Characterizing the Growth of Spatial Thinking Abilities Across Meteorology Courses

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Abstract

Spatial thinking describes how we find meaning in the shape, size, orientation, or relative position of one or more objects, processes, or phenomena. In the field of meteorology, the application of spatial thinking is critical for accurately interpreting, understanding, and predicting the four-dimensional atmosphere; tasks requiring spatial thinking skills are prevalent throughout the meteorology major, indicating that such skills are essential to student success. Spatial thinking abilities are known to be malleable, generally increasing with practice. However, the extent to which the current meteorology curriculum promotes continued growth in spatial thinking skills is unknown. Thus, the central purpose of this study is to measure spatial thinking abilities in students across the meteorology curriculum and identify any relevant factors at the individual, course, or curriculum level that influences the level of those abilities. Importantly, some courses may contribute to greater enhancement in spatial thinking abilities than others, so determining where additional, targeted training should be included will be an important outcome leading to enhanced student success.

Spatial thinking skills will be measured using the Spatial Thinking Abilities Test (STAT). This exam will be administered to students enrolled in required meteorology courses at the start and end of a course to determine course-level gains in spatial thinking. STAT scores will also be correlated to course performance, as well as other demographic factors. Statistical comparisons will be made among different classes (e.g., freshman vs. senior courses) to further characterize overall progression in spatial thinking abilities as students advance through the meteorology curriculum.

SoTL Budget Request Page
January 15, 2022 to June 30, 2023

BUDGET: *Request by budget category. Joint proposers must select one PI to be the lead and one department to receive this allocation.*

Lead Principal Investigator: _Casey Davenport__________

Principal Investigator 800#: _800881746__________________

Title of Project: _Characterizing the Growth of Spatial Thinking Abilities Across Meteorology Courses_____

Allocate operating budget to Department of: _____Geography and Earth Sciences__________

Fiscal Year One (January 15, 2022 to June 30, 2022)		
Faculty Stipend	Paid directly from Academic Affairs fund on May 15, 2022	$3850
911250	Graduate Student Salaries	$3360
911300	Special Pay to Faculty other than Grantee	
915000	Student (Undergraduate or Graduate) Temporary Wages	
915900	Non-student Temporary Wages	
920000	Honorarium (Individual(s) not with UNCC)	
921160	Subject Incentive Fee	
925000	Domestic Travel	
926000	Foreign Travel	
928000	Communication and/or Printing	
930000	Supplies	

942000	Computing Equipment	
944000	Educational Equipment	
951000	Other Contracted Services	
	Year One Subtotal	$7210
Fiscal Year Two (July 1, 2022 to May 30, 2023)		
Faculty Stipend	Paid directly from Academic Affairs fund on May 15, 2023	
911250	Graduate Student Salaries	$2880
911300	Special Pay to Faculty other than Grantee	
915000	Student (Undergraduate or Graduate) Temporary Wages	
915900	Non-student Temporary Wages	
920000	Honorarium (Individual(s) not with UNCC)	
921160	Subject Incentive Fee	
925000	Domestic Travel	
926000	Foreign Travel	
928000	Communication and/or Printing	
930000	Supplies	
942000	Computing Equipment	
944000	Educational Equipment	
951000	Other Contracted Services	
	Year Two Subtotal	$2880
	TOTAL FUNDS REQUESTED (Year One + Year Two)	$10090

Budget Narrative

I am requesting a $3850 faculty stipend for the summer of 2022. The summer funds will be used to cover time working on the objectives of this proposed research project and provide guidance and supervision to a graduate student (L. Decker). This student will have completed her first year of the M.S. in Earth Sciences degree by summer 2022, and will take a leading role in developing, conducting, and interpreting the data analyses. Thus, the remainder of the requested budget will be used to support L. Decker's efforts on this proposal. Funds are requested to pay L. Decker an hourly rate of $12 over a full 40-hour work week. In Year 1, $3360 is requested to cover 7 weeks of work between May 15 and June 30. Then, in Year 2, $2880 is requested to cover 6 weeks of full-time effort between July 1 and August 15.

CHARLOTTE
COLLEGE OF LIBERAL ARTS & SCIENCES

Office of the Dean

Banita W. Brown
704.687.0074
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October 19, 2021

SOTL Grants Committee
Center for Teaching and Learning
ctl@uncc.edu

Dear Committee Members:

On behalf of Dean Nancy Gutierrez in the College of Liberal Arts & Sciences, I am writing this letter in support of the SOTL proposal submitted by Dr. Casey Davenport from the Department of Geography and Earth Sciences which is entitled, "Characterizing the Growth of Spatial Thinking Abilities Across Meteorology Courses." The proposed study aims to assess how spatial thinking skills develop among students as they progress through the meteorology curriculum. I fully support this proposal since the study may result in the development of pedagogical activities and other improvements to the meteorology curriculum that will further train students on this important skill. Their increased spatial reasoning skills and better understanding of certain spatial concepts will result in furthering student success.

Sincerely,

Banita W. Brown

Banita W. Brown
Associate Dean for Academic and Student Success
College of Liberal Arts and Sciences
Associate Professor of Chemistry

Project Narrative

A. *Specific Aims*

Spatial thinking is the process of finding meaning in the shape, size, orientation, or relative position of one or more objects, processes, or phenomena (National Research Council 2006). Representing, interpreting, and predicting spatial data related to the atmosphere is at the heart of the field of meteorology. Students receive extensive training throughout their undergraduate careers in identifying and analyzing the spatial patterns of variables such as temperature, pressure, or wind; geographic maps of meteorological data at various horizontal scales and vertical levels in the atmosphere are commonplace throughout the meteorology major curriculum. Importantly, identifying relevant patterns in the data and combining that information with understanding of key atmospheric processes is foundational for forecasting the weather. Even outside of the task of forecasting, the atmosphere is inherently four-dimensional in nature (encompassing spatial and temporal dimensions), requiring spatial reasoning and mental animation to accurately understand its associated phenomena.

The ability to identify relevant aspects of spatial data and accurately combine them with a mental model varies among individuals, but can be improved with targeted training (e.g., Titus and Horsman 2009; Uttal et al. 2013). However, validated, effective meteorology-specific interventions to improve spatial thinking do not currently exist, nor has it been established *where* such interventions should be placed in a meteorology curriculum to maximize their efficacy. One reason for this is that there is limited research on the specific types of spatial skills that meteorology students use, and thus no broader framework to understand spatial reasoning in meteorology. The information we do have suggests that meteorologists use a unique combination of spatial thinking skills (differing from other related geoscience disciplines) and thus will require carefully designed trainings in the distinct contexts present in atmospheric science problems (McNeal et al. 2018; McNeal et al. 2019a, b).

To facilitate the development of such targeted pedagogical activities and related improvements to the meteorology curriculum, it is first necessary to identify the typical trajectory of gains in spatial thinking ability in meteorology students as they progress through the degree. Is it a smooth progression, with steady gains each year with more practice in applying spatial thinking? Are greater leaps in spatial thinking abilities present for specific courses? Are there courses that inadvertently contribute to *reductions* in spatial thinking ability? Is prior elective coursework in geography or other student characteristics correlated to spatial thinking ability? To address such questions, *the central purpose of this proposed study is to quantify spatial thinking abilities in students across the meteorology curriculum and identify relevant factors at the individual, course, or curriculum level that may influence the extent of spatial thinking ability.* The Spatial Thinking Ability Test (STAT; Lee and Bednarz 2012) will serve as the standardized assessment to measure spatial thinking abilities. Performance on STAT will be placed in context of individual characteristics as well as specific courses and overall progression in the meteorology program. Determining the current landscape of student gains in spatial thinking ability is an important first step in determining exactly *where* curriculum changes and improvements need to be made to enhance student success both within the program (e.g., providing better scaffolding of important skills to all meteorology students as they advance in their coursework) and in their post-graduate careers.

B. *Literature Review*

The importance of spatial thinking skills for science, technology, engineering, and math (STEM) disciplines is well-established. For example, Shea et al. (2001) conducted a 20-year longitudinal study of 563 adolescents with exceptional aptitude in mathematics. Quantitative abilities are known to be an important component for success in STEM fields (e.g., Austin and Hanisch 1990; Wai et al. 2010), but Shea et al. (2001) demonstrated that those who ultimately ended up in STEM careers initially had higher levels of spatial ability. Indeed, spatial skills are a strong predictor of selecting into and remaining in STEM majors and post-graduate STEM careers (e.g., Uttal and Cohen 2012; Uttal et al. 2013; Hegarty 2014).

One reason for the success of students in STEM with higher spatial thinking abilities is that these skills can be used to overcome limitations in content knowledge. For example, stronger spatial reasoning can allow a student to more easily identify patterns from a spatial representation of data, or enable them to mentally piece together given information more accurately (e.g., Hambrick et al. 2012). Accordingly, enhanced spatial reasoning leads to a better grasp of domain-relevant concepts once presented, further improving performance on domain-specific tasks (e.g., Hegarty 2014; McNeal et al. 2019a).

Importantly, spatial thinking skills are not fixed, and can dramatically improve for students with targeted training (e.g., Lord 1985; Gerson et al. 2001; Uttal et al. 2013). Interventions on the scale of an entire course (e.g., Sorby 2009) or even practice limited to 5 – 10 minutes a week (e.g., Titus and Horsman 2009) can lead to significant advances. Notably, targeted trainings earlier in a student's career tend to be more impactful, since novices lack broader conceptual knowledge (Uttal and Cohen 2012).

Spatial thinking encompasses the application of several different skills; the way these skills are enumerated and characterized vary substantially, however, both within and across various disciplines (Hegarty and Waller 2005; Newcombe and Shipley 2015; McNeal and Petcovic 2020). Though no coherent framework exists for spatial thinking within atmospheric science (McNeal and Petcovic 2020), a survey of meteorologists that leveraged a broad geoscience framework encompassing six spatial thinking skills (Manduca and Kastens 2012) identified three with high use: mental animation (defined as developing a plausible subsequent sequence of events based on static information), disembedding (identifying coherent patterns from a complex scene), and perspective taking (envisioning how something would appear from a different vantage point; McNeal et al. 2018). Follow-up studies have further underscored the importance of disembedding, which is a skill necessary for interpreting weather maps, a task prevalent throughout the meteorology curriculum (McNeal et al. 2019a, b). These findings indicate some overlap in key spatial thinking skills used by solid and fluid Earth scientists; however, the lack of use of other geoscience-specific skills implies that this framework may be insufficient to fully characterize spatial thinking in atmospheric science. Furthermore, this framework lacks a single, validated instrument with which to measure the enumerated components of spatial thinking.

Recognizing the above challenge, McNeal and Petcovic (2020) identified seven existing frameworks that could be applied to spatial thinking in meteorology. Of particular interest in the context of the proposed study is a framework rooted in geography, which has explored the foundations of spatial thinking for decades. Lee and Bednarz (2012) outlined eight spatial thinking skills, of which there appears to be significant (though not perfect) overlap with atmospheric science (McNeal and Petcovic 2020). Importantly, this framework has a reliable, validated inventory with which spatial thinking abilities can be measured: the Spatial Thinking Abilities Test (STAT; Lee and Bednarz 2012). The STAT exam differs from other tests developed by cognitive psychologists by assessing the application of spatial thinking in more domain-specific contexts, and by providing a more *holistic* assessment of spatial thinking ability; the exam sufficiently characterizes a wide range of spatial thinking skills that have been validated and applied in numerous contexts (Lee and Bednarz 2012; Bednarz and Lee 2019).

The proposed work herein will use STAT to quantify the growth in spatial thinking abilities in meteorology students as they progress through required courses in the major curriculum. This assessment will permit identification of when significant advances in spatial reasoning occur, and where targeted interventions or other curricular modifications may be useful to promote student success.

C. *Methods*

The central task of this proposed research is to quantify the progression in spatial thinking abilities in meteorology students throughout the undergraduate major curriculum. The level of these abilities will be measured using the STAT exam, a validated measure of spatial thinking abilities consisting of 16 multiple choice questions that assess 8 different spatial thinking skills (Lee and Bednarz 2012). This test can typically be completed in 15 min or less, causing minimal disruption to classroom instruction. In this study, a subset of 12 questions will be used; the 4 discarded questions are related to one component of spatial thinking with no reasonable direct application to atmospheric science. This slightly abbreviated version of STAT will still provide a valid assessment of spatial thinking, as other studies have used slightly truncated versions (Bednarz and Lee 2019). Importantly, a portion of these questions require students to interpret maps that include meteorological data, further supporting the use of STAT in an atmospheric science context.

The meteorology major at UNC Charlotte consists of 11 different required courses, exclusive of extra-departmental prerequisites and related requirements. This study will leverage 10 of those courses: 1) METR 1102 (Introduction to Meteorology); 2) METR 3140 (Fundamentals of Meteorology); 3) METR 3210 (Atmospheric Thermodynamics); 4) METR 3220 (Physical Meteorology); 5) METR 3245 (Synoptic Meteorology); 6) METR 3250 (Dynamic Meteorology); 7) METR 4205 (Climate Dynamics); 8) METR 4245 (Advanced Synoptic Meteorology); 9) METR 4250 (Advanced Dynamic Meteorology); and 10) ESCI 3101 (Global Environmental Change). The excluded course (METR 4105, Meteorological Computer Applications) does not explicitly teach or assess spatial concepts. Furthermore, this course is taken by students in the same semester as METR 3210; thus, any gains in spatial thinking skills are likely a result of that course and not METR 4105.

STAT will be administered to students enrolled in 10 required meteorology courses at the beginning and end of a given semester throughout this study (Spring 2022, Fall 2022, and Spring 2023). This pre- and post-test assessment is designed to identify course-level gains in spatial thinking skills; presumably, improvements will occur as a result of instruction and the heavy involvement of spatial thinking needed to understand and apply meteorological content in each of these courses. The concurrent administration of STAT in several courses allows for comparisons based on progression in the meteorology major (e.g., METR 1102 for freshmen majors versus METR 4250 for senior majors). Furthermore, the continuous administration over 3 consecutive semesters will reveal the trajectory of gains in spatial thinking abilities as cohorts of graduating classes progress through the major curriculum (e.g., changes from freshman to sophomore year). Required courses taught in spring semesters will be tested twice to assess the progression in spatial thinking skills in a single academic year (i.e., no gap in practice of skills over a summer), and also to enable comparison among different cohorts of students in the same course, providing context for how much year-to-year variability might exist, and whether such variability is greater than course-level gains.

It should be noted that a few of the required courses (METR 1102, METR 3140, and ESCI 3101) enroll non-majors as well, as they fulfill requirements for general education or other related majors. While these non-meteorology major students are not the primary target of this study (i.e., their trajectory in spatial thinking skills will not be measured), their STAT scores will nevertheless provide useful information regarding the impact of meteorology instruction on spatial thinking abilities. For example, does instruction in METR 1102 provide the same level of gains in spatial thinking skills for meteorology majors as for non-majors? Or, is improvement in spatial thinking heightened for non-majors who have completed a geography course previously? Such an analysis can reveal whether it may be beneficial to have meteorology students take a geography course before beginning (or elsewhere within) the major curriculum.

In addition to prior geography-related coursework, other individual student characteristics will be collected each time STAT is administered to identify other potentially influential factors. Prior research has determined that gender and major have had varying levels of influence and correlation to STAT scores (Bednarz and Lee 2019); these characteristics will also be considered in the present study.

D. *Evaluation*

Spatial thinking abilities will be quantified based on STAT scores; these scores will be grouped and evaluated in various subsets. First, and most broadly, it is expected that increasing levels of completion of meteorology coursework will result in improvements in spatial thinking abilities. Thus, for example, a curriculum-level comparison can be made between STAT scores in freshmen- (e.g., METR 1102) versus senior-level (e.g., METR 4250) courses, using information such as summary statistics (e.g., mean, median, and range of scores. The significance of any differences in the distribution of scores will be quantified via tests such as the two-sample t-test, the F test, or the Mann-Whitney U test. These tests are designed to quantify whether sample means and medians are different, and give a sense of the plausible ranges of scores for the two populations. Other similar comparisons in STAT performance among different combinations of graduating classes (e.g., freshmen vs. sophomore, sophomore vs. junior) will also be completed to characterize overall growth in spatial thinking abilities as students progress through the meteorology major.

Course-level impacts on spatial thinking skills will be evaluated primarily through statistical comparisons of pre- and post-test STAT scores. The expectation is that each course will aid in improving spatial thinking, given their application in many facets of meteorology. However, this may not always hold true; the differences from pre- to post-test may not be substantial or statistically significant. Additionally, caution will be needed in conducting and interpreting any statistical analyses for course-level changes, as many upper-level meteorology courses typically enroll only 10-20 students, providing small sample sizes for comparison. Course-level gains in spatial thinking skills will also be correlated to course performance.

Individual factors influencing spatial thinking abilities will be explored by comparing STAT performance among various demographic subsets as sample sizes allow. For example, men vs. women, 0 vs. 1+ geography courses, meteorology vs. non-meteorology majors, among others.

E. *Knowledge Dissemination*

The results of this project will be presented to the local community during UNC Charlotte's Teaching Week. Additionally, findings will be presented at the Education Conference at the American Meteorological Society Annual Meeting in 2023. The overall findings of the study will be published in the *Bulletin of the American Meteorological Society*, distributed to every member of the AMS (13,000+).

F. *Human Research Subjects*

The IRB application for this project has been submitted (IRB-22-0390) and is currently undergoing review.

G. *Extramural Funding*

The proposed project is intended to be a pilot study that will provide the foundation for a larger exploration of spatial thinking skills in meteorology students. This larger study will seek external funding from the NSF under the Education and Human Resources (EHR) Directorate, Division of Undergraduate Education. Two potential programs to be targeted include "Improving Undergraduate STEM Education" or "EHR Core," which accept new proposals every year.

H. *Timeline*

- Spring 2022
    - Administer STAT and collect demographic information
- Summer 2022
    - Perform statistical analyses to compare STAT performance at the course-level and curriculum level; subset and correlate performance based on demographics
- Fall 2022
    - Continue data collection
    - Incorporate newly-collected data into statistical analyses
- Spring 2023
    - Finish data collection
    - Incorporate newly-collected data into statistical analyses
    - Compare Spring 2022 and Spring 2023 data
    - Summative reports and presentations at UNC Charlotte and the AMS Annual Meeting

References

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