Using Worked Examples to Enhance Learning in an Upper-Level Meteorology Course

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Abstract

For many students, the atmospheric dynamics course sequence (METR 3250 and METR 4250) represents a formidable requirement for graduation, as it represents the first experience students have in explicitly integrating the principles of physics, calculus, and meteorology. The *worked examples* approach may help in this regard; its ability to improve student understanding in scientific disciplines is well-documented. Students examine sample problems that demonstrate an expert's solution, accompanied by self-explanation prompts that illuminate the reasoning behind each step. The goal is for students to construct a basic understanding of concepts and their application; in-class time solidifies key concepts and provides additional depth. Despite its successes, the pedagogy has yet to be applied in atmospheric science courses. The proposed study fills that gap by quantifying the impact of worked examples into METR 3250 and METR 4250 on student learning.

Beginning in Spring 2017, the atmospheric dynamics course sequence went from being lecture-driven (Fall 2014/2015 and Spring 2015/2016 semesters) to application-driven (via worked examples). The impact of this change on student learning will be measured by comparing scores on various assessments (quizzes, homeworks, and exams) and overall course grades. The significance of differences among these measures will be assessed through a variety of statistical tests. It is anticipated that these results will help remove some of the stigma associated with the course, giving students more confidence moving forward through the meteorology curriculum. Results will be presented to the UNC Charlotte community and the American Meteorological Society to inspire changes in other courses.

Budget Request for SOTL Grant

Year 2017-2018

Joint Proposal? _____ Yes __X__ No

Title of Project: Using Worked Examples to Enhance Learning in an Upper-Level Meteorology Course

Duration of Project: 18 months

Primary Investigator(s): Casey Davenport

Email Address(es): Casey.Davenport@uncc.edu

UNC Charlotte SOTL Grants Previously Received (please names of project, PIs, and dates): None

Allocate operating budget to Department of: Geography and Earth Sciences

		Year One
Account #	**Award**	**January to June**
Faculty Stipend	Transferred directly from Academic Affairs to Grantee on May 15	$ 3200
911250	Graduate Student Salaries	
911300	Special Pay (Faculty on UNCC payroll other than Grantee)	
915000	Student Temporary Wages	
915900	Non-student Temporary Wages	
920000	Honorarium (Individual(s) not with UNCC)	
921150	Participant Stipends	
925000	Travel - Domestic	

926000	Travel - Foreign	
928000	Communication and/or Printing	
930000	Supplies	
942000	Computing Equipment	
944000	Educational Equipment	
951000	Other Current Services	
	GRAND TOTAL	$ 3200

		Year Two
Account #	**Award**	**July to June**
Faculty Stipend	Transferred directly from Academic Affairs to Grantee on May 15	$ 0
911250	Graduate Student Salaries	
911300	Special Pay (Faculty on UNCC payroll other than Grantee)	
915000	Student Temporary Wages	
915900	Non-student Temporary Wages	
920000	Honorarium (Individual(s) not with UNCC)	
921150	Participant Stipends	
925000	Travel – Domestic	$2500
926000	Travel – Foreign	
928000	Communication and/or Printing	$3000
930000	Supplies	
942000	Computing Equipment	

944000	Educational Equipment	
951000	Other Current Services	
	GRAND TOTAL	$ 8700

Attachments:

1. Attach/provide a narrative that explains how the funds requested will be used.

   I am requesting a $3200 stipend for the summer of 2018. The summer funds will be used to perform statistical analyses on the formative and summative assessments, examine student feedback, and write up the results for publication.

   In the second year, I am requesting $3000 for publication costs associated with the *Bulletin of the American Meteorological Society*. The page charges are assessed based on the number of words and figures; I conservatively estimate a 7,000 word manuscript and 6-7 figures, approximately 11-12 printed pages. More details about page charge estimations are provided on the *BAMS* website: https://www.ametsoc.org/ams/index.cfm/publications/authors/journal-and-bams-authors/page-charges-waivers-and-fees/bams-page-charges/.

   I am requesting $2500 for costs related to submission of an abstract to the American Meteorological Society Annual Meeting in January 2019. These funds will also defray transportation costs associated with presenting the findings of this proposed research at the Education Symposium within the Annual Meeting.

2. Has funding for the project been requested from other sources? _X__ Yes ___ No. If yes, list sources.

   This proposal was originally envisioned as the education component of a National Science Foundation CAREER grant, submitted in July 2015. However, the proposal was not funded. In response to some of the reviewer comments concerning the education portion, I am submitting this proposal as a pilot study that will serve as the foundation for a future NSF submission.

Letter of Support

UNC CHARLOTTE
College of Liberal Arts & Sciences

Office of the Dean

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Banita W. Brown
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October 17, 2017

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 & Earth Sciences which is entitled, "Using Worked Examples to Enhance Learning in an Upper-Level Meteorology Course." Dr. Davenport proposes to use a pedagogy known as worked examples to impact student learning in the atmospheric dynamics courses. This particular sequence of courses is challenging for students since it integrates concepts of physics and calculus with meteorology. It is well known that both of these subjects, physics and calculus, can be very challenging for our students. The University has targeted various PHYS and MATH courses among those with high DFW rates. Thus, students in METR 3250 and subsequently, METR 4250 may not have mastered physics and mathematical principles required for success in these atmospheric science courses. Through the use of the worked examples instructional approach, students would be able to better grasp key atmospheric science concepts that are associated with physics and mathematical theories. Dr. Davenport describes appropriate formative and summative assessments and has a reasonable dissemination plan.

I fully support this proposal. It closely aligns with the college's and university's focus on student success, retention, and graduation. Furthermore, student persistence in a STEM field has become an important performance goal for this campus. This proposal presents a pedagogy that has not yet been applied in atmospheric sciences courses. But, the anticipated improvements in student performance should cause students to persist in this STEM-related field.

Sincerely,

Banita W. Brown

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

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An Equal Opportunity/Affirmative Action Employer

Project Narrative

A. *Specific Aims*

Atmospheric dynamics forms the theoretical and mathematical basis for describing cause and effect in the atmosphere; such information is foundational for developing weather forecasts, a career that the vast majority of undergraduate meteorology students desire post-graduation. However, for many students, the atmospheric dynamics course sequence represents a formidable and much maligned requirement for graduation, as the course sequence represents the first experience students have in explicitly integrating the principles of physics, calculus, and meteorology. Further complicating matters, the concepts in dynamic meteorology are at times counter-intuitive, and students struggle to interpret the mathematical representations of concepts (Persson 2010).

The fact that meteorology is an inherently visual and tactile science (i.e., weather is something we observe and experience on a daily basis) lends credence to findings demonstrating that atmospheric science students strongly prefer learning from concrete examples, rather than mathematical theory (Roebber 2005); indeed, novice learners in many subjects prefer and learn best from examples (e.g., Anderson et al. 1997). Other scientific disciplines have had great success in increasing student understanding of concepts using a pedagogy known as *worked examples* (e.g., Chi and Bassok 1989), where students are given sample problems with an expert's solution, accompanied by questions that are designed to illuminate the reasoning behind each step. Despite the successes of this approach, it has yet to be applied and tested in atmospheric science courses.

A pilot run of the worked examples pedagogy began during the Spring 2017 semester at UNC Charlotte in METR 3250: Dynamic Meteorology I, wherein class time focused on using a series of worked examples to illustrate concepts and associated mathematical theory. Student feedback at the end of the semester was overwhelmingly positive, with one representative comment stating that using worked examples "made concepts much more concise and less confusing." Whether this translates to enhanced student learning is unclear; thus, the central question of this proposed study is "*Does the worked examples approach improve student learning and student outcomes in atmospheric dynamics courses?*" Quantifying the (anticipated) positive effects of using worked examples will help to remove some of the stigma associated with the course, giving students more confidence moving forward through the remainder of the meteorology curriculum.

B. *Literature Review*

In the early stages of learning, novices often rely on, heavily prefer, and actually *learn more* through real-world examples and applications (e.g., Pirolli and Anderson 1985; Anderson et al. 1997; Cooper and Sweller 1987; Roebber 2005). However, examples that are the most effective in enhancing learning are those that guide students through *self-explanations* of concepts. These self-explanation prompts not only encourage students to critically examine the given scenario, but also help to address and correct any misunderstandings students may have. The more self-explanation a student does, the more successful they will be (Chi and Bassok 1989).

The aforementioned guided examples are otherwise known as *worked examples*, and aim to demonstrate an expert's solution to a given problem. As an instructional tool, worked examples are given as a pre-class assignment where students examine and analyze (via a series of self-explanation prompts) a problem involving an application of upcoming lesson material. The goal is for students to construct a basic understanding of concepts and how they are used; in-class time is then spent on solidifying the key concept and providing additional depth (Atkinson et al. 2000).

A key benefit of students working through guided examples is a reduction in cognitive load (Sweller and Cooper 1985). Cognitive load refers to the extent of mental effort used in working memory; novice learners often experience a high cognitive load when presented with a problem to solve, making it more difficult to recognize patterns and identify key concepts needed to solve the problem, resulting in a lower rate of success (e.g., Sweller and Cooper 1985; Ward and Sweller 1990; Yuan et al. 2006). Worked examples reduce cognitive load by highlighting (both in text and diagrams) features crucial to solving the problem, annotating figures with important values and variables, and providing an explicit schema in solving the problem (Sweller 1994).

Another important benefit of worked examples is that students are exposed to explicit demonstrations of domain-specific problem-solving strategies (e.g., Greeno 1980). Given that atmospheric dynamics is a mixture of physics, calculus, and meteorology, each with its own specific terminology and approaches to solving problems (e.g., Lucas 1974; Heller and Heller 2000; Persson 2010), it is important to have well-crafted examples that provide explicit descriptions unifying these disparate disciplines, and how they are combined to produce a final solution.

As a result of the aforementioned benefits, the worked examples instructional approach has proven to be effective in enhancing learning and problem solving skills in a variety of scientific disciplines, including mathematics (e.g., Sweller and Cooper 1985), physics (e.g., Chi and Bassok 1989), engineering (e.g., Moreno et al. 2013), chemistry (e.g., Crippen and Brooks 2009), and statistics (e.g., Paas 1992); yet, no such routinely successful pedagogical method has been implemented and its efficacy been assessed in atmospheric sciences. Further, testing of the worked examples pedagogy has largely focused on introductory-level courses; the approach is potentially less effective for upper-level courses due to the expertise reversal effect (Kalyuga et al. 2003; Kalyuga 2007). This decrease in effectiveness is linked to a higher level of prior knowledge, which makes studying a worked-out solution redundant and unnecessary. Yet, creating guidance that is scaffolded in some way (i.e., explicit steps shown early on, then gradually reducing the amount of detail) may help in this regard (e.g., Van Merriënboer and Kirschner 2012). The proposed work will address this gap by utilizing worked examples in the atmospheric dynamics course sequence: METR 3250 and METR 4250 (Advanced Dynamic Meteorology II). Importantly, the effectiveness of this approach in enhancing learning will also be assessed.

C. *Methods*

A pilot-run of implementing the worked examples pedagogy into the atmospheric dynamics course sequence began in Spring 2017 in METR 3250 and is currently being continued into the Fall 2017 semester in METR 4250. The approach is executed in the following manner. Before each class period, students are assigned to complete 1-2 worked examples as a pre-class activity; they are also expected to read through the associated textbook sections. Students are encouraged to complete the examples by assigning points for demonstrated effort in answering the self-explanation prompts. In-class time consists of a combination of activities. First, a brief (< 5 min) lecture is given, designed to reinforce the basic principles of the relevant concept(s) and get students in the appropriate frame of mind. Next, each assigned example is discussed. Each guided step is summarized, student questions are answered, and responses to the prompts are discussed. Finally, to provide additional depth and reinforce concepts, students are given in-class problem sets, consisting of both conceptual and mathematical problems. Time is given to work through the problems either individually or in small groups, and the answers to the problems are discussed by the end of class.

The central task of this proposed research is to quantify the impact that the worked examples approach has on student learning and student outcomes. This impact will primarily be measured by comparing student scores on a variety of assignments; comparisons will be made between students currently subjected to the worked examples pedagogy (in the Spring 2017 and Fall 2017 semesters) and students from previous semesters of the course where traditional lecture was employed (Fall 2014, 2015; Spring 2015, 2016). Scores from quizzes (6/semester), exams (2 midterms and a cumulative final exam), and homework assignments (8/semester) will be compared, as well as overall course grades. The content of these assessments vary somewhat, but the vast majority of questions have been consistent from year to year; additionally, the final exam in both METR 3250 and METR 4250 has remained unchanged, providing the most reliable measure for comparison.

The overall enrollment for METR 3250 and METR 4250 is small, around 7-15 students per semester. Thus, statistical analyses will be conducted and interpreted with caution. Summary statistics including mean, median, and range for individual assignments (e.g., quiz #1) and overall groups of assignments (e.g., all quiz scores) will be collected for both sets of students. It is expected that students who experienced worked examples will have higher assignment, exam, and course grades than students in the traditional lecture sections. The significance of any differences among these measures will be quantified via the two-sample t-test, the F test, the Mann-Whitney U test, and confidence intervals. These tests are designed to quantify whether the sample means and medians are different, and give a sense of the plausible ranges of scores for the two sample sets.

In addition to comparing worked example versus traditional lecture student scores, the degree of improvement from METR 3250 to METR 4250 in groups of assignments will also be assessed. By its nature, the content in METR 4250 is more difficult, and student grades tend to drop during the second semester. It is hypothesized that the worked examples pedagogy provides a firmer foundation in the basic concepts of METR 3250, allowing students to perform better in METR 4250. Thus, while the content may be more challenging, students exposed to worked examples should either experience an *increase* in assignment grades (e.g.., higher overall quiz grades) from first to second semester, or a *smaller decrease*, when compared to the traditional lecture students.

There are some potential issues and limitations associated with the proposed analysis. One concern is sharing of old course material among students, potentially enhancing student grades in subsequent semesters. However, the cumulative final exams have never been handed back to students, nor have they changed over the past few years, providing a reliable measure of student learning. Even so, another factor that needs to be considered is natural year-to-year variability in student ability. To account for this, incoming GPAs associated with meteorology course work (including meteorology, physics, and calculus courses) will be collected. GPAs will be correlated with assignment, exam, and quiz scores, along with overall course grades to determine its influence.

Students who did not complete either METR 3250 or METR 4250 will not have their scores included in the analysis. However, the number of incompletions will be used as a metric of student outcome; it is hypothesized that improvements in student performance associated with worked examples will reduce students needing to drop either course.

D. *<u>Evaluation</u>*

Evaluation of the worked examples pedagogy will be conducted using both formative and summative assessments. One method of formative assessment will include completion grades of the worked examples. Students are assigned up to 10 points per worked example based on the level of completion in responding to the self-explanation prompts and short mathematical exercises throughout the assigned example. This assessment is intended to be a measure of student "buy-in" to the worked examples approach, as it is expected that students who find the pedagogy worthwhile and helpful will put in the effort needed, particularly during the middle and end of semesters, when other assignments and due dates can compete for student attention. Trends in completion over the course of both semesters will also be examined. Student completion of the worked examples could also be a function of the overall readability of each example; the instructor collects informal feedback from students on each example to identify where additional guidance or clarity is needed to improve future iterations.

Another formative assessment to be utilized is "learning audits" collected during each semester of the course, completed by all students. Learning audits consist of 3 questions answered once per week to reflect on learning; students identify what is new that they've learned, concepts they are comfortable with and could teach to others, and concepts that they need help to understand better. The answers to these questions are collected electronically each week; while answers to each question will be useful to compare among traditional lecture and worked examples students, particular focus will be given to student responses to the last question concerning what concepts remain unclear. The degree of similarity or differences in stated areas of confusion will provide qualitative information on whether worked examples helped to better clarify certain topics than the traditional lecture approach.

The primary summative assessment will be the cumulative final exams of METR 3250 and METR 4250; their consistency provides the most trustworthy measure of student learning. Other summative assessments include exam, homework, and quiz scores, but these measures are less ideal due to some changes in content from year to year. Even so, these scores will be statistically compared between traditional lecture students and worked example students, as described in the Data and Methods section. Finally, student responses on end of semester evaluations will also be analyzed to identify themes related to use of classroom time and the perceived usefulness in helping students to learn the material.

E. *Knowledge Dissemination*

The results of this project will be presented to the local community during the UNC Charlotte Scholarship of Teaching and Learning Showcase. Additionally, findings will be presented at the 2019 American Meteorological Society Annual Meeting. 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*

This proposed project was originally envisioned as a portion of a National Science Foundation grant that was not funded; thus, the Institutional Review Board granted approval back in 2015 (IRB number 15-0537). For a number of reasons, the pilot study did not begin until the Spring 2017 semester, but the study was approved for renewal in Summer 2017.

G. *Extramural Funding*

The proposed project is intended to be a pilot study that will provide the foundation for a larger study concerning the efficacy of the worked examples pedagogy in atmospheric sciences. This larger study will seek external funding from the NSF under the Education and Human Resources Directorate, Division of Undergraduate Education. One potential program to be targeted is "Improving Undergraduate STEM Education," which has a new call for proposals every fall.

H. *Timeline*

- Spring 2018
  - Implement worked examples in METR 3250
  - Collect summative and formative assessments for each semester of Atmospheric Dynamics (including current semester); partition among traditional lecture and worked examples students
- Summer 2018
  - Perform statistical analyses to compare formative and summative assessments
  - Begin writing a manuscript summarizing the results

- Fall 2018
    - Implement worked examples in METR 4250
    - Collect additional data for current semester and incorporate statistical analyses
    - Finish writing manuscript
- Spring 2019
    - Undergo peer review and edits to manuscript
    - Summative reports and presentations at UNC Charlotte and the AMS Annual Meeting

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