there exists no physics that support the idea of saturation. This, in turn, makes the long taught concept of relative humidity something of a problem. It is especially curious because there has been a perfectly sound explanation in existence, taught in some branches of science, for at least the last 50 years.

Research on correcting misconceptions in science gives us several guidelines (e.g., Anderson and Lindsey 1998; Chinn and Brewer 1993; NRC 1997; Resnick 1983). One known factor is that merely presenting the “correct” concept and expecting the individual to accept it, will likely fail. The individual must be able to categorically compare the misconception with the correct explanation and make the switch to the new idea on his or her own. In order to provide this comparison, though, we must first try to find some specifics about what the individual actually believes.

The misconception of saturation is particularly interesting in that, while acquired early on as most misconceptions are, this concept of saturation is still formally presented at higher education levels and is accepted as part of the normal scientific vocabulary.

This paper 1) reviews historical aspects of water vapor and a probable source of this misconception, 2) presents examples of how and where the misconception has been perpetuated, 3) describes the correct explanation and who has actually been using it, and 4) provides a preliminary evaluation of a survey developed to measure current concepts of relative humidity.

2. **Historical Background**

A picture of the historical background is important because it shows that our modern day misconception of humidity has roots that go back to the middle of the 18th century. A discussion of problems facing scientists (natural philosophers) of this period is presented: why did evaporation occur: what was the form of this evaporated water in the air: could this moisture in the air be quantified and measured?

a. Development of vapor model concepts

In antiquity, there were many puzzles about water. Liquid water could “evaporate”; disappear. Clouds could form and produce rain. What was the form of water that evaporated and how did this happen? How did clouds form and why? There was a strong suspicion that evaporated water was the source of water for clouds, fog etc. The big problem was that liquid water was obviously heavier than air and thus vapors of water should also be heavier than air. So how did water vapors get up to where clouds formed?

1) The mechanical model of evaporation

Early ideas of evaporation were based on what was called mechanical models. “Fire” particles (the unknown nature of heat) physically knocked water particles loose from the liquid. Or water particles became more and more agitated as heat was applied and finally, with boiling, flew off with fire particles attached (Middleton 1965).

2) The solution paradigm of evaporation

In a 1750 paper Charles LeRoi proposed a novel explanation (though not a mechanism) for evaporation whereby evaporating water dissolved in air the same way that a solid dissolved in a liquid (Feldman 1983). One proof was that dissolved solids resulted in a clear solution and it was observed that air containing water vapor was also clear. Water would form on a sufficiently cold surface, proving that water truly was a part of the air. Furthermore, Le Roi observed that the air inside a covered container of water acted like a solution with a dissolved substance. Proof of this was that at some point and some temperature the air inside the container became saturated with water vapor and the excess appeared as condensation. Le Roi’s quoted description of this state was that of “le degree de saturation de l’ air” (Middleton 1969). Since it was known from exploring mountains that air aloft was cooler, this would be the reason clouds formed. This was called the Solution Theory. It required the air to saturate. And it bears a strong resemblance to how we interpret things today.

Opponents of the solution theory countered with observations that water would evaporate in a vacuum. This should not be possible if it was necessary for air to be present to “dissolve” the water (Middleton 1965). Others noted that neither the observed pressure of water vapor nor the heat consumed in producing this vapor by boiling could be explained by the solution theory (Feldman 1983). The solution theory was nonetheless widely accepted, even by significant “natural philosophers” studying this phenomenon such as Benjamin Franklin (1706-1790) and Alessandro Volta (1745-1827) (Middleton 1965).

3) The heat model for evaporation

A significant opponent to the solution theory was Jean Andre Deluc (1727-1817) who, along with many others of that time, was keenly interested in the use of the barometer for accurate altimetry measurements in mountains. At the time, there was a strong suspicion that errors in barometry were due to variations in the quantity of water vapor in the atmosphere. Deluc studied the characteristics of water vapor and came to different conclusions from LeRoi. Deluc interpreted his own experiments as proof that it was heat that drove water to evaporate, not a solution concept (Feldman 1983). Deluc's idea was also taken up by many others including the noted chemist Antoine de Lavoisier (1743-1794) who considerably advanced the concept (Middleton 1965).

So at this point we had a competing concept to the solution theory of evaporation. Still, nothing adequately explained the apparent "saturation" effect.

b. Quantification of water vapor pressure

Some quantification of the relationship between water vapor pressure and temperature had been done by scientists studying this evaporation phenomenon. But the advent a new device provided far more reason for detailed empirical data.

Joseph Black (1728-1799) and James Watt (1736-1819) did considerable work to accurately quantify the relationship between vapor pressure and temperature in an effort to improve the efficiency of newly developed steam engines. They were convinced that knowledge of heat was key to understanding steam. But even though their data included vapor pressures at temperatures well below the boiling point of water, they felt, like many others, that steam was different from simple room temperature evaporation. They did not connect that heat for evaporation was the same thing as heat required to produce steam. The solution concept and saturation was still considered adequate for explaining evaporation (Feldman 1983).

c. Measurements of "Humidity"

Detailed empirical data had been collected on the relationship between the saturation vapor pressure of water and the temperature, and it was possible to accurately measure ambient water vapor pressure independent of the air. Yet there were still these devices called hygrometers that seemed to be responding to something else in the air; what was thought to be the "actual humidity" (whatever that was).

Of all the investigators working on the design of these hygrometers, three are most significant; Johann Lambert (1728-1777) (who later developed his famous map projections), Jean Andre Deluc and Horace-Bénédict de Saussure (1740-1799) (Feldman 1983).

There was much debate on how to construct the best hygrometer, what to use for calibration points, how to scale such devices, and even what to call the units of measure. Convention was the use of degrees for both temperature and humidity. Lambert's catgut hygrometer twisted a pointer around a disk so his instrument reported 0 to 360 degrees. Saussure's unit used carefully prepared hairs, scaled from 0 to 100 degrees. Both Lambert and Saussure used a chamber containing drying salts for the low humidity and a container with wet cloths for the maximum. Deluc's device of whalebone and mercury was also scaled with dry salts for 0, but achieved the maximum value of 100 by completely immersing the instrument in water. Thus Deluc's hygrometer produced a maximum saturation value air of only about 80 degrees (Feldman 1983). These three scientists devoted considerable time and effort to their designs and in trying (unsuccessfully) to relate the readings from their hygrometers to quantifiable water vapor values. "Humidity", which could be subjectively felt, measured and intuitively understood, resisted being correlated to actual measurements of water in the air.

d. Operational observations: what should be recorded?

Although the state of instrumentation at this time was becoming relatively mature, exactly what hygrometers actually measured and how to read them was still somewhat ill defined. So observers in the field tried to record everything. For instance, in 1799 Alexander von Humbolt, on his famous 5 year ocean expeditions, collected air temperature and air moisture data from two state of the art hygrometers, one made by Deluc and the other made by Horace-Bénédict Saussure (Humbolt 1799). For example: "June 9, 1799. temp of the air, 15 degrees; Hygrometer at noon, 47 deg Deluc, (83.5 Saussure)" (Humbolt 1799).

But more moisture details were recorded. Earlier empirical work by James Dalton (1766-1844) and equations developed by Pierre-Simon La Place (1749-1827), allowed the conversion of temperature and humidity data to additional values. Humbolt's logbooks show tables for "quantity of vapor contained in the air to a) saturation and to b) reality" (Humbolt 1799). In other words, Humbolt recorded derived values of saturation vapor pressure and actual vapor pressure. Thus the working concept of the air and its moisture still had the air "containing" moisture and having a "saturation" point. Additional log comments were made by Humbolt about the ratio of the "reality" values to the "saturation" values but the concept of "relative humidity" was not yet in common use (Humbolt 1799).

e) The scientific dictionary: the state of knowledge

In 1795 Charles Hutton (1773-1823) published "A Mathematical and Philosophical Dictionary" (Hutton 1795). This was very similar to our contemporary Van Nostrum Scientific Dictionary. Although by the end of the 18th century how water vapor was produced and what it did in the air once it evaporated was still being hotly debated, Hutton apparently felt that certain concepts were well accepted. In Hutton's Dictionary, evaporation, condensation, other forms of water vapor activity and its measurements were explained to the reader by the concept of the air's capacity for holding water vapor and the phenomenon of saturation (Hutton 1795). These two concepts continued to be passed forward to today and still appear to be guiding our thinking, in spite of modern advances in physics and chemistry.

g) Advances in understanding vapor pressure concepts

Advances in understanding water vapor processes in the 1700's ends with what seems to be a well accepted concept involving the idea of saturation. Since then, concepts of partial pressures developed by Dalton in 1801, and concepts of kinetic theory advanced by James Maxwell (1831-1879) and others, have been progressively added to our textbooks. Based on these improved concepts we would expect our educational material to have advanced accordingly.

What progress do we actually find? Mid 1800 and early 1900 science textbooks still teach the "holding capacity" and "saturation" concept. Entry level science textbooks in the mid 1900's did start presenting Dalton's Law of Partial Pressure and concepts of molecular kinetic theory. But close by in the same textbook, we still find explanations of the air's holding capacity and the use of the word "saturation". Later period textbooks discussed molecules evaporating and condensing to produce equilibrium vapor pressure but again went on to explain that at equilibrium, the air is saturated. The use of this word saturation has no meaning other than to convey the idea that something has a limit that cannot be exceeded.

h) Vapor pressure: the traditional vs. the conceptually correct model

The traditional explanation for vapor pressure starts with the image of an open container of some volatile liquid. A tight cover is placed on this container and the pressure of the airspace monitored. The pressure of the airspace will increase due to the evaporating liquid but will, after a time, reach some maximum value. This pressure increase (whether we start with a vacuum above the liquid or ambient air) is called the vapor pressure of the liquid and is said to be specific for that liquid and that temperature. The traditional explanation ends at this point, telling us that the pressure stops increasing because the evaporation of the liquid has stopped; the air space can only hold so much of the liquid's vapor and is thus saturated.

Chemistry textbooks near the start of the 1900's did not differ much from physics books in their presentation of vapor pressure. However, in the middle 1960's, many chemistry textbooks started adopting a different approach. The concept was called Dynamic Equilibrium. The following explanation is typical for college level introductory chemistry books from about 1966 (Brescia, Arents, Meislich and Turk 1970; Sienko and Plane 1966; Silberberg 2003).

Molecules in a liquid possess a temperature and therefore possess also kinetic energy. But the velocity representing this kinetic energy is not a single value for a constant temperature liquid. There is a wide distribution of velocities, similar to the distribution of velocities in a gas (illustrated by a Maxwell-Boltzmann (MB) velocity distribution). At any moment in time, the random thermal motion of all the other molecules in the liquid will result in some with very low energies and others with very large energies.

A unique characteristic of liquids is what keeps them in a container; the surface tension created by those molecules at the surface. At any moment in time, there will be some molecules that will have acquired enough kinetic energy to break through the surface tension energy barrier. These molecules will become vapor, joining others whose statistical fate has allowed them to escape earlier. Given enough time, all the liquid molecules in the container will have acquired sufficient energy, escaping through the surface. The liquid will have completely evaporated.

However, if a lid is placed on this container the vapor molecules, instead of escaping completely, will be confined to the enclosed space above the liquid, resulting in an increase in the vapor pressure. This increase would continue indefinitely if it were not for the fact that some of the molecules already in the vapor state will, by chance, contact the surface of the liquid. If they happened to be slow enough (low end of the MB curve) they will be trapped by the liquid's surface tension energy barrier. They will have condensed.

At some point in time, the number of liquid molecules continually escaping (evaporating) will be balanced by the number of vapor molecules continuously striking the liquid surface (and maybe condensing). The measured vapor pressure will reach some constant value due to the total number of molecules in the vapor state and their kinetic energy (i.e. temperature).

We could say that the resultant vapor pressure is an equilibrium vapor pressure. That would be inadequate and misleading, though, as many equilibrium states are thought of as being static. And a static equilibrium vapor pressure is easily misinterpreted as a "saturation" vapor pressure. The equilibrium resulting from this system is a *dynamic equilibrium* and the vapor pressure is a d*ynamic equilibrium vapor pressure (DEVP)*.

If the temperature of the liquid should increase, the evaporation rate will increase as will the vapor pressure. As the vapor pressure increases, the number of gas molecules striking the liquid surface will increase and some will condense. At some point in time a new DEVP will be reached.

It should be apparent from the above description that the vapor presure of any volatile liquid is not due to some capacity of the air space to "hold" that vapor. As an example, two small containers of different volatile liquids could be placed inside of one covered jar. Each liquid would produce its own DEVP and would add to the total pressure. The DEVP is the **result** of a condition of dynamic equilibrium between molecules of that particular liquid evaporating and molecules of that particular liquid's vapor condensing.

Relative humidity is, thus, not the ratio of the amount of water in the air compared to the maximum amount of water the air can hold. Relative humidity is the ratio of the ambient partial pressure of water, to a number represented by the *dynamic equilibrium vapor pressure* produced by a *plane surface of pure water*. Air has virtually no role.

f. Textbooks from 1800's through today: Saturation in spite of progress

How has this concept of vapor pressure and saturation been presented in textbooks? A survey of physics textbooks from 1892 to the present, meteorology textbooks from 1859 to the present, and chemistry textbooks from 1899 to mid 1960 show the idea of the holding capacity of the air and that of saturation to be a very persistent concept. For example:

1) Physics

"A given space, -for example, a cubic foot (it matters little whether there is air in the space or whether it is a vacuum), can only hold a limited amount of water vapor. When a space contains such an amount of water vapor that its temperature cannot be lowered without some of the water being precipitated in the form of liquid, the vapor is said to be *saturated*." (Gage 1892)

"If the concentration of water vapor, or the absolute humidity, is such that the partial pressure equals the vapor pressure, the vapor is *saturated*." (Sears, Zemansky and Young 1980)

"If the partial pressure of water vapor in the air is kept constant as the air is cooled, a temperature is reached, called the dew point, at which the partial pressure and vapor pressure coincide and the vapor is called saturated." (Young 1992).

2) Meteorology

"This peculiarity in the constitution of the atmosphere is termed the *capacity of the air for moisture*, and when the intervals [between the particles of air] are full of vapor, it is said to be *saturated*." (Brocklesby 1859).

"*Warm air can hold more water vapor molecules before becoming saturated than can cold air*. (This concept is very important. We will use it throughout this book)." (Ahrens 1991)

3) Chemistry

"At any given temperature the air cannot hold more a certain quantity [of water vapor]. When it contains this quantity it is said to be *saturated*." (Remsen 1899)

"The atmosphere now holds the maximum amount of vapor it can *at a given temperature*. The atmosphere is said to be *saturated*." (Choppin and Jaffe 1965).

The types of ideas depicted by these quotes, such as holding capacity of the air and saturation, form the basis of what we consider misconceptions of relative humidity.

3. Developing the relative humidity survey

During the summer of 2005 three meteorologists associated with the National Severe Storms Laboratory (NSSL) and one physical science educator from Arkansas Tech University decided to collaborate on the development of a relative humidity survey to detect misconceptions among college students. This initiative started because of the meteorologists' observation that most science textbooks either defined relative humidity incorrectly or applied the concept incorrectly. As a consequence, we hypothesized that college students, including meteorology majors, shared common misconceptions about relative humidity.

After two meetings to discuss the concept of relative humidity and some of the misconceptions students might have, the first draft of the multiple-choice survey was developed by modeling the strategy used in the creation of the Force Concept Inventory or FCI (Halloun and Hestenes, 1985; Hestenes, Well, and Swackhammer, 1992). Specifically:

- The survey used forced choices in all items. The commonly used "all of the above" and "none of the above" distractors were avoided to make students choose the option they thought was the best. When students are often not sure about an item, they will tend to choose "all of the above" and "none of the above" more often than other distractors.

- The authors did their best to integrate the three explanatory paradigms of relative humidity (solution and dynamic equilibrium) on the alternatives to assure that most distractors looked plausible to most students.
- The authors carefully designed the distractors with intuitive but incorrect information, as well as known misconceptions to assure that the distractors looked plausible to most students.
- Some misconceptions were probed using more than one question type (multiple choice and graphical question, for example).

Some of the misconceptions about relative humidity emphasized by the survey were:

- Air has a role in evaporation and the retention of water vapor.
- Evaporation and condensation are mutually exclusive processes.
- Air has a limited water holding capacity.
- Temperature is not related to evaporation, condensation, and dew point.
- Relative humidity values of less than 100% imply no condensation.
- Relative humidity values of 100% or higher imply no evaporation.
- Relative humidity values higher than 100% are impossible.
- Moist air is heavier/denser/stickier than dry air.

Once the final draft was completed, its preliminary validity had to be assessed, as described in the following section.

4. Validating the relative humidity survey

In educational research, validity is defined as the degree to which test scores are *both* relevant and reliable (Cangelosi 1982). Scores are relevant to the same degree that they provide information that is pertinent to the inferences that are to be made from them (Thorndike 1997). On the other hand, scores are reliable to the degree that they can be depended upon to yield the same result (S_o) when used repeatedly to measure a constant true score (S_t; Cangelosi 1982). Preliminary analysis of both traits follows.

a. Validity

To ensure internal validity (the extent to which results can be interpreted accurately) and external validity (the extent to which results can be generalized), several strategies were followed. First, the authors reached a consensus about the face validity of each of the items, that is, whether the survey items looked like good items for the purpose at hand.

Second, the survey was offered to 15 junior and senior college students participating at the summer 2005 National Weather Center's Research Experience for Undergraduates Program (REU; one of our target populations;

Zaras 2005). Most of the students were meteorology and earth science majors, with one student each representing the fields of physics, mathematics, computer sciences, engineering, and geography. This group was selected to answer the survey because of their knowledge of weather and their availability. After completing the survey, students offered their feedback, specifically the rationale behind the selection or non-selection of alternatives. Based on their recommendations, which included rewording of some items, using simpler words whenever possible, and removing seemingly obvious distractors, additional changes were made to the survey. Interestingly, the REU students expressed their feelings of frustration and inadequacy for not knowing the correct answers. They were informed that the survey was engineered to detect misconceptions. Having a low score on the survey only meant that traditional instruction (compounded by instructors who may have taught relative humidity under the solution paradigm) may have not been the most effective way to challenge long-held science views. The students' response appeared to be consistent with results from undergraduate physics majors after they took the FCI.

Third, a week later, two senior high school students who were working as interns at the NSSL agreed to take the survey and discuss the results, especially why they choose or ignored alternatives. These students were selected because of their availability and because they resembled the non-meteorology major target population. These students pointed out that they had a very vague idea of the concept of relative humidity, probably from school or television. Overall, these students did not perform as well as the REU students, but they showed some of the same misconceptions. Their feedback was also used to modify the wording of some of the items. Although we believe that survey questions generally represent the content we are testing (misconceptions of relative humidity), the poorer scores of high school students indicate that the survey may lack content validity for this group. In this case, the scientific terminology used may interfere with the assessment of their knowledge of relative humidity.

The current version of the Relative Humidity Survey is located in Appendix A. Note that the first five items gather information about student education level and exposure to the concept of relative humidity and therefore have no correct answer. Items 6 through 20 measure student knowledge of relative humidity and related concepts and have one correct answer. The last item (20) differs from the other items in that it is short answer rather than multiple-choice. In the section below, reliability, the second condition necessary for validity, is determined for only items 6 through 19.

b. Reliability

To assess reliability, the first step was to give the survey to four different classes at the University of Oklahoma (OU). During the first few days of the 2005 fall semester, 91 non-meteorology majors who were enrolled in introductory courses at the University of Oklahoma took the Relative Humidity Survey (48 students in "Severe and Unusual Weather" and 43 students in "Weather and Climate"). Additionally, the survey was administered to 24 junior and 47 senior meteorology majors. Owing to time constraints and concerns about changes in student knowledge as the semester progressed, the survey was administered only once to each group. Therefore, it was necessary to choose a statistical method that measures internal consistency from one measurement of each group.

There are several methods available for measuring reliability, including odd-even method, Spearman-Brown Formula, and Kuder-Richardson coefficients, and two-part alpha coefficient ($r_{2\alpha}$), to name a few (Cangelosi 1982). The second step was to choose the formula most appropriate for our survey. Because the survey was relatively short and the two halves of the test (odd and even) likely did not meet the assumption of classically parallel halves required by the Spearman-Brown Formula (Charter 2001), we decided to employ the two-part alpha coefficient.

The $r_{2\alpha}$ was computed for the 2 non-meteorology major groups, the 24 junior meteorology majors, and the 47 senior meteorology majors. According to Cangelosi (1982), ideal values of $r_{2\alpha}$ are 0.80 and higher, whereas the cut-off value is 0.65. Interestingly, for both sets of non-meteorology major scores, $r_{2\alpha}$ = 0.0, whereas for junior and senior scores, $r_{2\alpha}$ = 0.60. The total lack of reliability of non-meteorology major scores suggests that either survey items were too difficult, making students guess most of the answers, or the students felt a lack of incentive for performing well. Mean scores for non-majors, 3.4 and 3.6, support the idea that guessing was the primary cause of the lack of reliability (Crocker and Algina 1986).

The higher $r_{2\alpha}$ associated with meteorology majors' scores suggests that the survey is more reliable for majors than non-majors. The higher score for meteorology majors (0.60 vs 0.0) is likely due to a substantial decrease in guessing and a greater desire to perform well. Because the score was just below the cut-off, the authors decided to assess the impact of sample size on $r_{2\alpha}$. A t-test revealed that the sample means (juniors=5.25 and seniors=5.89) were not significantly different at the 99% confidence level. The merging of samples from both classes resulted in a new $r_{2\alpha}$ (0.71) that surpassed the cut-off value (0.65) and showed that the lower initial $r_{2\alpha}$ (0.60) was due, at least in part, to small sample size. Given this positive result, we believe that the survey is a viable first measurement of relative humidity misconceptions that, with further adjustment, will become a valid tool for use by teachers in other meteorology departments.

The next steps in the validation process include reassessing the survey items to help improve relevance and reliability and running a factor analysis, a commonly used technique to quantitatively validate the survey. It is expected that the findings from these statistical analyses will be reported shortly.

4. **Summary**

This paper addresses a misconception in the science of meteorology called relative humidity. The crux of the misconception is that air has the capacity to “hold” water vapor; that at some point it reaches saturation. The misinterpretation, in this same form, can be traced all the way back to the mid-

1700's. In spite of advances in physics and development of the correct concept of vapor pressure and thus relative humidity, the naive understanding prevails in both physics and meteorology textbooks. As a result, we hypothesize that college students, including meteorology majors, base their understanding of the concept of relative humidity and its implications from the perspective of the incorrect solution paradigm. In order to quantify the magnitude of the problem, the Relative Humidity Survey was designed and is in the process of validation.

To date, the survey has been administered to four classes at the University of Oklahoma, including two classes for non-meteorology majors (N=91) and two classes for meteorology majors (N=71). The reliability of student scores was computed using the 2-part alpha coefficient ($r_{2\alpha}$). Results show that the survey meets the reliability threshold ($r_{2\alpha}$=0.65) for meteorology majors only ($r_{2\alpha}$=0.71). Therefore, subsequent iterations and validation of the survey will first focus on meteorology majors. As more research in this area unfolds, more information will be discovered about the details of these misconceptions and, more importantly, potential content-specific teaching strategies can be developed to challenge it.

Acknowledgments

Funding was provided by NOAA/Office of Oceanic and Atmospheric Research under NOAA-University of Oklahoma Cooperative Agreement #NA17RJ1227, U.S. Department of Commerce. The statements, findings, conclusions, and recommendations are those of the auhor(s) and do not necessarily reflect the views of NOAA or the Department of Commerce.

References

Ahrens, C. D., 1991: *Meteorology Today, An Introduction to Weather, Climate, and the Environment*. West Publishing Company. 576 pp.

Anderson, C. A., and J. J. Lindsay, 1998: The Development, Perseverance and Change of Naïve Theories. *Social Cognition*, **16**, 8–30.

Barnes, J., 1984. The complete works of Aristotle: The revised Oxford translation. Princeton, NJ: Princeton University Press.

Brocklesby, J., 1859: Elements of Meteorology with Questions and Examinations for Schools and Academies, New York: Pratt, Oakley & Company. 268 pp.

Cangelosi, J. S., 1982: *Measurement and Evaluation*. Wm. C. Brown Company Publishere, 421 pp.

Charter, R. A., 2001: It is time to bury the Spearman-Brown "Prophecy" Formula for some common applications. *Educational and Psychological Measurement*, **61**, 690–696.

Chinn, C. A., and W. F. Brewer, 1993: The Role of Anomalous Data in Knowledge Acquisition: A Theoretical Framework and Implications for Science Instruction. *Review of Educational Research. Spring*, **63**, 1–49.

Choppin, G.R., and B. Jaffe, 1965: *Chemistry: Science of Matter, Energy, and Change*. Silver Burdett Company, New Jersey. 724 pp.

Clement, J., 1993: Using bridging analogies and anchoring intuitions to deal with students' preconceptions in physics. *Journal of Research in Science Teaching*, **30**, 1241–1257.

Clement, J., 1982: Students' preconceptions in introductory mechanics. *American Journal of Physics*, **50**, 66–71.

Crocker, L., and J. Algina, 1986: *Introduction to classical and modern test theory*. Holt, Rinehart, and Winston. 520 pp.

Dykstra, D. I., C. F. Boyle and I. A. Monarch, 1992: Studying conceptual change in learning physics. *Science Education*, **76**, 615–652.

Feldman, T. S., 1983: The History of Meteorology 1750-1800: A Study in the Quantification of Experimental Physics. Ph.D. dissertation, University of California, Berkeley. 284 pp.

Fraser, A. B., 2005: Bad meteorology.Electronic document available at http://www.ems.psu.edu/~fraser/BadMeteorology.html.

Frisinger, H. H., 1977: The history of meteorology to 1800. New York, NY: American Meteorological Society (Science History Publications). 148 pp.

Gage, A.P., 1892: *Introduction to Physical Science*. Ginn & Company, Boston. 352 pp.

Gonzalez-Espada, W. J., 2002: A last chance for getting it right: Addressing alternative conceptions in the physical sciences. *The Physics Teacher*, **41**, 36–38.

Hutton, C., 1795: *A Mathematical and Philosophical Dictionary*. Electronic Document available at: http://141.14.236.86/cgi-bin/archim/dict/hw?step=list&id=d006&max=50

Halloun, I., and D. Hestenes, 1985: The initial knowledge state of college physics students. *American Journal of Physics*, **53**, 1043–1055.

Henriquez, L., 2000: *Children's misconceptions about weather: A review of the literature*. Paper presented at the annual meeting of the National Association of Research in Science Teaching, New Orleans, LA.

Hestenes, D., M. Wells, and G. Swackhammer, 1992: Force concept inventory. *The Physics Teacher*, **30**, 141–158.

Humbolt, von, A., and A. Bonpland, 1966: *Personal Narrative of Travels to the Equinoctial Regions of the New Continent during the years 1799-1804*. Written in French by Alexander de Humbolt and translated by Helen Maria Williams. AMS Press Inc, New York.

Middleton, W.K.E., 1965: "*A History of the Theories of Rain and Other Forms of Precipitation*". Oldbourne,Book Co. LTD. London. 223 pp.

Middleton, W.K.E., 1969: "*The Invention of Meteorological Instruments*". Johns Hopkins Press. Baltimore. 362 pp.

National Research Council, 1997: Science teaching reconsidered: A *handbook*. Washington, DC: National Academy Press. 88 pp.

Newton, I., 1730/1952: Opticks or A treatise of the reflections, refractions, inflections and colors of light. New York, NY: Dover Publications.

Philips, W., 1991: Earth science misconceptions. *Science Teacher,* **58**, 21–23.

Remsen, I., 1899: *An Introduction to the Study of Chemistry*. 5th edition revised. Henry Holt and Company, New York. 435 pp.

Resnick, L.B., 1983: Mathematics and Science Learning: A New Conception. *Science*, **220**, 477–478.

Sears, F.W., M.W. Zemansky and H.D.Young, 1980: *University Physics*. 5TH Edition. Addison-Welsey Publishing Company. 405 pp.

Thorndike, R. M., 1997: Measurement and evaluation in psychology and education, 6th ed. Upper Saddle River, NJ: Merrill.

Todaro, R. M., 2003: *Bad weather: Misconceptions and myths revealed*. New York, NY: John Wiley & Sons.

Wandersee, J. H., J. J. Mintzes, and J. D. Novak, 1995: Research on alternative conceptions in science. In D. L. Gabel (ed.), *Handbook of research on science teaching and learning.* Macmillan.

Young, H. D., 1992. *University Physics*, 8th edition. Addison-Wesley Publishing Company. 1132 pp.

Zaras, D. S., 2005: Activities, Findings, and Recent Developments of the National Weather Center Research Experiences for Undergraduates Program. Preprints, *14th Symposium on Education*, San Diego, Calif., American Meteorological Society, CD-ROM, 2.3.

Appendix A: Relative Humidity Survey

Instructions: Read each item carefully. Choose the best answer for each question.

*1. What is your college rank status?

a. Freshman (0 or 1 semesters completed)
b. Sophomore (2 or 3 semesters completed)
c. Junior (4 or 5 semesters completed)
d. Senior (6 or more semesters completed)

*2. Why are you taking the course METR 1014?

a. Required for my science major
b. Required for my non-science major
c. Elective course (science major)
d. Elective course (non-science major)

*3. At what grade level did you recall first learning about the concept of relative humidity?
a. Lower elementary (K–2nd grades)
b. Upper elementary (3rd – 5th grades)
c. Middle school (6th – 8th grades)
d. High school (9th – 12th grades)
e. College

*4. From what source have you predominantly **heard** about relative humidity?
a. Teachers
b. Radio
c. TV
d. Family
e. Others (Boy or Girl Scouts, friends, mentors)

*5. From what source have you predominantly **read** about relative humidity?
a. School materials (textbooks)
b. Newspaper
c. Magazines
d. Internet
e. Books

6. The range of the relative humidity scales is:
a. 0 to 100
b. 0 to 50
c. 50 to 100
d. -100 to 100
e. 0 to 212

7. What is the role of air in evaporation?
a. Air has a certain amount of space into which water molecules can evaporate.
b. Air molecules collide with water molecules, keeping them floating.
c. Air has no role in evaporation.
d. Air molecules exert an attractive force on liquid water molecules and pull them into gas.
e. Air molecules attach themselves to water molecules in the air.

8. After it rains, puddles of water can be seen on a concrete sidewalk. A few hours later, most of the water is gone.
What is the best explanation?
a. Water molecules escaped the liquid form and went into the air.
b. The air absorbs water molecules from the liquid state.
c. Water molecules already in the air stay as an invisible gas.
d. The Sun boiled the water, changing it into water vapor
e. There are more water molecules escaping the liquid form than water molecules going back into it.

9. When condensation forms on a glass of iced tea:
a. all water molecules in the air return from the gas state to the liquid state.
b. there are more water molecules going from gas to liquid than molecules going from liquid to gas.
c. the air squeezes water molecules out of the atmosphere until most of the water is gone.
d. the air has exceeded its capacity to hold water and excess water condenses out.
e. the air has just reached its capacity to hold water.

10. Out of a lake, 60 liters of water are evaporated per hour at an **air temperature** of 80ºF (no wind). Which of the
following is correct?
a. If the air temperature increases, the amount of evaporated water per hour will stay the same
b. If the air temperature increases, less water will evaporate per hour
c. If the air temperature increases, more water will evaporate per hour
d. If the air temperature decreases, then no evaporation will be occurring
e. If the air temperature remains at a constant 80ºF, then no condensation will occur

11. Out of a lake, 40 liters of water are evaporated per hour if the **water temperature** is 65ºF (no wind). Which of the following is correct?

a. If the water temperature increases, more water will evaporate per hour.
b. If the water temperature increases, the amount of evaporated water per hour will stay the same.
c. If the water temperature increases, less water will evaporate per hour.
d. If the water temperature decreases, then no evaporation will be occurring
e. If the water temperature remains at a constant 65ºF, then no condensation will occur

12. Out of a lake, 20 liters of water are evaporated per hour if the wind is 20–25 miles/hour. (no change in water or air temperature). Which of the following is correct?

a. If the wind remains at a constant 20–25 miles/hour, then no evaporation will occur
b. If the wind remains at a constant 20–25 miles/hour, then no condensation will occur
c. If the wind increases, the amount of evaporated water per hour will stay the same.
d. If the wind increases, less water will evaporate per hour.
e. If the wind increases, more water will evaporate per hour.

13. What is the dew point?

a. Temperature at which the air is saturated and cannot hold more water vapor.
b. Temperature at which the liquid water starts releasing water particles.
c. Temperature at which the air starts releasing water particles.
d. Temperature at which clouds and dew forms.
e. Temperature at which an equal number of water molecules are evaporating and condensing.

14. What do you think is the best definition of relative humidity?

a. The ratio between the amount of water vapor in the air and the maximum amount it can hold at a certain temperature and pressure.
b. The ratio between the amount of liquid water in the air and the maximum amount it can hold at a certain temperature and pressure.
c. The ratio of vapor pressure to equilibrium vapor pressure over a plain water surface at a certain temperature and pressure.
d. The volume of water vapor absorbed by the air at a certain temperature and pressure.
e. The probability that water vapor will condense at a certain temperature and pressure.

15. For what do weather forecasters use relative humidity?

a. To directly tell them how much moisture is in the air.
b. To calculate how much moisture is in the air
c. To estimate what is the probability of rain (If the relative humidity is 30%, the probability of rain is 30%).
d. To know how close the air is to its water-holding capacity limit.
e. To know the correct temperature on a hot and muggy day.

16. What does a relative humidity of less than 100% mean to you?

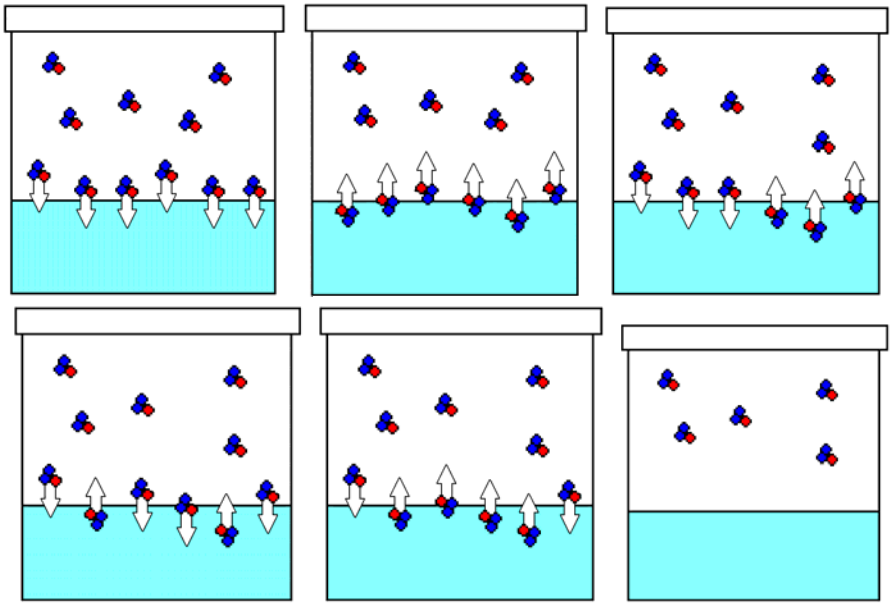
a. The air is not saturated with water vapor.
b. There is equilibrium between evaporation and condensation.
c. There is less evaporation than condensation occurring.
d. There is more evaporation than condensation going on.
e. There is no condensation occurring.

17. Is it possible to have relative humidity values higher than 100%?

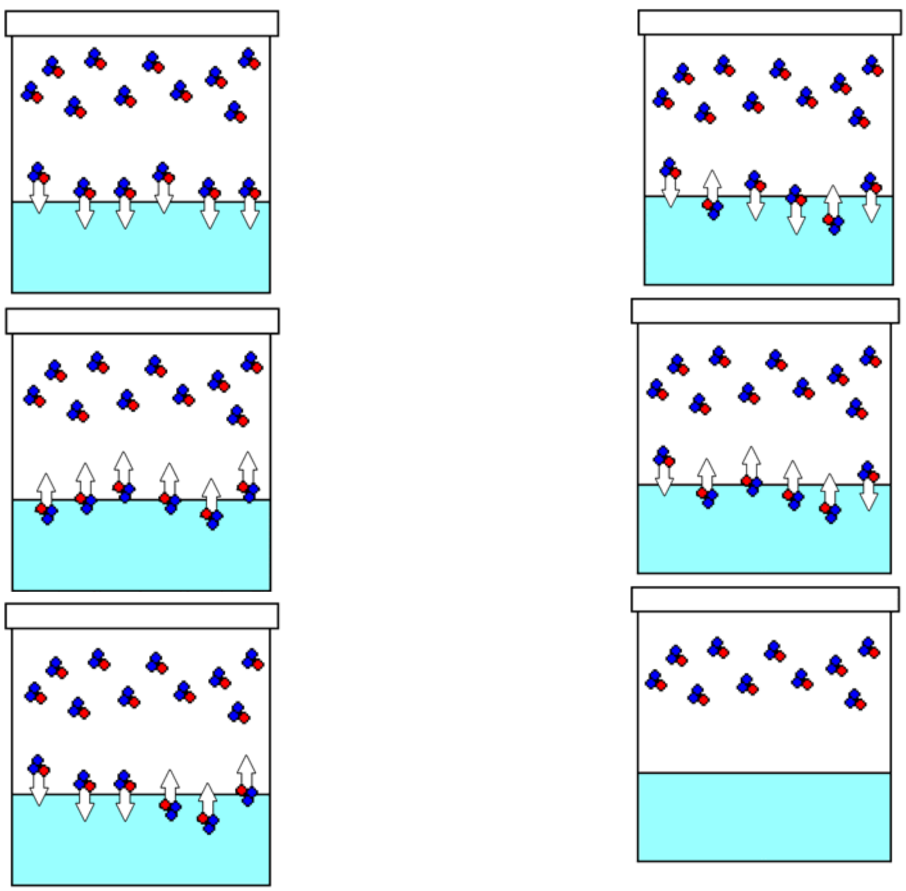
a. Yes, if the day is cold enough.
b. Yes, if the atmospheric conditions are just right.
c. Yes, if the day is warm enough.
d. No, the air cannot be oversaturated.
e. No, the equilibrium vapor pressure is a constant that cannot be exceeded.

A closed plastic container is about ⅓ full with water. In the diagram  **means water molecules condensing,**  **means water molecules are evaporating, and**  **means water vapor.**

18. Circle the diagram that best represents the behavior of water molecules if the relative humidity is 50%.



19. Circle the diagram that best represents the behavior of water molecules (in red and blue) if the relative humidity is 100%.



20. Short answer question: What is relative humidity in your own words?

Thank you for your participation!

* Items 1-5 have no unique correct answer and were included in the survey for descriptive purposes. They will not be subjected to factor analysis.

Answer key: 6-a, 7-c, 8-e, 9-b, 10-a, 11-a, 12-e, 13-e, 14-c, 15-b, 16-d, 17-b, 18-second (bottom row), 19-(third (top row), 20- The ratio of vapor pressure to equilibrium vapor pressure over a plain, still surface of pure water at a certain temperature and pressure.