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Implementing Active Learning Techniques in an Undergraduate Aviation Meteorology Course

Daniel J. Halperin
Embry-Riddle Aeronautical University, halpea17@erau.edu

Robert W. Eicher
Embry-Riddle Aeronautical University, eichefca@erau.edu

Thomas A. Guinn
Embry-Riddle Aeronautical University, guinnt@erau.edu

Joseph R. Keebler
Embry-Riddle Aeronautical University, keeblerj@erau.edu

Kim O. Chambers
Embry-Riddle Aeronautical University, chambek3@erau.edu

Introduction

While a relatively small percentage of general aviation, non-commercial fixed-wing aircraft accidents are weather related, these accidents have a disproportionately high rate of fatalities (Aircraft Owners and Pilots Association [AOPA], 2019). The most recent data, compiled for 2016, indicates that the deadliest weather-related accidents are for aircraft flying under Visual Flight Rules (VFR) that encounter Instrument Meteorological Conditions (IMC). Furthermore, “the majority of weather accidents were flown in single-engine fixed-gear aircraft” (AOPA, 2019). Blickensderfer et al. (2018, 2020) found general aviation (GA) pilots struggle to understand weather information and interpret aviation weather products. These findings highlight the need for pilots to demonstrate an understanding of the weather hazards associated with flight operations and the atmospheric conditions that are favorable for the development of such hazards. However, Lanicci et al. (2012) noted that it is possible for a person to pass a Federal Aviation Administration (FAA) knowledge test even if they answer all weather-related questions incorrectly and that weather-related training does not have to be included in a Biennial Flight Review (BFR). This suggests that educating future aviators on weather-related hazards is critical and that educators must employ teaching methods that will maximize students’ understanding and retention of weather-related information.

Background

As an institution that trains pilots with a fleet of predominantly single-engine fixed-gear aircraft, aviation weather education is emphasized at Embry-Riddle Aeronautical University’s (ERAU) Daytona Beach, Florida campus. Approximately 500 students were enrolled in 19 sections of Aviation Weather taught by five different instructors during the 2018-19 academic year. In an effort to provide a standardized experience for the students, historically, all sections were assessed using the same set of assignments and exams. The lecture materials were also standardized and were primarily PowerPoint-based.

Current Study

Student feedback from end-of-course evaluations repeatedly indicated a desire to change the format of the course by de-emphasizing the PowerPoint-based lectures. These traditional lectures can be replaced with active learning, which is broadly defined as “anything that ‘involves students in doing things and thinking about the things they are doing’” (Bonwell & Eison, 1991). For example, active learning takes place when: “students are involved in more than listening[;] less emphasis is placed on transmitting information and more on developing students skills[;] students are involved in higher-order thinking (analysis, synthesis, evaluation)[; and,] students are engaged in activities” (Bonwell & Eison, 1991). Recent pedagogical research has shown the benefits of incorporating active-learning techniques in the classroom, particularly for STEM fields (e.g., Freeman et al., 2014; Harrington & Zakrajsek, 2017). Including active-learning techniques in the classroom could serve the dual purposes of enhancing student understanding and retention of the course material, which is important for flight safety, as well as making the course more engaging and less reliant on traditional PowerPoint lectures. Therefore, the goal of the present study is to determine whether including a set of new active-learning techniques in an Aviation Weather course would result in better student understanding (as measured by exam scores) and make the course more engaging (as measured by end-of-course evaluations). The following sections detail the changes made to the course so far and their effectiveness based on direct and indirect assessments.[1]

[1] The active-learning techniques were implemented with guidance from ERAU’s Center for Teaching and Learning Excellence (CTLE).

Methods

Active Learning Intervention

During 2018-19, three instructors implemented five different active-learning techniques into their classes (i.e., the experimental group), while two instructors continued to use the unrevised course materials (i.e., the control group). The new active-learning techniques, described below, included daily quizzes, polling questions, flipped classroom sessions, in-class activities, and assertion-evidence based lectures. All sections used the same assignments and exams, allowing for direct assessment of the effectiveness of the active-learning techniques. Analyses of Variance (ANOVA) tables were used to determine the statistical significance of the differences in exam scores. Indirect assessments in the form of end-of-course evaluations were also examined.

Daily Quizzes

A primary goal in the course is to ensure that students understand the weather-related hazards to flight operations and retain this information long-term throughout their careers as professional aviators. Brown, Roediger, and McDaniel (2014) found that repeated retrieval of information is crucial for long-term memory. The experimental group began each class with a three-question quiz that was available for five minutes before and after the start of class. The questions were relevant to any of the course material covered to date. Questions related to more recently discussed material emphasized the salient points of that topic; meanwhile, questions relevant to material discussed many weeks prior refreshed course content and helped with preparation for exams. After the quiz, students had an opportunity to discuss the solutions and ask follow-up questions to further reinforce the concepts. The points earned on the quizzes counted toward extra credit on the students' final grades and, because they were only open for a few minutes at the beginning of class, provided incentive for students to arrive to class on-time.

Polling Questions

Interactive questions were interspersed throughout the PowerPoint lectures via the Poll Everywhere software (www.polleverywhere.com). Polling tools in general, and Poll Everywhere in particular, are quite popular among students (e.g., Draper & Brown, 2004; Shon & Smith, 2011) and have been linked to better student performance. For example, Campbell and Mayer (2009) found that students who answered questions during lectures performed better on an open-ended retention test compared to students who were simply given the answers to those questions during the lecture. Many of the Poll Everywhere questions incorporated into the course were multiple choice while others asked the students to identify a feature on a map. These questions were often placed immediately after a sub-topic had been discussed during the lecture. The percentage of students who selected each response was shown to the entire class and provided instructors real-time feedback regarding how well students understood the sub-topic. Questions with a large percentage of incorrect answers provided opportunities for think-pair-share exercises (e.g., Kaddoura, 2013; Harrington & Zakrajsek, 2017) where students tried to convince their classmates why the answer that they chose was correct. This was followed by a discussion of the correct answer.

In-Class Activities

The format and length of in-class activities varied. The activities were, in general, relevant to the more difficult course concepts and/or synthesized a few concepts that had recently been discussed. Students often completed these activities in groups and helped lead the discussion of the correct answers. The activities were assessed predominantly for completion rather than solely for accuracy, and these scores were substituted for the daily extra credit quiz scores. Several examples are discussed below.

Students historically have struggled the most with the concept of atmospheric stability and how to diagnose stability using a thermodynamic diagram known as the skew-T ln-p (often referred to as a "skew-T"). Therefore, several in-class activities were developed to help students become more comfortable with skew-T diagrams. The first activity asked students to plot the temperatures at various pressure levels to become familiar with the skewed temperature axis (Figure 1). Next, students were provided a blank skew-T diagram and were asked to plot the profile of a hypothetical air parcel given three different atmospheric conditions at the surface (Figure 2). The goal was to illustrate how an air parcel that contained more water vapor at the surface was warmer in the mid- and upper levels of the atmosphere. The final exercise simulated lifting an air parcel up and over a mountain to demonstrate how clouds and precipitation were favored to develop on the upwind side of the mountain, while warmer and drier conditions were favored on the downwind side.

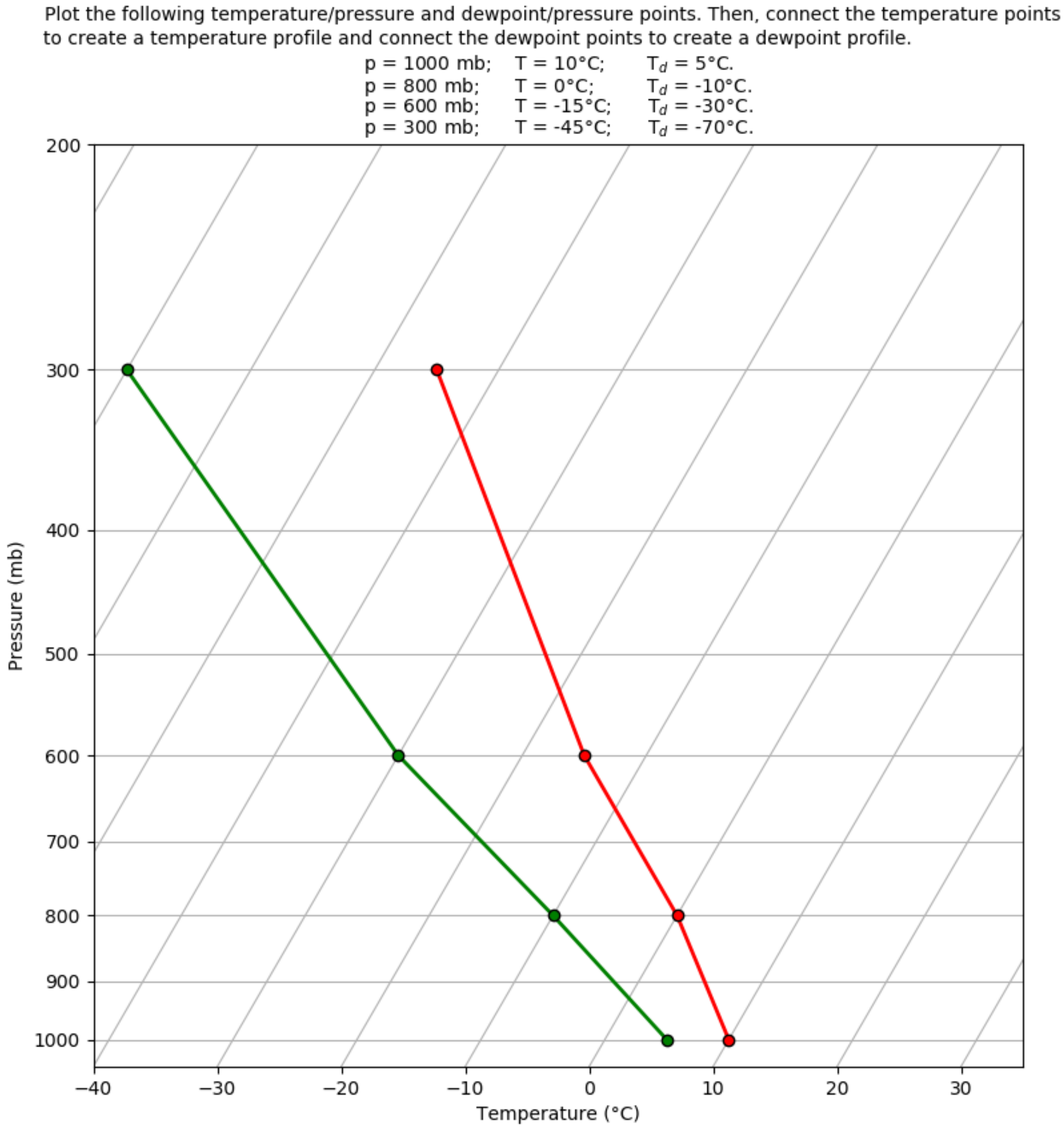

Figure 1. Example of a completed in-class activity to familiarize students with plotting temperature and dewpoint values at various pressure levels along a skewed temperature axis. Skew-T diagram developed using MetPy (May et al., 2020).

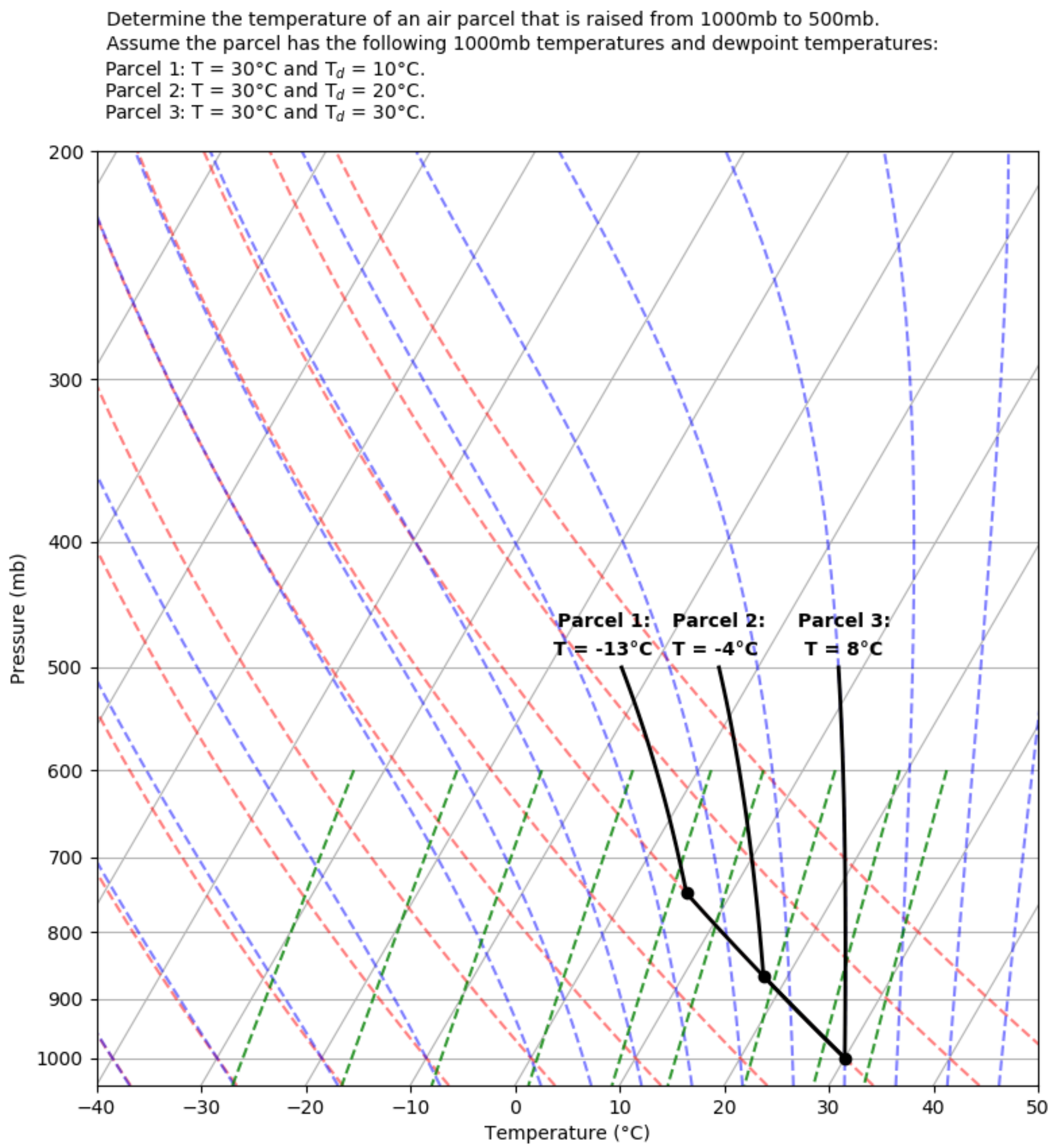

Figure 2. Example of a completed in-class activity where students are asked to find the temperature of a theoretical air parcel at a pressure of 500 mb, given three different temperature and dewpoint conditions at the surface. Skew-T diagram developed using MetPy (May et al., 2020).

Most lectures had a corresponding in-class activity to emphasize the main concepts of that lecture. Case studies often used archived data, but real-time data were used when possible. For some activities, the students assumed the role of an aviation weather forecaster and determined whether or not it would be appropriate to issue Airmen's Meteorological Information

(AIRMET) and/or Significant Meteorological Information (SIGMET) products (Federal Aviation Administration [FAA], 2019) for hazards such as icing and turbulence (see Appendix).

Flipping the Classroom

While many topics in the course require a conceptual understanding of a meteorological phenomenon, other topics can be mastered via rote memorization. The topics in this latter category were prime candidates for flipping the classroom (also known as inverting the classroom). Rather than introducing the material to the students in class and then giving the students a related assignment to complete at home, flipping the classroom consists of the students learning the material on their own time (e.g., through reading or video lecture prior to class) and using the time in class to discuss the topic in greater detail or complete an activity that requires higher-order thinking. Day and Foley (2006) demonstrated the effectiveness of the flipped classroom approach while Bishop and Verleger (2013) indicated that students generally have a positive view of this technique. Accordingly, the series of lectures on weather codes – specific formats and abbreviations for Aviation Routine Weather Reports (METARs), Pilot Weather Reports (PIREPs), and Terminal Aerodrome Forecasts (TAFs) (FAA, 2019) – was partially flipped. Students were tasked with reading part of an FAA document and corresponding PowerPoint slides that discussed how to interpret the main sections of the various coded products. To test their understanding, they were required to take a ten-question multiple choice, online quiz on each product prior to the beginning of class. Students were given three attempts on these quizzes. Class time was then devoted to a discussion of the non-standard attributes of these products and examples of some rather unusual, more interesting observations. Finally, a group “Jeopardy!” game was created to review this topic. These changes made more efficient use of class time and allowed the material discussed during class to be more engaging.

Revising the Lecture Slides to Assertion-Evidence Format

In order to address student feedback and make time for the addition of the active-learning techniques, the PowerPoint lecture slides required revision. Garner and Alley (2013) described the methodology and effectiveness of the "assertion-evidence" (AE) approach to designing presentation slides. In short, the top of each slide contained a declarative sentence or assertion and the remainder of the slide contained visual evidence (schematics, data, examples, etc.) that supported the assertion. The AE format required instructors to distill the lecture slides to the most important concepts and remove supplementary information. Garner and Alley (2013) found that students who attended lectures in the AE format exhibited better comprehension and retention of the course material, and a lower perceived cognitive load compared to students who attended lectures in the standard PowerPoint format of slides with a title and bulleted text. The original slides with the supplemental material were posted online for students to review at their convenience. Only the revised AE format slides were used in-class and those lectures were far more condensed. Exam questions remained focused on the in-class lecture material that was presented in both versions of the lecture slides.

Results

Direct Assessments

The mean score for each exam (Exam 1, Exam 2, Final Exam) was recorded for each section and was used as the dependent variable in the following analyses. All exam means were given equal weighting. The experimental vs. control group (hereafter "Active Learning") and MWF vs. TTh class meeting days (hereafter "Course Schedule") were the between-subjects factors. The exam number (hereafter "Exam Time") was the within-subjects factor. Tests for outliers, normality, and homogeneity of variances were conducted (not shown). One outlier was identified but was kept in the sample because there was no justification for removing it – it was a valid mean exam score and was 1.67 standard deviations from the mean of that group. The null hypotheses for normality and homogeneity of variances tests could not be rejected. Therefore, we proceeded with the analysis. The Greenhouse-Geisser correction was applied if the assumption of sphericity was violated.

Analysis of Active Learning and Course Schedule across Exam Time

The data were analyzed using a 2x2x(3) three-way mixed-designed ANOVA (Table 1). Table 1 shows that there was a significant main effect for the Exam Time factor, a significant two-way interaction between Active Learning and Exam Time, and a significant three-way interaction between Active Learning, Course Schedule, and Exam Time. The Exam Time factor had the greatest generalized effect size and was investigated further with a one-way ANOVA (Table 2), which confirmed the significance of the Exam Time main effect. In addition, paired post-hoc t-tests of the exams (Table 3) indicated that the mean score on the Final Exam (80.5%) was significantly higher than the means scores of the two-unit exams (75.1% and 75.9%, respectively). In other words, students were scoring significantly higher on the final exam compared to the first two exams.

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Table 1

Three-Way Mixed-Design ANOVA Comparing Active Learning, Course Schedule, and Exam Time Factors

Factor	**p-value**	**Generalized Effect Size**
Active Learning	0.154	0.119
Course Schedule	0.824	0.003
Exam Time	$3.68*10^{-8}$	0.388
Active Learning : Course Schedule	0.85	0.002
Active Learning : Exam Time	0.037	0.062
Course Schedule : Exam Time	0.763	0.005
Active Learning : Course Schedule : Exam Time	0.009	0.092

Table 2

One-Way ANOVA of the Exam Time Factor

Factor	**p-value**	**Generalized Effect Size**
Exam Time	$1.22*10^{-6}$	0.288

Table 3

Paired t-Tests of Each Exam

Sample A	**Sample B**	**Mean A**	**Mean B**	**p-value**
Exam 1	Exam 2	75.1%	75.9%	0.389
Exam 1	Final Exam	75.1%	80.5%	$1.31*10^{-5}$
Exam 2	Final Exam	75.9%	80.5%	$1.34*10^{-4}$

Two-way mixed-design ANOVAs between (1) Active Learning and Exam Time and (2) Course Schedule and Exam Time did not produce significant interactions (not shown). The significant three-way interaction between Active Learning, Course Schedule, and Exam Time was examined further by comparing the means when grouped by these three factors (Figure 3). The highest performing group (83.3%) was the experimental group, during the Final Exam, for TTh meeting days. Meanwhile, the lowest performing group (71.3%) was the control group, during Exam 1, for MWF meeting days. While it is apparent that mean exam scores improved over the course of the semester and there was an interaction between Active Learning and Exam Time, it appears that the effect of Course Schedule was small and non-significant.

Analysis of Faculty

Faculty tend to teach this course at the same time each semester and each faculty member taught either the experimental or control version of the course, so the relationship between Instructor and Exam Time was also investigated (Table 4). The two-way interaction between Instructor and Exam Time was significant. When mean scores grouped by these two factors were examined, results were similar to the three-way interaction between Active Learning, Course Schedule, and Exam Time. The highest performing group (83.3%) was during the Final Exam for Instructor E (who taught the experimental group on TTh). The lowest performing group (71.3%) was during Exam 1 for Instructor C (who taught the control group on MWF). Therefore, we cannot determine whether class meeting day was significant or simply a result of each faculty member teaching at relatively consistent times each semester. Overall, the significant interactions revealed by the ANOVA tables suggest that the active-learning techniques were beneficial.

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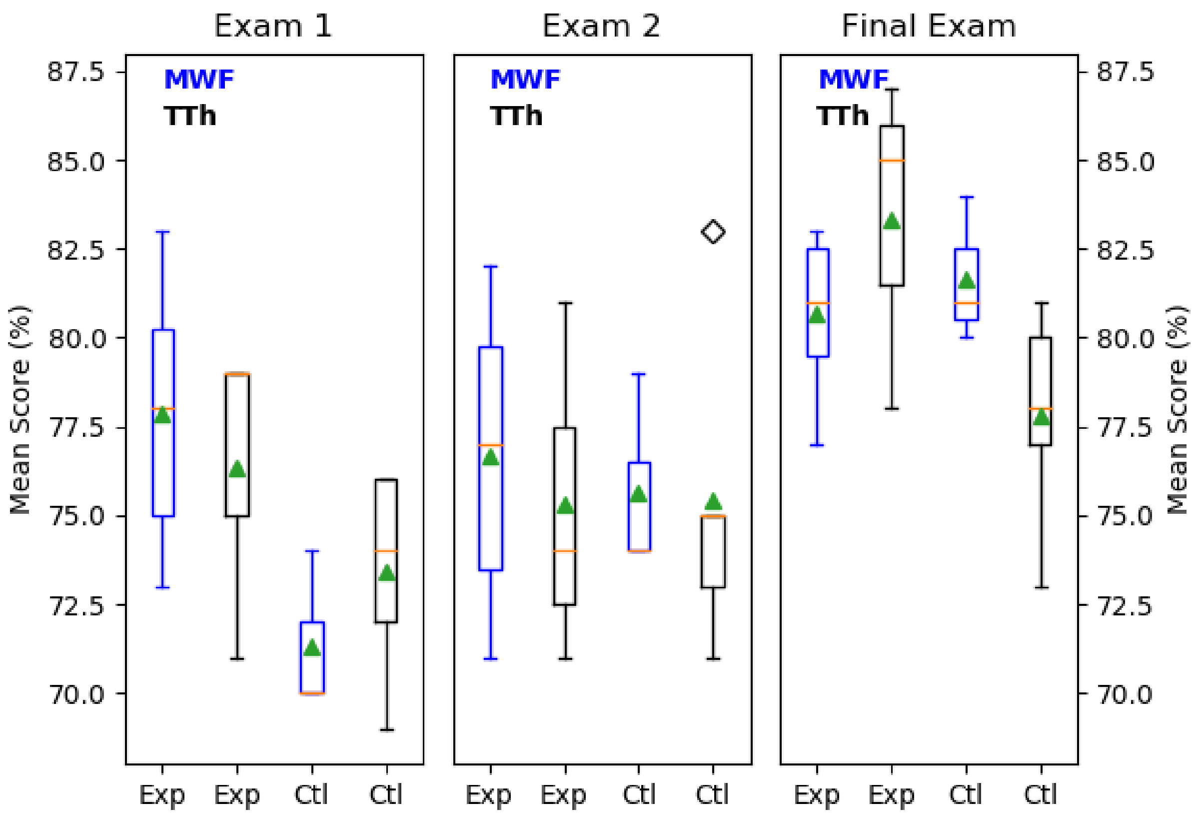

Figure 3. Box and whiskers plots of the distribution of mean exam scores for each Active Learning, Course Schedule, and Exam Time. Orange lines denote median values, green triangles denote mean values, and diamonds denote outlier events.

Table 4

Two-Way Mixed-Design ANOVA of the Instructor and Exam Time Factors

Factor	**p-value**	**Generalized Effect Size**
Instructor	0.105	0.365
Exam Time	$1.68*10^{-7}$	0.435
Instructor : Exam Time	0.025	0.210

Indirect Assessments

The primary indirect assessments were comments and responses to questions received through end-of-course evaluations. In seven sections of the course during the 2018-19 academic year, the following custom, Likert-scale questions were added to the end-of-course evaluations:

i. The daily extra credit quizzes helped me understand and retain the course material.

ii. The daily extra credit quizzes helped me prepare for the exams.

iii. The Poll Everywhere questions helped me better understand the course material.

iv. I would have preferred more in-class lecture time devoted to learning how to decode METARs, TAFs, and PIREPs instead of the pre-class quizzes on those topics.

In addition, during the Fall 2019 semester, approximately 30% of the lectures were presented in the AE format. Therefore, the following question was added to the end-of-course evaluation in three sections of the course for the Fall 2019 semester to determine student perceptions of the AE lecture format:

v. The Assertion-Evidence (i.e., “new format”) slides […] were more engaging and easier to follow than the traditional (i.e., “old format”) slides.

Answer choices to the above questions were *strongly agree, agree, no opinion, disagree,* and *strongly disagree*. For questions (i)-(iii) and (v), *strongly agree* was weighted as 5; *strongly disagree* was weighted as 1. For question (iv), *strongly disagree* was weighted as 5; *strongly agree* was weighted as 1. In this context, a rating of 5 implies the active-learning techniques have had a positive impact for all questions. The responses to these questions are provided in Tables 2-6.

In general, students’ perceptions of the course revisions were quite positive. Approximately 84% of students thought that the daily extra credit quizzes helped them

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understand and retain the course material (Table 5). Most of the students also thought that the daily quizzes served as good preparation for the exams (Table 6).

Table 5

Responses to the Custom Question on the End-of-Course Evaluations that States, "The daily extra credit quizzes helped me understand and retain the course material."

Response	Weight	Number of responses	Percentage of responses
Strongly agree	5	104	52.53%
Agree	4	62	31.31%
No opinion	3	16	8.08%
Disagree	2	11	5.56%
Strongly disagree	1	5	2.53%

Table 6

Responses to the Custom Question on the End-of-Course Evaluations that States, "The daily extra credit quizzes helped me prepare for the exams."

Response	Weight	Number of responses	Percentage of responses
Strongly agree	5	78	39.20%
Agree	4	64	32.16%
No opinion	3	27	13.57%
Disagree	2	25	12.56%
Strongly disagree	1	5	2.51%

Notably, 88% of students had a positive view of the Poll Everywhere questions as a tool to help improve understanding of the course material (Table 7). This was consistent with the positive student perceptions of Poll Everywhere reported by Shon and Smith (2011). In addition, 74% of students perceived the AE format lectures to be more engaging and easier to follow (Table 8). This was consistent with students in the AE group reporting a lower perceived mental effort required to comprehend the lecture compared to the control group in the study by Garner and Alley (2013).

Table 7

Responses to the Custom Question on the End-of-Course Evaluations that States, "The Poll Everywhere questions helped me better understand the course material."

Response	**Weight**	**Number of responses**	**Percentage of responses**
Strongly agree	5	101	51.27%
Agree	4	73	37.06%
No opinion	3	16	8.12%
Disagree	2	7	3.55%
Strongly disagree	1	0	0.00%

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Table 8

Responses to the Custom Question on the End-of-Course Evaluations that States, "The Assertion-Evidence (i.e., 'new format') slides […] were more engaging and easier to follow than the traditional (i.e., 'old format') slides.

Response	**Weight**	**Number of responses**	**Percentage of responses**
Strongly agree	5	38	40.86%
Agree	4	31	33.33%
No opinion	3	22	23.66%
Disagree	2	2	2.15%
Strongly disagree	1	0	0.00%

The question regarding the weather codes lecture and flipping the classroom was the only one that produced relatively mixed responses (Table 9). Students in the course often have different levels of flight training experience (i.e., no flight experience up to a certificated flight instructor rating). Therefore, it is possible that students who have a greater level of flight training experience and prior knowledge of weather codes support flipping the classroom while students with little or no prior knowledge of weather codes would prefer in-class lecture time devoted to the topic. Future course evaluations will need to explore this possibility.

Table 9

Responses to the Custom Question on the End-of-Course Evaluations that States, "I would have preferred more in-class lecture time devoted to learning how to decode METARs, TAFs, and PIREPs instead of the pre-class quizzes on those topics."

Response	**Weight**	**Number of responses**	**Percentage of responses**
Strongly agree	1	30	15.23%
Agree	2	32	16.24%
No opinion	3	47	23.86%
Disagree	4	54	27.41%
Strongly disagree	5	34	17.26%

Limitations

It is important to note that numerous variables that cannot be controlled are present in our samples (e.g., length of class period, students' prior knowledge). Therefore, while it is encouraging to find that the sections that implemented the active-learning techniques have significantly higher mean exam scores, we cannot say with confidence that the result is solely due to the implementation of those techniques.

Summary and Conclusions

A set of active-learning techniques to increase student engagement, comprehension, and retention of the course material were implemented in the course Aviation Weather at Embry-Riddle Aeronautical University's Daytona Beach, Florida campus during 2018-2019 academic year. The goal of this study was to determine whether these active-learning techniques resulted in better student performance and made the course more engaging. The large enrollment in the course and common assessments in all sections provided an opportunity to test the effectiveness of the course changes.

Three of the five course instructors implemented the following changes: daily extra credit quizzes, Poll Everywhere questions, in-class activities (individually and in groups), flipping the classroom for some lectures, and a revised set of lecture slides that follow the "assertion-evidence" format. The remaining two instructors did not make any changes to the course and served as the control group. Students in the experimental group with the course changes exhibited higher mean exam scores than students in the control group and there was a significant improvement in exam scores as the semester progressed for both groups. A significant two-way interaction between group and exam number and a significant three-way interaction between group, class meeting day, and exam number suggest that including the active-learning techniques has been beneficial. However, it was unknown whether class meeting day or instructor is significant since instructors taught the course on the same meeting days each semester. Students in the experimental group had a positive perception of the course changes as evidenced by open-ended comments and responses to custom Likert questions in the end-of-course evaluations, with the possible exception of the METAR-TAF-PIREP question in Table 9.

The results of this study are consistent with prior research on the effectiveness and student perceptions of incorporating active-learning techniques in the classroom (e.g., Shon & Smith, 2011; Bishop & Verleger, 2013; Garner & Alley, 2013; Freeman et al., 2014; Harrington & Zakrajsek, 2017). These course changes are being implemented in all sections of the course following the positive results demonstrated by the experimental group in this study.

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Appendix

Example of in-class activity on diagnosing clear air turbulence potential

1. Calculate the environmental lapse rate (ELR) in **°C per 1000 m** (i.e. km) in the 372-280mb layer. Is this lapse rate absolutely stable, absolutely unstable, or conditionally unstable? *Recall the DALR is about 10°C/km, while the MALR varies but is approximately 6°C/km in the lower atmosphere. If the ELR is less than both the DALR and MALR, it is absolutely stable.*

2. Calculate the vertical wind speed shear **per 1,000 ft** in the 372-280mb layer. What type of CAT would be forecast based on the Air Force guidelines?

3. Is this combination of stability and shear at this location conducive for CAT?

4. Calculate the lapse rate in **°C per 1000 m** in the 275-250mb layer. Is this lapse rate absolutely stable, absolutely unstable, or conditionally unstable?

5. Calculate the vertical wind speed shear **per 1,000 ft** in the 275-250mb layer. What type of CAT would be forecast based on the Air Force guidelines?

6. What is the height **in ft** of the bottom of the lowest shear layer (i.e., 620.6mb)?

7. What is the height **in ft** of the top of the highest shear layer (i.e., 250mb)?

8. What type of turbulence was being reported?

9. At what range of altitudes was the turbulence reported?

10. What types of aircraft were reporting turbulence?

11. How well do the layers you identified for potential CAT match with the PIREPs over Colorado in terms of altitude and intensity?

12. What feature is the likely cause of the observed CAT?

13. How well does the Graphical Turbulence Guidance (GTG) product match with the jet stream?

14. Given the data analyzed, would you have issued a G-AIRMET TANGO and/or Turbulence SIGMET over Colorado? If so, for what levels?