

## Using Online Active-Learning Techniques to Convey Time Compensated Sun Compass Orientation in the Eastern North American Monarch

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**A common tool that animals use to navigate in a constant direction is known as “time compensated sun compass orientation.” This is a process by which animals use the position of the sun along with information from their internal circadian clocks to determine and maintain a directional heading. Many circadian scientists and educators use this process as an example of how the internal circadian clock can directly influence animal behavior. However, many students have difficulty grasping this biological process due to its multivariable nature. We have created an online module that uses the principles of active learning to facilitate student comprehension of this process. Our module contains instructional videos, practice problems and an interactive diagram. We implemented the module in an undergraduate biological clocks class at Vanderbilt University, where its use significantly improved students’ understanding of time compensated sun compass orientation as well as their ability to solve complex problems involving principles associated with this process.**

### INTRODUCTION

Circadian rhythms are an important but often overlooked aspect of animal biology. One of the main challenges instructors face when teaching students about circadian rhythms is providing students with real-world examples of how circadian rhythms directly influence animal behavior beyond sleep. One such example used by many instructors is a phenomenon known as “time compensated sun compass orientation” (also called time compensated sun compass navigation). This is the biological process by which some animals orient themselves using the sun. Simply put, animals are able to combine information from their internal circadian clock and the position of the sun at different times during the day to maintain a constant directional heading (4). One of the best examples of this process at work is in the incredible migration of the eastern North American monarch butterfly. These butterflies travel almost 2,500 miles from the northern US and southern Canada to central Mexico using this form of navigation (4).

A critical experimental test of the circadian clock’s involvement in sun compass orientation is to alter the timing of an animal’s internal clock compared to local solar time, and then assay for systematic misorientation (2, 3). To illustrate

how the internal circadian clock of the butterflies plays a critical role in their navigation, instructors outline how changing the butterfly’s internal circadian time compared to the local time, and thus changing the position of the sun, can cause misorientation events. Unfortunately, students consistently have a hard time grasping this concept due to its multivariable nature.

To help convey this concept, we developed an online module that incorporates many principles of active learning. The module provides in-depth information about the migration and navigation of the butterflies as well as tools to allow students to test their understanding. The first section of this module is composed of three instructional videos intended to provide a more comprehensive view of monarch butterfly migration and navigation. The second section contains a series of practice problems that allow students to test their understanding of misorientation events. This element is key for helping students actively process the complex information. Along with the practice problems, we give students “things to think about,” which remind students of the key elements they should consider when solving the problems. In the third section, an interactive diagram allows students to change the parameters involved in time compensated sun compass navigation, such as initial orientation direction, local time and internal butterfly time. Changing these parameters in the diagram moves an arrow on a compass face, indicating which direction the butterflies would travel in any combination of the base parameters. This tool provides an alternate way for students to visualize the problems. This tool also helps reinforce students’ knowledge of the relationships

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between the variables involved in time compensated sun compass orientation. Taken together, the three portions of this module engage students in the main aspects of active learning: learning by doing and metacognition (1).

This project was developed as a CIRTL (Center for the Integration of Research, Teaching, and Learning) Teaching as Research project through the BOLD (Blended and Online Learning Design) program at Vanderbilt University.

### Intended audience

This module was designed as a supplemental tool for undergraduate students learning about real-world applications of circadian rhythms, specifically time compensated sun compass orientation. However, the instructional videos within the module provide enough background that the vast majority of the public can make use of the module outside of the classroom setting.

### Prerequisite student knowledge

There is little to no prerequisite knowledge for this module. The instructional videos cover the background knowledge that a student may need to effectively utilize the other parts of the module.

### Learning time

There is essentially no preparation time for instructors planning to use this module since the content has already been created and is available on an open-access website. The three instructional videos are relatively short with a total run time of just under 13 minutes. Students may spend as much time as they see fit on the five practice problems and the interactive diagram. However, we estimate most students will spend about 15 to 30 minutes working through the problems and 10 to 20 minutes investigating the interactive diagram.

### Learning objectives

This module was designed to provide students with real-world examples of how circadian rhythms can significantly impact and alter animal behavior. It also serves as a tool the general public can use to understand the migration and navigation of the eastern North American monarch butterfly and the serious threats to its survival. Upon completion of the activities in this module, students are expected to be able to:

1. Describe the major aspects of the migration of eastern North American monarch butterflies (not assessed).
2. Describe the biological processes behind this migration.
3. Explain why the internal circadian clock is important in the migration and navigation of these animals.

4. Accurately predict misorientation events due to changes in the relationship between the butterfly's internal circadian time and the local time.

Assessment techniques and learning outcomes to quantify students' achievement of these objectives are outlined in "Suggestions for student learning."

## PROCEDURE

### Materials

Students and faculty may access this module at <https://my.vanderbilt.edu/noahgreen/>. Some content in the instructional videos was taken from "Monarch Butterfly Migration Google Earth Tour," a video produced by Atlantic Public Media in cooperation with the Encyclopedia of Life Learning + Education group located at the Harvard Museum of Comparative Zoology, under a Creative Commons license (reuse allowed).

### Student instructions

We recommend students use the module as follows: First, students should watch the instructional videos in order (Introduction, Migration, Navigation). Next, students should answer each of the practice problems without using the interactive diagram. An explanation of each problem will appear after each question is answered, to help students understand why they selected the correct or incorrect answer. Finally, students should spend 5 to 15 minutes changing the parameters within the interactive diagram to familiarize themselves with how changing the internal butterfly time compared to the local time results in directional misorientation. Students should test their knowledge and understanding by asking questions, making predictions, and then using the diagram to check those predictions. For example, "If the initial direction is north, what direction would the butterfly navigate if its internal time was three hours ahead of the local time?"

To use the diagram students will have to download the Wolfram Mathematica CDF player; there is a link to download the player on the diagram page but it can also be accessed on the Wolfram website ([www.wolfram.com/cdf-player/](http://www.wolfram.com/cdf-player/)). The download is free but may take up to 15 minutes depending on Internet speed. This player will function using Internet Explorer and Firefox but *not* in Google Chrome. To use the diagram:

1. Click on the small + symbol next to the toggle bars to drop down the numeric display.
2. Set the initial orientation direction using the buttons at the top of the diagram.
3. Either drag the bar on the continuum or change the numbers below the bar to set the local time and the butterfly time. *Please note that the time is in 24-hour time, so 2 a.m. = 2 but 2 p.m. = 14.*

4. As the butterfly time or local time is changed, the arrow on the compass face will point in the direction the butterflies would travel under each combination of conditions.

Once students have finished experimenting with the diagram, they can open the practice problems and the diagram in separate windows and use the diagram to revisit any questions they answered incorrectly when they worked through them the first time.

### Faculty instructions

If faculty use this module in conjunction with a course they are teaching, we recommend doing so after the concept of time compensated sun compass orientation has been covered in class. This will allow students to discuss with their instructor any questions they may have about the process before they expand their understanding through use of the module. Because the concept is complex, students benefit from out-of-class reinforcement, and the module can serve as such in place of a more traditional out-of-class reading assignment. However, due to the background information provided in the instructional videos, the module can also be used on its own. In this case, faculty would only need to provide students with a link to the module. We recommend that faculty become familiar with the module before they provide students access so that they are able to answer any questions students may have.

### Suggestions for determining student learning

There are multiple ways to determine how well students learn the concepts presented in the module. First, instructors can assign as homework a set of misnavigation questions similar to those in the module. This would allow instructors to evaluate how well students are able to predict misnavigation events, and by extension their functional understanding of the concept of time compensated sun compass orientation, after exposure to lecture content as well as module content. Homework assignments could include questions such as:

- A butterfly is trained to fly north in Nashville at noon. It is then flown three time zones west to an island in the Pacific. Ignoring travel time, in which direction would the butterfly fly at noon island time?
- A group of butterflies is trained to fly south in New York. Then they are entrained to a light cycle that is three hours delayed from the local light cycle in New York and released at 3 p.m. local time. Which direction would they fly?

Instructors can also measure module effectiveness through formative assessment in the classroom. Instructors

can ask students to complete all videos and activities within the module between class periods and then give a quiz (either written or using clickers) containing simplified misnavigation problems and questions regarding the migration patterns of the butterflies. The quiz could include questions such as:

- Where would a butterfly position the sun relative to its body if it aims to fly southwest at 3 p.m.? How about at 9 a.m.?
- How many generations does it take for a group of butterflies to make their round trip migration?
- Where are the internal circadian clock cells responsible for butterfly navigation located in the animal?

Instructors can also include questions similar to those included in homework or quizzes on exams covering material related to module content. All of these assessment techniques can help instructors gauge the influence of the module on student comprehension and functional understanding of the concepts presented.

### Sample data

View the module itself here: <https://my.vanderbilt.edu/noahgreen/>.

### Safety issues

There are no safety concerns associated with using this module.

## DISCUSSION

### Field testing

We used this module in fall 2015 in the undergraduate biological clocks class that one of the authors (DM) teaches at Vanderbilt University. This is an upper-level elective course in the Biological Sciences Department; enrollment is typically about 40 students. We used three techniques to assess the efficacy of this module.

First, we randomly divided the biological clocks class into two groups, one of which had access to the module and one of which did not. Students in both groups received the same lecture on biological clocks and were assigned a set of practice problems regarding time compensated sun compass orientation. Completion of the problems resulted in credit; performance on the problems did not affect students' grades. An example of these problems would be: "A group of butterflies is trained to fly west in Nashville. Then they are flown three time zones west to an island in the Pacific and released the next day. Assuming they have not entrained to the local time zone and the local time is 10 a.m., what is their internal circadian time and what direction would they fly?" We gave the students one week to complete the assignment. Once they completed the problems, we

scored them to determine which group performed better on average.

All students were given access to the module before the first exam. The first exam in the course contains several questions regarding time compensated sun compass orientation which are very similar to the questions asked in the homework assignment, with the initial direction, times, and direction of travel changed. We compared the scores on these questions of current students in the class (who had access to the module) to those of students from two previous years (before the module was constructed) to determine if there was a difference in performance on test questions concerning time compensated sun compass orientation as well as on the exam overall.

Finally, after the first exam the students completed a survey concerning the success of the module. This survey included questions such as: “Did you use the module in preparation for the exam? If so, did you find it helpful? Which portion of the module did you find most helpful?” This gave us a qualitative idea of how well we satisfied our learning goals. Out of 25 responses, 78.3% of students stated that they had used the module to prepare for the exam. They were then asked to rate the value of each section of the module on a scale from 1 to 5 (1 being of no value and 5 being very valuable). Overall, students found the practice problems most valuable: all students rated the value of the practice problems at 3 or higher (Fig. 1A). The vast majority of students found the interactive diagram to be valuable as well, with 88% of students rating the value of the diagram at 3 or higher (Fig. 1B). Finally, the responses suggested that the majority of students also found the videos valuable, with 80% of students rating the value of the videos at 3 or higher (Fig. 1C). This suggests that while students found all three sections of the module valuable, giving students extra practice solving problems that force them to apply their knowledge of time compensated sun compass orientation was most valuable.

### Evidence of student learning

After an introductory lecture covering time compensated sun compass orientation and how butterflies use this mechanism to navigate, we assigned all 37 students a problem set for homework. These problems asked the students to consider how the misalignment of the butterfly’s internal circadian clock with the external time would cause the butterflies to misnavigate. Nineteen of the students were allowed access to the module and 18 were not. Students with access to the module scored significantly higher on this homework than those who were not allowed access (w/ module:  $9.16 \pm 0.32$  out of 10, w/o module:  $6.33 \pm 0.74$  out of 10). Figure 2A shows mean scores, with error bars indicating standard error of the mean; a Mann-Whitney U rank sum test yielded  $p = 0.005$ .

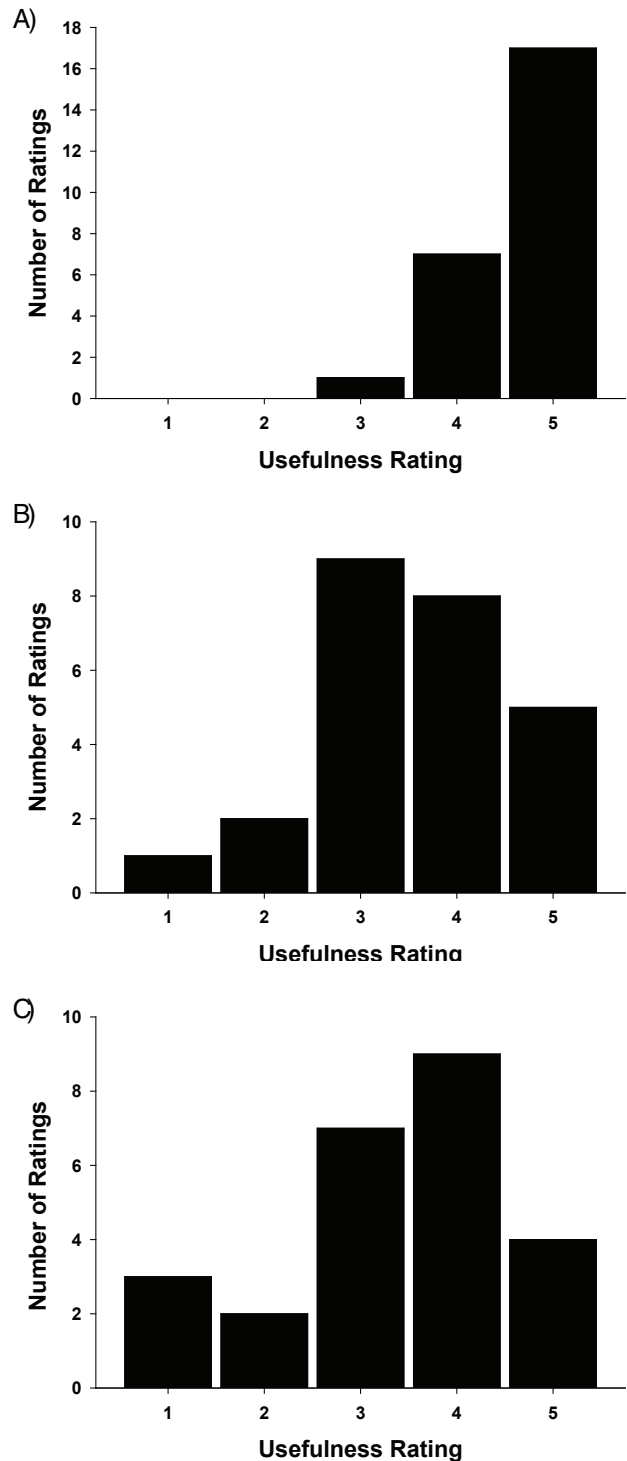


FIGURE 1. Usefulness surveys for the practice problems (A), interactive diagram (B) and instructional videos (C). Students were asked to rate how useful each aspect of the module was on a scale of 1 (no value) to 5 (very valuable).

After completion of this homework assignment, all students were allowed access to the module to prepare for the first exam. The exam contained three butterfly navigation questions, worth four points each (accounting for 12% of the total exam score). We compared exam

scores from 2014, when students did not have the benefit of the module, to exam scores from this year, 2015, when students had access to the module while preparing for the exam. Students who had access to the module (2015) performed significantly better on the exam as a whole than those who did not (w/ module:  $83.2 \pm 2.11$  out of 100, w/o module:  $76.8 \pm 2.59$  out of 100). Figure 2B shows mean scores, with error bars indicating standard error of the mean; a Mann-Whitney U rank sum test yielded  $p = 0.005$ .

Finally, we were able to compare scores on the butterfly questions only from 13 exams that were not claimed by students in 2010 and 2014 to scores on those questions from the 37 students who took the exam in 2015. Students who had access to the module performed astoundingly better on butterfly navigation questions than those who did not have access to the module in previous years (w/ module:  $8.54 \pm 0.71$  out of 12, w/o module:  $2.77 \pm 0.49$  out of 12). Figure 2C shows mean scores, with error bars indicating standard error of the mean; a Mann-Whitney U rank sum test yielded  $p < 0.001$ . However, since the exams that were analyzed from previous years belonged to students who did not claim them, we worried there might be a sampling bias toward a certain cohort of students. Therefore, we normalized the

students' performance on the butterfly navigation questions to their total score on the exam, to make sure we were not sampling from a population of students who did not perform well on the exam as a whole during previous years. We found that the ratio of butterfly-navigation-question scores to total-exam scores was still significantly higher for students who had access to the module than those that did not, suggesting that sampling bias did not influence the results significantly (w/ module:  $0.098 \pm 0.008$ , w/o module:  $0.043 \pm 0.009$ ). Figure 2D shows mean scores, with error bars indicating standard error of the mean; a Mann-Whitney U rank sum test yielded  $p = 0.003$ .

In summary, we have created a multifaceted online module to aid in student comprehension of time compensated sun compass orientation. Each aspect of this module uses the principles of active learning to provide students with an in-depth look at the migration and navigation of the eastern North American monarch butterfly. Our results showed that use of this module significantly improved students' ability to predict misorientation events arising from the misalignment of the butterfly's internal circadian clock and the local solar time. See Table 1 for an outline of how our assessment strategies aligned with our learning objectives. These results suggest that students who used

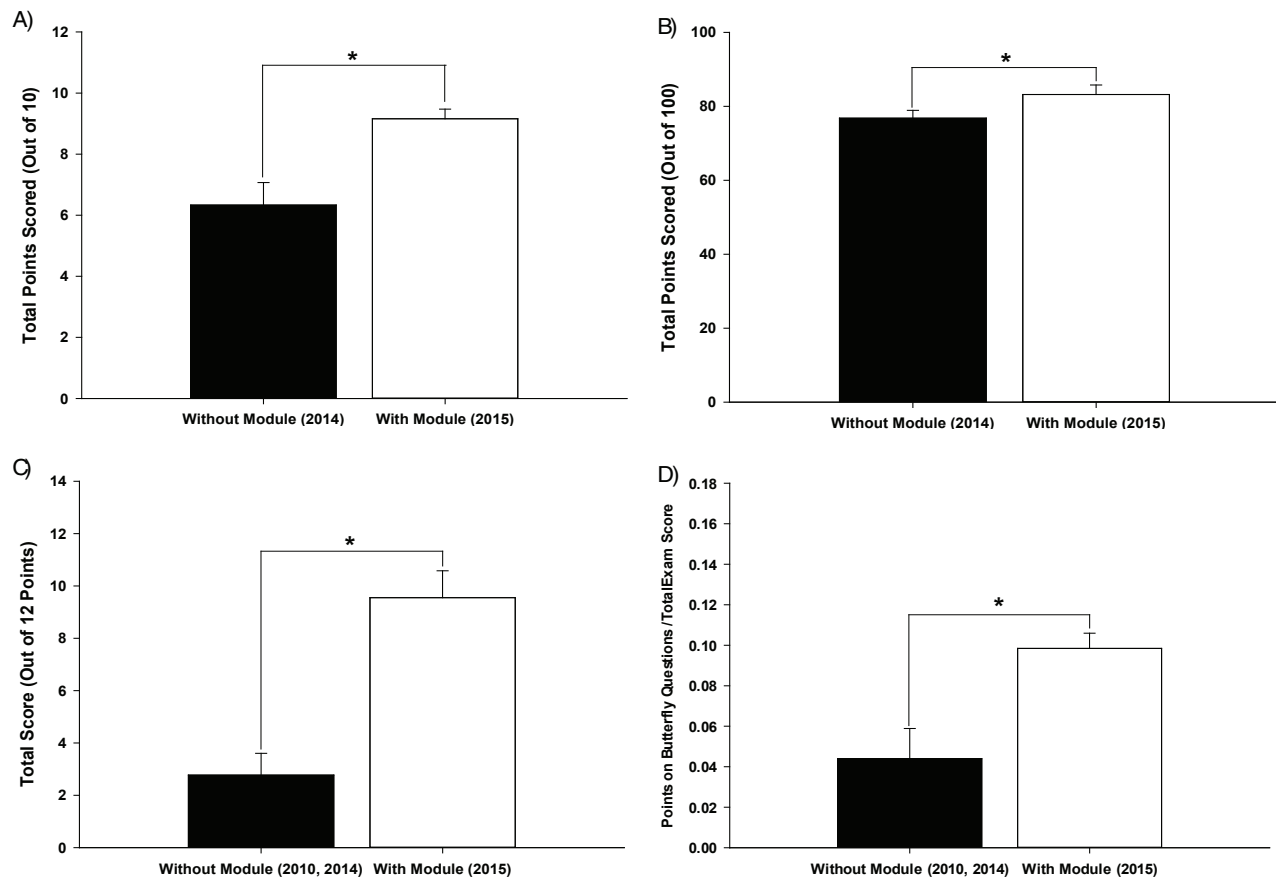


FIGURE 2. Comparisons of student performance with and without use of the module on butterfly homework (A), exam #1 (B), butterfly questions on exams (C), and normalized butterfly questions on exams (D). \* =  $p < 0.05$ .

TABLE 1.

How each learning objective was addressed and/or assessed and references to the resulting assessment outcomes.

Learning Objective	How We Addressed and/or Assessed It	Figure Reference
Describe the major aspects of the migration of eastern North American monarch butterflies.	Not assessed	Data not shown
Describe the biological processes behind this migration.	Exam questions Example: Draw a diagram of the molecular circadian clockwork in insects.	Figure 2B
	In-video questions Example: Where would the butterflies position the sun relative to their bodies to continue traveling southwest at 4 pm?	Data not shown
Explain why the internal circadian clock is important in the migration and navigation of these animals.	Exam questions Example: Describe two experiments that demonstrate why circadian rhythms are important to an animal's fitness (one of which can be butterfly navigation experiments).	Figure 2B
	In-video questions Example: Imagine you were taken an unknown distance in an unknown amount of time and dropped in a body of water. Would you know which direction is which by the position of the sun?	Data not shown
Accurately predict misorientation events due to changes in the relationship between the butterfly's internal circadian time and the local time.	Homework problems Example: A group of butterflies is trained to fly north in Nashville. Then they are flown 6 time zones west to an island in the Pacific and released the next day. Assuming they have not entrained to the local time zone and the local time is 1 pm, in what direction would they fly?	Figure 2
	Exam questions Example: A group of butterflies is trained to fly west in Nashville. Then they are flown 3 time zones east to an island in the Atlantic and released the next day. Assuming they have not entrained to the local time zone and the local time is 10 am, in what direction would they fly?	

the module gained a deeper and more thorough understanding of the concept of time compensated sun compass orientation. The success of this module demonstrates the power of online active-learning tools in conveying complex biological concepts.

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