# ARTICLE
# Does Insomnia Cause Revenge Seeking Behavior? Using a Puzzle-Based Sleep Lab Educational Escape Room to Teach Circadian Rhythms in a Large Introductory Neuroscience Course

**Boris Nakashyan and Erin B.D. Clabough**
*Department of Psychology, University of Virginia, Charlottesville, VA 22904.*
https://doi.org/10.59390/ZGTH8157

Traditional large lecture classes can be passive experiences for students. Instead, imagine that several of those learners work at a sleep laboratory and admit four new patients. Within hours, the entire facility is on lockdown, and a mysterious voice on the intercom proclaims that all researchers will lose their ability to sleep within the next hour. This story is the plot of an interactive educational escape room (EER) where students work together and apply concepts related to the history of sleep research, circadian rhythms, and neurological concepts of sleep to solve puzzles. Conventionally, escape rooms are an entertainment experience that requires participants to escape a room in a limited timeframe. We have created a neuroscience EER designed to educate students about the neural basis of sleep, while providing small groups of students with an immersive and interactive experience. Students follow a specially designed digital escape room framework to review sleep pathways, researchers, and brain regions involved with sleep. Unlike conventional escape rooms that can accommodate a limited number of participants, this sleep lab EER is scalable to hundreds of students without the need for a specialized room. Puzzles are enhanced by digital technology that allows instructors to track the progress of every team and note how the entire classroom is doing. Students and teaching assistants had very positive experiences with this EER activity, reporting that the EER solidified course concepts while using creativity, collaboration, and critical thinking skills. We find that EERs are an easy, useful tool to increase engagement and boost inclusivity within large classroom settings, with potential to also be used as an assessment tool.

*Key words: educational escape rooms; sleep cycles; circadian rhythms; puzzles; collaborative learning; inclusivity; sleep laboratory; engaging learning; creative classroom design, active learning; gamification; large lecture course, belonging, blended learning, flipped classroom*

---

An active learning classroom is a type of classroom that enables students to think for themselves. Various active learning models exist to support student success, including educational escape rooms (EERs). EERs can serve as a tool to promote active learning through gamification in the classroom. Immersing students in the interactive worlds of escape rooms requires them to use the problem-solving and collaboration skills that form the foundation for a lifetime of engaged learning. This EER approach to active learning has been shown to increase student performance on tests and improve understanding of content material (Baepler et al., 2014). Thus, escape rooms can facilitate active learning in a way that encourages students to be active players in their education.

The use of EERs was explored in the Survey of the Neural Basis of Behavior undergraduate course (PSYC 2200) in the context of an active learning classroom with 300 students. This course has traditionally been taught in a large lecture hall twice a week. In order to increase the number of meaningful connections students make within the course, the course was converted to a flipped classroom design. In the new version, students learn the material online before coming to class through two pre-recorded lectures each week, followed a brief online quiz for each lesson. Students meet in person for a single weekly active learning enrichment session where they spend time reinforcing their understanding of the material through activities and group work. There are three discussion sections consisting of 100 students each, where the weekly active learning sessions reinforce the concepts taught during the previous two online lectures.

## ACTIVE LEARNING CLASSROOM

The new flipped classroom emphasized group activity, allowing students to facilitate their own learning and collaborate together. Various active learning activities were presented each week to reinforce complex neuroscience concepts. For instance, groups played a signaling pathway game to help students strengthen their understanding of lower and upper motor neuron signaling. Students competed in a match throwing pom poms which resembled neurotransmitters to recreate the actions at neuromuscular junctions. This approach of turning learning into a game, also known as gamification, increases enthusiasm and student educational benefits (Subhash and Cudney, 2018).

EERs act as a combination of active learning and gamification. Since escape rooms require collaboration and problem-solving as players navigate and solve the puzzles in the plot, they act as a tool for engaged learning and were a logical choice for an active learning class activity. One

significant difference between recreational and educational escape rooms is that in the classroom, all puzzles must tie back to educational concepts. This difference can make engaging students and developing puzzles harder (Veldkamp et al., 2020). Considering this, we developed puzzles to fit the sleep theme, specifically targeting more complex sleep topics. These puzzles allowed students to work with traditionally difficult material in person collaboratively, capitalizing on the fact that EERs foster more significant student interaction and engagement than regular lecture time. This may boost knowledge acquisition through social interdependency, as one study also found improvement between pre- and post-test knowledge scores after completing an escape room activity, and importantly, observed unintended effects of learning by students teaching each other (Veldkamp et al., 2020).

The goals of the Sleep Lab EER were threefold: 1) To explore the feasibility of EER use in large introductory STEM lecture courses, 2) To enhance a sense of student belonging, inclusion, and engagement, and 3) To use collaborative learning to better understand topics that are difficult for students to grasp through passive lecture alone.

## MATERIALS AND METHODS

### Solving Educational Escape Room Challenges

One major challenge many EERs face is offering the space and team size that recreational escape rooms have. Instructors must work around the physical limitations of a traditional classroom and find ways to engage within the allotted course time block. We developed a framework that combines standard escape room immersion and scalability to engage all students. At the start, we played a short video introducing the plot and immersing the students. In the story, all students work in a sleep research lab where, one day, the lab admits four patients with various sleep problems for overnight observation. The players set up monitoring devices for each patient for the night and return the next morning. As the students enter the lab the following day, all exit doors suddenly lock and trap the students inside.

The speakers in the building start playing a pre-recorded message. The recording states that one of the patients secretly set up a device that contains Chemical-X. This chemical destroys circadian rhythms and prevents anyone from sleeping again. Since the secret patient terminated all communication devices and locked all doors, accessing the outside world is impossible without deactivating the device. Students have one hour to identify the patient behind this, where the patient hid the device, and how to deactivate it before it releases Chemical-X.

### Escape Room Framework: The Physical and Digital Immersion

The escape room followed a structure allowing scalability, team participation, and implementation of budget-friendly physical and digital components. Students were placed into groups of 2-3. Students were handed class stickers and were told they could place them on their computers or water bottles. Unbeknownst to the students, that sticker contained the key to unlock the final puzzle. A single PowerPoint slide set the expectations for the open notes escape room activity, followed by the 1-minute introductory video to set up the escape room scenario. Each group was then handed four sealed envelopes with QR codes on them, which represented locked cabinets, as well as loose starting game materials. We instructed students to solve the starting puzzles. Once a team found the hidden code in a starting puzzle, they were free to scan the QR code of the next cabinet envelope and use puzzle answers to open it. Each QR code took students to a conditioned Google Form, meaning that students must input the correct answer in order to submit the form successfully and open that specific cabinet envelope to see its contents. Each cabinet envelope had a separate QR code, required a different code to unlock it, and contained new puzzles. Supplemental File 1 contains an Escape Room Instructor Guide and materials list to create this ER puzzle experience.

Once the students opened all cabinet envelopes and solved the last puzzle, they completed the escape room. Each time students filled out a form and submitted it, a timestamp was generated to track in real-time when teams advanced from puzzle to puzzle. This real-time feedback allowed us to help set pacing and see which puzzles took students longer to solve. Additionally, it gave proof for whether a group finished the escape room or not. As such, the escape room had both physical and technological components.

### Puzzle Materials

We printed all escape room puzzles on paper, allowing students to physically engage with the content while making this activity budget-friendly. We designed some of the puzzles for students to write on (like the crossword puzzle) and we provided new copies to students in each section. The puzzles that did not require students to write on them were reused for other sections, minimizing the amount of paper used. Students did need a way to interact with QR codes through phones or computers, though all teams had a student with a phone that could scan the QR codes.

The escape room followed a pyramid-based structure. The escape room contained six puzzles: students had to solve the starting two to unlock a cabinet envelope that held the third puzzle. From there, the escape room became a sequential model, where solving each puzzle and opening the cabinet led to the following riddle. We set each puzzle to take students approximately ten minutes to solve—since they had sixty minutes, all students could pace themselves to try and finish on time. Supplemental File 2 contains an answer key for all puzzles, as well as clues.

### Escape Room Facilitation

During the escape room, student responsibilities were to 1) engage with their partner or group to brainstorm about how to solve each puzzle and how to use the solutions effectively to open the next puzzle, 2) use preexisting knowledge collaboratively or look up information in their notes, textbook, or online, and 3) ask for clues if needed.

Undergraduate and graduate teaching assistants (TAs) supported the class by walking between their assigned groups of students, listening to the student process, offering encouragement, and pointing people towards resources.

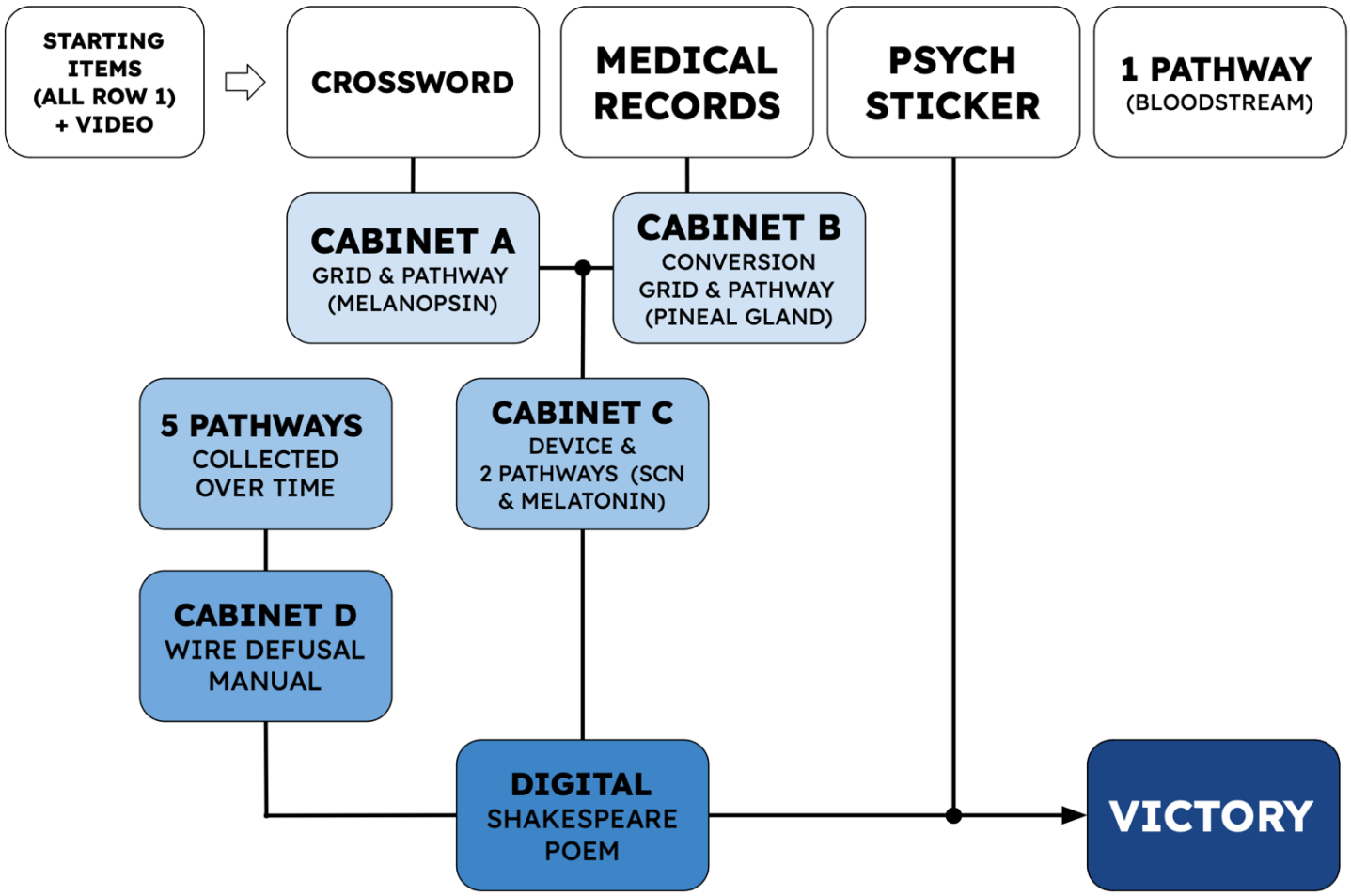


*Figure 1.* Mind map of the Sleep Escape Room. Diagram represents the puzzle sequence in which students had to solve the escape room to unlock the cabinets and reach the end goal.

| ESSENTIAL KNOWLEDGE | LEARNING OBJECTIVE |
|---|---|
| **A. History of sleep research** | 1. Identify names of researchers that contributed to our understanding of sleep and key experiments that provided evidence for sleep as either an active or passive process<br>2. Define lesions/cuts that helped our understanding of the neural systems/brain areas that contribute to sleep or wakefulness |
| **B. Empirical data of sleep** | 3. Interpret conceptual understanding of how EEG, EMG, and EOG would look depending on what sleep stage a person is in<br>4. Distinguish brain waves in relation to sleep stages |
| **C. Brain/body anatomy that contributes to sleep** | 5. Compare brain regions related to sleep/awake states<br>6. Recognize which brain regions release specific sleep neurotransmitters<br>7. Select the sensory and neuroanatomical pathway that detects the presence/absence of light and releases melatonin in the bloodstream |
| **D. Sleep chemistry** | 8. Classify chemicals/molecules associated with sleep and wakefulness stages |

*Table 1.* Key topics and learning objectives summarize the content covered within the escape room.

| Puzzle Name | Puzzle Location/ Placement | Description | Concepts assessed* *refer to Table 1 for content points | Explanation | Conclusion |
|---|---|---|---|---|---|
| Crossword puzzle | Given at start of escape room without restrictions | A blank crossword where some boxes where letters go are shaded | (1), (2) | The crossword provides clues (across/down) to fill in the key vocabulary words that relate to the history of sleep research. The shaded boxes contain letters; rearranging the letters in a certain way leads to the codeword. | Solving the puzzle opens Cabinet A |
| Medical records puzzle | Given at start of escape room without restrictions | Medical records of the four admitted patients that include the EEG, EMG, and EOG recordings as well as patient history (one of the four patients is responsible for the Chemical-X placement) | (3) | The medical records puzzle contains a file of the patients and their EEG, EMG, and EOG recordings. Since the patient that committed the crime would be out of bed, his/her EMG (electromyography) recordings would show activity. Only one patient has EMG recordings that show activity. Other patients have some activity with EEG and EOG, indicative of transitions across different sleep stages; however, no other patient demonstrates major muscle movement, eliminating all others from the suspect list. | Solving the puzzle opens Cabinet B |
| Grid puzzle | Inside of Cabinet A & B (players must solve both puzzles) | First component: a 4x4 grid with different icons, 3 brain regions, and 3 neurotransmitters. Second component: Icon-to-number conversion chart, key for connecting brain regions | (6) | The puzzle on the first component instructs students to connect the brain area to its sleep neurotransmitter, using every space only once, not diagonally. As the students connect the brain regions to neurotransmitters, their pencils will move over different shapes with the grid. The shapes that intersect can be decoded to digits using the second component. The digits can then be transcribed into a code. The puzzle asks the students to relate a brain region to a neurotransmitter visually. | Solving the puzzle opens Cabinet C |
| Five pathway cards puzzle | Five separate cards forming a puzzle pathway. Given progressively | The five cards each have a brain region/chemical/structure, and a black arrow - each card has arrows pointing in different locations | (7) | Students must arrange the cards in the pathway of how the body knows when to release melatonin by relying on stimuli and signals from different brain regions. The correct order will give the code for the position of arrows and yield a sequence for a directional code. | Solving the puzzle opens Cabinet D |
| Wire defusal manual puzzle | Chemical-X device (digital) accessed by scanning QR code in Cabinet C. Wire defusal manual in Cabinet D | The Chemical-X device has five wires associated with brain waves, brain regions, or chemicals. The wire defusal manual states to cut wires in order from top to bottom and only cut the wires associated with sleep-promoting states | (4), (5), (8) | To solve this puzzle, players need to cut the wires in order from top to bottom AND only cut the wires associated with sleep-promoting states. Since players must only select the wires associated with sleep/sleep promoting states, and each wire represents a different concept, this puzzle assesses whether a student can identify what promotes/relates to sleep. | Solving the puzzle opens Part 2 of the Google Form |
| Shakespeare Poem Puzzle* | Inside Chemical-X Device Defusal Google Form | Digital copy of a poem written by Patient X referencing Shakespeare, along with a sticker clue given prior to the escape room | N/A *This puzzle does not assess any sleep concepts and is instead a logic-based puzzle to energize students | The final puzzle is a logic-based one to energize students and reinforce their experience positively. | Solving the puzzle completes the escape room and results in victory |

*Table 2.* Puzzle Matrix: Each sleep lab Educational Escape Room puzzle has different mechanics linked to specific learning objectives.

TAs were instructed to not provide exact answers, but instead to ask questions and encourage collaboration. TAs were provided with an answer key and structured clues, so if students remained on a puzzle for more than 15 minutes, specific written clues could be handed to that student group.

**Learning Objectives and Puzzles**

The asynchronous video lectures covered biological rhythms (daily cycles, zeitgebers, circadian rhythms), the anatomy of how light informs our biological clocks (from the eye through the pineal gland), the molecular biology of

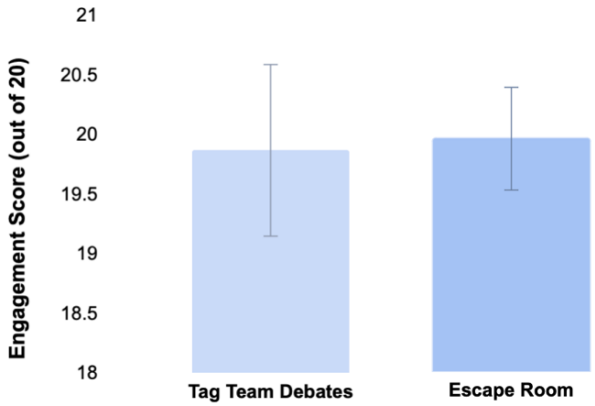


*Figure 2.* Activity engagement scores assessing Preparedness, Activity Contribution, Lifelong Learning Practices, Group Climate, and Knowledge Resources were very high in both types of sleep active learning activities, but not statistically different (by 2-tailed t-test, p=0.085; tag team n=183; escape room n=256).

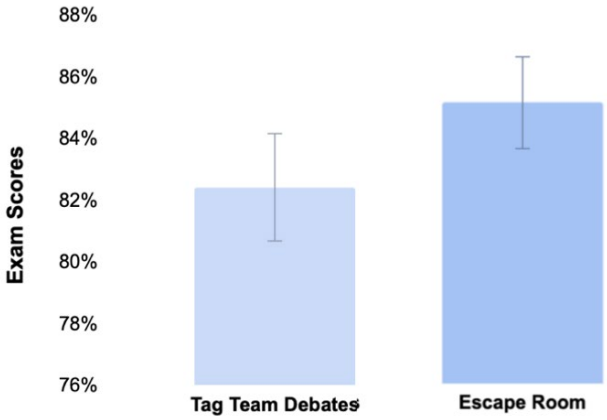


*Figure 3.* Activity scores on exam sleep questions assessed were not significantly different between types of sleep active learning activities (by 2-tailed t-test, p=0.32). Data is depicted as the percentage of students in each activity who got the question correct (n=28 different questions). Students received a random draw for a subset of the questions on the exam (tag team n=183 students; escape room n=256).

cellular clock genes, sleep stages (EEG brain waves), sleep pathology and available treatments, history of research establishing sleep as an active process (Bremer's experiments and Moruzzi/Magoun), brain areas involved in sleep (locus coeruleus, raphe nucleus, hypothalamic regions), neurotransmitter systems involved in wakefulness/sleep, and theories about why we sleep. The escape room assesses the 8 key concepts grouped into four categories (A-D) (shown in Table 1).

There were 6 puzzles and 4 locked cabinets (see Figure 1) and although all puzzles did not need to be completed in an exact sequence, some puzzles held necessary clues to later cabinets. Students were initially handed a starting materials folder containing a crossword puzzle found in a patient's room and medical records for all four current patients at the sleep center. These were clues to solve locked cabinets A and B. Below is a breakdown of each puzzle and how its content assesses the material. Each puzzle and the mechanics are summarized in the "Puzzle Matrix" (Table 2).

**Classroom Management**

When this PSYC2200 class was initially taught in an active format in a previous semester (Spring 2022), the active learning activity for the sleep lecture was a tag team debate, where student groups researched and performed debates on sleep topics within the single class period. At the end of that past semester, students voted for their favorite and least favorite activity, and the sleep debate overwhelmingly won for least favorite activity. In response, a replacement activity—the sleep lab escape room—was designed for the Fall 2022 semester, allowing past tag team debate activity data to provide a basis for comparison.

Students were administered the EER in teams of 2-3 people sitting at 11 tables of 9 students during regular class time. Table groups were randomly assigned on the first day of class and remained consistent for the semester. Our class conducted the escape room activity towards the end of the semester. Prior to that, students met with the same groups once a week to conduct active learning games on the relevant topics that we were learning in class. For example, during week three of the course, students participated in a fake play where each student acted as the parts of the synapse, such as a neurotransmitter moving across the synapse or a reuptake transporter recapturing the neurotransmitters.

By the time students did the EER, they had already had experience working together, which likely contributed to effective and successful group work. No explicit instructions were given to navigate group work, but teaching/helping one another is encouraged and no group grades were assigned throughout the course.

In preparation, students had previously watched two-hour long sleep lectures online and read relevant textbook content. Class contribution during the escape room activity was assessed by TAs individually for each student in real time using a 20-point grading rubric on iPads. This rubric was used in the course during each active learning session over the course of the semester to evaluate five different criteria (Preparedness, Activity Contribution, Lifelong Learning Practices, Group Climate, and Knowledge Resources) on a scale of 0-4 each. Each TA was responsible for assigning individual engagement scores to 2 tables (18 students). Each TA managed approximately 18 students and was responsible for giving each person an individual grade for the active learning session.

When an EER team completed the entire escape room, they wrote the time they completed it on the whiteboard, and they were permitted to leave class at that time. Student groups took an average of 46 minutes to complete the room and all students were able to complete the room in 60 minutes (range of 28-59 min, n=89 teams). A week after the activity, students and TAs were sent an anonymous short online survey to fill out on their own time to inquire about their experiences with the EER.

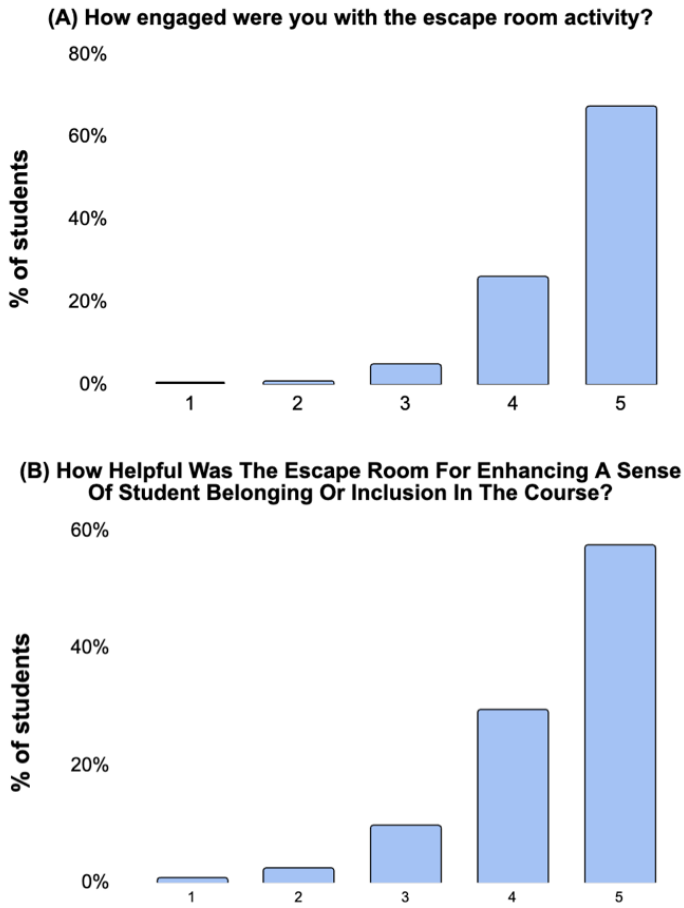


*Figure 4.* Students reported *(A)* high levels of engagement during the Educational Escape Room activity, and *(B)* also reported the activity as helpful for inclusion and belonging in the course (n=122 respondents) on a follow-up anonymous survey.

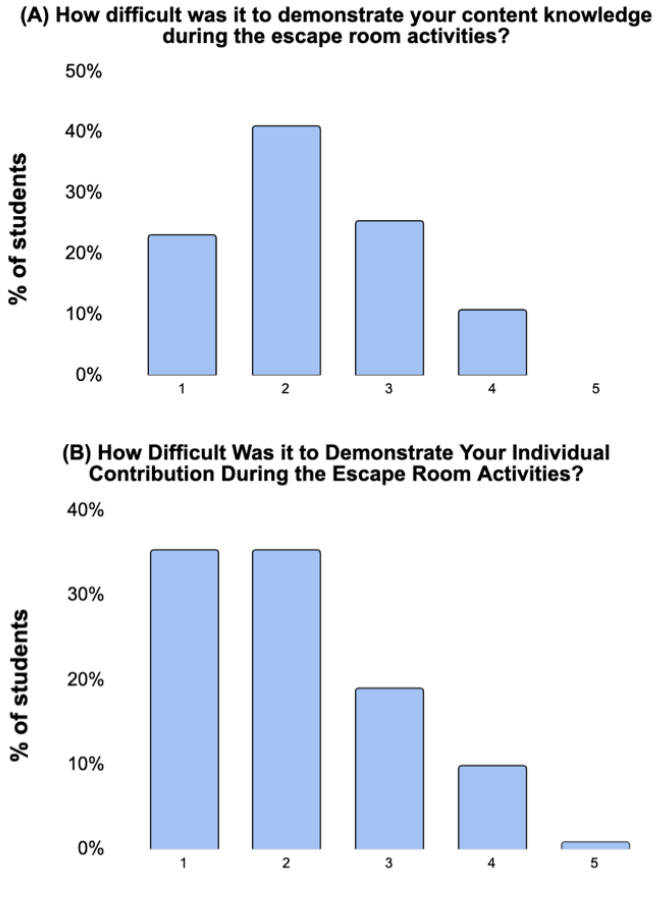


*Figure 5.* Students reported they were able to adequately demonstrate both *(A)* content knowledge and *(B)* individual contribution during the Educational Escape Room activity (on a scale of 1= relatively easy and 5= relatively difficult; n=122 respondents) on a follow-up anonymous survey.

# RESULTS

## Activity Engagement Assessment

There was no statistical difference on engagement scores between students that did the tag team debates (Spring 22) vs. students that did the Escape Room (Fall 22) activity (by 2-tailed t-test, p=0.085; mean tag team 19.87 points +/- SEM 0.72, n=183; mean escape room 19.95 points +/1 SEM 0.43, n=256; out of 20 points; Figure 2) Students typically score very high, however, on the Activity Engagement Assessments during each class (even during their least favorite activities), as these activities are designed to encourage high engagement, so there may have been a ceiling effect here.

## Content Knowledge Assessment

There was no significant difference in scores for the pre-activity knowledge check quizzes between semesters (data not shown), so students appeared equally prepared for the active learning session in the tag-team debates vs. the escape room activity. Although there was no formal in-class assessment after the escape room, student performance on specific exam sleep questions at the end of the module can be used to measure how well students understood sleep concepts. The end of module exam drew multiple-choice questions from a large question pool, so students received exam questions on biological rhythms and sleep randomly.

There was no statistical difference between the percentage of students who got each of the sleep questions correct ((by 2-tailed t-test, p=0.32; mean tag team debates 82.43% +/- SEM 2.11%, n=28 questions [195 students]; mean escape room 85.17% +/- SEM 1.76%, n=28 questions [283 students]; Figure 3). The exam data, however, was difficult to analyze because there were questions with multiple correct answers that all needed to be selected and the random draw meant that each student received a different subset of the 28 sleep questions in the pool.

## Reflecting on the Experience

Students and TAs were asked for feedback about the EER the following week using an anonymous asynchronously administered survey. Student respondents (n=122) indicated that about 73% had participated in an ER before this activity, while 80% of TA respondents (8 undergraduate TAs and 2 grad student TAs) had previously participated in an ER.

When asked if they would like to participate in an ER in the future, 100% of all student and TA respondents said

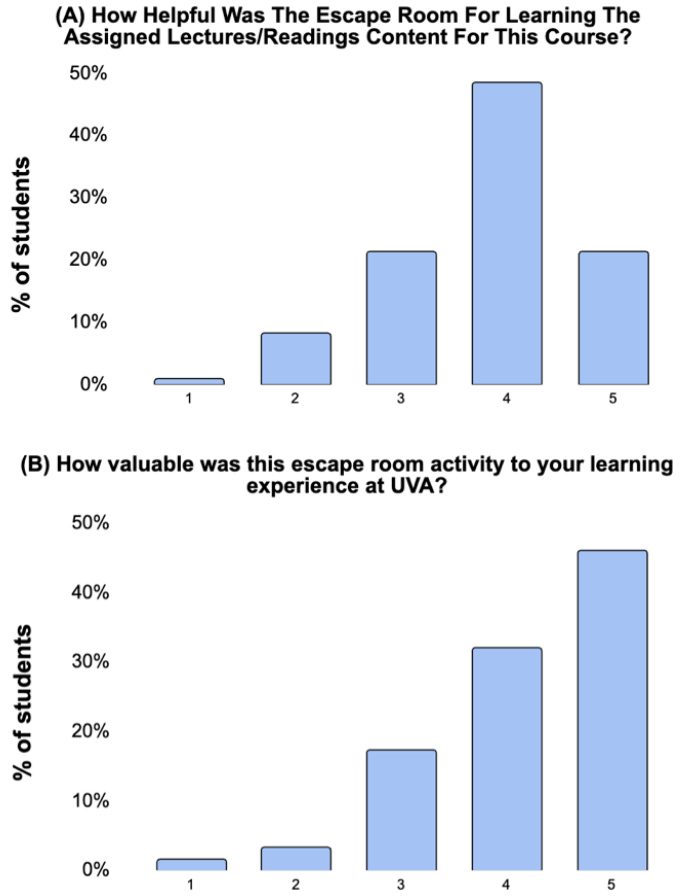


*Figure 6.* Students found the Educational Escape Room to be *(A)* helpful to learn course content (on a scale of 1= very unhelpful and 5= extremely helpful), but *(B)* additionally, they viewed the activity as a valuable addition to their overall university learning experience (on a scale of 1= very low value and 5= extremely valuable) on a follow-up anonymous survey (n=122 respondents).

maybe or yes.

In terms of engagement and belonging, nearly all students rated themselves as highly engaged during the EER (either 4 or 5 on a scale of 1= minimally engaged and 5=extremely engaged; Figure 4A), and nearly all students rated the activity as helpful for enhancing a sense of belonging or inclusion (either 3, 4 or 5 on a scale of 1= very unhelpful and 5= extremely helpful; Figure 4B). All TAs rated the activity as a 4 or 5 for engagement and a 4 or 5 for belonging.

According to student feedback on real-time assessment of group contributions and knowledge in class, demonstrating content knowledge (Figure 5A) and individual contributions (Figure 5B) were relatively straightforward. On a scale of 1 to 5 (where 1 is very easy and 5 is very difficult), 80% of Teaching Assistants (TAs) found it easy to assess student content knowledge, giving it a score of 2 (with the range being 1-3). When it came to assessing individual contributions, however, it was rated the lowest by TAs, with 40% of them giving it a score of 3 (with the range being 1-3). This suggests that determining individual scores may be more challenging compared to assigning group grades based on escape time.

In terms of value added to the student, most students rated the EER activity as helpful for learning this specific course's content (on a scale of 1= very unhelpful and 5= extremely helpful; Figure 6A), and a large majority of students rated the EER as valuable to their learning experience at the University overall (on a scale of 1= very low value and 5= extremely valuable; Figure 6A). All TAs rated the EER as between 3-5 as helpful for students to learn course content. When asked, "How valuable was the Escape Room activity to your own experience learning how to teach and facilitate learning in a classroom," 90% of TAs responded with a 4 or 5 (range 3-5). Comments from students and TAs are included in Figure 7.

The amount of hands-on facilitation needed to perform the activity is low, as 92% of students responded to the question: "How much facilitation did you need during the Escape Room activity?" with either a 1, 2, or 3 on a scale of 1= almost none and 5= a great deal. TAs responded that students needed either a 2 (60% of TAs) or a 3 (40%) for the facilitation level.

## DISCUSSION

This exploration demonstrated the feasibility of EER use in a large introductory STEM lecture course, showing that it enhanced a sense of student belonging, inclusion, and engagement, and it allowed for students to work with difficult content topics in a collaborative learning space. Our course experience with the sleep escape room was overwhelmingly positive. Students and TAs rated the sleep lab EER activity as a valuable experience that boosted student inclusion with low need for facilitation. We found that the observed sense of classroom wonder and excitement is not easy to capture with surveys and assessment data, but sometimes this is the nature of experiential learning—when we focus on process instead of outcome, we can make greatly needed change in our classrooms.

### Scale and Transferability

Previous research illustrates the benefits of EER in enhancing analytical, communication, and problem-solving skills in the workplace. Our experience bringing EER into the academic environment does not contradict this and also allows for the development of skills that may be more difficult to teach than traditional course content, including communication, collaboration, teamwork, and shared leadership (Makri et al., 2021; Morrell et al., 2020; Vidergor, 2021). Instructors interested in game-based learning as an educational strategy can follow published guidelines to create digital EERs with low budgets and wide applications (Pornsakulpaisal et al., 2023), starting with their own learning objectives and storyboard and using our QR code study as a design template. The QR codes are not an essential part of the EER design though, and instructors can simply require students to produce the correct code in exchange for the next cabinet folder.

The simple folder and QR code design met several of our key design goals by allowing use of escape rooms in larger courses and keeping administration costs and requirements low. Because it seems to work best in very small groups of 2-3 students and has no special material requirements, it

**Selected student comments:**

- I absolutely loved the escape room. It got us all talking about the lectures and made reviewing our notes really fun!
- There could have been a little more content integrated into the escape room, but overall it was a very engaging experience and I would love to do it again in the future. This was one of the most well-designed active learning sessions we've had so far.
- This was a good way of applying my knowledge. It's hard to remember content just by watching the lectures and this didn't feel like studying, it felt more like a game but I got to practice.
- It was an extremely engaging and fun experience! It allowed us to demonstrate our knowledge of contents in a fun way that encouraged students to participate.
- I really liked how hands-on and engaging the activity was because it was unlike anything I would ever do in another class.
- I feel like this activity would have been easier with pairs rather than trios. It was really difficult for all three members of the group to participate at the same time. One person was often left out while two group members worked on a clue.

**Selected teaching assistant comments:**

- The students seemed even more excited and engaged with this activity than normal!
- I think this activity is a really awesome way to seamlessly combine education and fun! The only future suggestion I have is maybe a way for the students to take the learned material (like the crossword) with them so they can reflect on what they learned later that day. Maybe it would be helpful to make all of it digital so they can access the materials later!

*Figure 7.* Student and teaching assistant comments following use of the Educational Escape Room to reinforce sleep concept.

can be used as an active learning element in any size classroom, irrespective of how the room is set up for learning or if the course is a traditional lecture course. This escape room is not an actual room at all, but instead a pedagogical tool, so it can scale up and be simultaneously administered to many hundreds of students.

In addition, designing the room with inexpensive materials (printing, papers, folders, and stickers only) also allows for the template to be easily adopted by other courses, though neuroscience instructors can use the room design "as is" with the sleep content. The basic structure of the room (QR codes and folder cabinets) and the same numerical access codes for the cabinets can be kept, while the overall story and the actual content of the puzzles can be modified as needed for any course.

## The Pedagogy Behind EERs

The student learning experience depends on how the student can approach, engage with, and own the material. We describe an EER that uses nontraditional university instructional methods to boost those aspects of the student learning experience. The teaching tools embedded in the EER activity design solve several learning hurdles that are present in large introductory classes, including a potential lack of engagement when a student solely listens to lectures. The EER uses instructional knowledge catalysts of "Motivate Me," where learners are presented with real-world problems to solve, "Trust Me," where students make their own learning decisions, and "Connect Me," where students work collaboratively to generate knowledge (Clabough, 2023).

Some feedback from stuck groups expressed their frustration at the problem-solving process, but this frustration is a deliberate element in this learning activity, and is particularly important to replicate real-world learning, where there is rarely a single correct answer or where there are interdisciplinary threads that need to come together over time. Previous studies have found learning benefits when cognitive disequilibrium is supported by productive failure in a space of optimal confusion, which describes the setup of a small group escape room with real time facilitation (as reviewed in Lodge et al., 2018).

The benefits of fostering creativity in the classroom will never come without the dip and frustration that is an inherent part of the incubation period, and instructors need to be careful to not eliminate all sources of frustration within the learning process for students. Sometimes frustration is a reflection on the ability of students to creatively use available resources and think flexibly instead of an indication of a poorly designed activity, and these are both skills that students need to practice and cultivate. Teaching in this way is part of a larger effort toward cultivating the whole person, accounting for socio-emotional learning as equal to academic, ethical, and psychological learning (Darling-Hammond et al., 2020).

It is also important to ensure that as university professors we remain aware that college students aged 18-24 years old are still undergoing large developmental periods of brain development, specifically myelination. Though older adults remain able to sculpt and change existing brain connections, young adults in their teens and 20s are uniquely poised to respond quickly to exposure to different learning and teaching techniques, since they are still actively undergoing developmental myelination, particularly in areas of the cortex (Tau and Peterson, 2010). Because the window of plasticity during development has not yet shut, small amounts of practice may lead to large changes within our classrooms.

## Skill Development

In addition to serving as an active learning and engagement tool, EERs can further help students develop critical skills such as collaboration, critical thinking, and communication. Escape rooms can also help explore social ideas related to leadership, group hierarchy, and distributed cognition. Also, by incorporating technology, escape rooms can more easily enhance collaboration, awareness, and cognitive and social skills (Pan et al., 2017). In our sleep EER example, some

puzzles required multiple levels of analysis, like the grid puzzle, which would have been more challenging to work on alone rather than obtaining input from the group members.

Since EERs provide a unique scenario that students have never encountered, it forces them to start thinking critically rather than following a pre-determined path. Additionally, because of the time constraint and complexity of the puzzles, players had to practice their leadership skills effectively without overpowering each other. Under pressure, students better understand how to communicate effectively with different teammates. Some puzzles will mostly inevitably split students and create opposing opinions. Students, in turn, learn how to analyze and challenge each other's ideas logically and coherently, thus strengthening the connection (Morrell et al., 2020).

We found that we could directly adjust the skills tested by changing the structure of the puzzles. At the start of the escape room, we gave players two starting puzzles independent of each other. Some groups prioritized working on both puzzles, while others split into smaller groups to work on the puzzles simultaneously. By providing more than one puzzle at a time, our escape room tapped into a skill of delegation and analysis: students realized that the strict time constraint would only allow them to spend a little time on any puzzle. Towards the middle end of the escape room, the puzzles became sequential, meaning that students had to solve one puzzle at a time. This framework encouraged students to work, share their ideas collectively, and help each other learn the content. Thus, escape rooms created a welcoming active learning environment, helping students acquire skills like communication and critical thinking.

### EERs as a learning and Assessment Tool

Though the main goal of the project was not to enhance learning or boost performance on assessments, students reported that the EER did facilitate understanding of course content, and scores on the sleep section of the exam were not lower after use of the EER this semester than they were following the sleep tag team debates the previous semester. Future work could investigate the use of the escape rooms as an alternative format for assessment, with students being evaluated on their ability to escape from the classroom quickly. We did notice that when students did not have preexisting knowledge (either they had not thoroughly read the textbook or understood the lecture material), more time was spent looking up key information while trying to complete the escape room. The room's structure ensured that all students had the correct information before “escaping,” so it can be used as a learning tool. Still, more knowledgeable students appear to have completed the activity faster, making escape times a reasonable measure for assessment in the future.

## SUMMARY AND FUTURE DIRECTIONS

In summary, the EER created for the PSYC 2200 class on sleep cycles and circadian rhythms was engaging for students and helped facilitate their learning. The escape room also helped to create a more inclusive classroom environment. We also found that students especially appreciated the immersive and creative way of delivering the puzzles. Future directions for research include the development of escape rooms for other subjects like science and math to literature and history.

Additionally, further research can investigate the use of EERs as an assessment tool, including developing more rigorous standardized measures of student performance. One approach to objectively measuring student performance in an escape room setting could be through pre- and post-escape room assessments, including multiple-choice and open-ended questions and performance-based tasks, such as solving puzzles or decoding messages, or simply using escape times as a group measure of assessment. Another approach could be through surveys and interviews to gather student feedback about their experience and understanding of the material.

Evaluating the impact of the EERs on student performance and engagement compared to traditional lectures in large introductory courses could provide a simple way of boosting a sense of belonging within huge lecture classrooms, especially if included near the start of the term. A collaborative ER can make students feel seen and lay the groundwork for a connection with their peers and future study groups. Additionally, it could be valuable to study how instructors could adapt escape rooms to different learning environments, such as online platforms to enhance a sense of community and joint purpose, or with mixed levels of student competence to allow for learning by collaborative teaching. Overall, the EER presents a compelling way to foster group cohesion by overtly working towards a common goal as a class, allowing opportunities for future research to examine the impact on measures of well-being and learning.

The supplemental materials contain an Escape Room Instructor Guide to create the ER experience (Supplemental File 1), as well as an answer key for all puzzles (Supplemental File 2). Instructors seeking additional ER information are encouraged to contact one of the co-authors.

## SUPPLEMENTAL MATERIALS

S1. Sleep ER Assembly Instructions
S2. Sleep ER Answer Key

## REFERENCES

Baepler P, Walker JD, Driessen M (2014) It’s not about seat time: Blending, flipping, and efficiency in active learning classrooms. Computers & Education 78:227–236. doi: 10.1016/j.compedu.2014.06.006

Clabough E. (2023) Knowledge Catalysts: A Structure to Promote Incorporation of Active Learning Techniques. In Proceedings of the 45th Annual Conference of the Cognitive Science Society (Goldwater M et al., eds). Merced, CA: University of California Merced. Available at https://escholarship.org/uc/item/9q34w9kp

Darling-Hammond L, Flook L, Cook-Harvey C, Barron B, Osher D (2020) Implications for educational practice of the science of learning and development. Applied Developmental Science 24(2):97–140. doi: 10.1080/10888691.2018.1537791

Lodge JM, Kennedy G, Lockyer L, Arguel A, Pachman M (2018) Understanding Difficulties and Resulting Confusion in Learning: An Integrative Review. Frontiers in Education 3. Available at https://www.frontiersin.org/articles/10.3389/feduc.2018.00049.

Makri A, Vlachopoulos D, Martina RA (2021) Digital escape rooms as innovative pedagogical tools in education: A systematic literature review. Sustainability 13(8):4587. doi: 10.3390/su13084587

Morrell BLM, Eukel HN, Santurri LE (2020) Soft skills and implications for future professional practice: Qualitative findings of a nursing education escape room. Nurse Education Today 93:104462. doi: 10.1016/j.nedt.2020.104462

Pan R, Lo H, Neustaedter C (2017) Collaboration, awareness, and communication in real-life escape rooms. In: Proceedings of the 2017 Conference on Designing Interactive Systems pp1353–1364. New York, NY, USA: ACM. doi: 10.1145/3064663.3064767

Pornsakulpaisal R, Ahmed Z, Bok H, de Carvalho Filho MA, Goka S, Li L, Patki A, Salari S, Sooknarine V, Yap SW, Moffett J (2023) Building digital escape rooms for learning: From theory to practice. The Clinical Teacher 20(2):e13559. doi: 10.1111/tct.13559

Subhash S, Cudney EA (2018) Gamified learning in higher education: A systematic review of the literature. Computers in Human Behavior 87:192–206. doi: 10.1016/j.chb.2018.05.028

Tau GZ, Peterson BS (2010) Normal Development of Brain Circuits. Neuropsychopharmacology 35(1):147-168. doi: 10.1038/npp.2009.115

Veldkamp A, Daemen J, Teekens S, Koelewijn S, Knippels M-CPJ, van Joolingen WR (2020) Escape boxes: Bringing escape room experience into the classroom. British Journal of Educational Technology 51(4):1220–1239. doi: 10.1111/bjet.12935

Vidergor HE (2021) Effects of digital escape room on gameful experience, collaboration, and motivation of elementary school students. Computers & Education 166:104156. doi: 10.1016/j.compedu.2021.104156

Received June 8, 2023; revised October 7, 2023; accepted October 7, 2023.

The authors are grateful to Tessa Berman for her work creating the TA assembly guide for this project and we thank Catherine Croft for the initial pom-pom motor system game idea. We also thank the students and teaching assistants in PSYC 2200 for their open-minded approach to learning, collaborative spirit, helpful feedback, and willingness to try new things. The active learning version of this course was supported by a Learning Technology Incubator grant to E.C. from A&S Learning Design and Technology in the UVA College and Graduate School of Arts and Sciences. We acknowledge the Monacan Nation as the owners of the land upon which this learning exploration was conducted.

Address correspondence to: Dr. Erin B.D. Clabough, Department of Psychology, 485 McCormick Rd, Charlottesville, VA, 22904. Email: ebd2r@virginia.edu