

**Reframing Rest: The Importance of Sleep and Interactive Education for Children and
Adolescents**

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Abstract

Sleep is a critical physiological process that lays the foundation for health and prosperity. Regulated by the circadian rhythm and sleep drive, it consists of four stages that cycle throughout the night, each serving distinct physiological functions. Various areas of the brain work in concert to coordinate sleep, including the hypothalamus, pineal gland, basal forebrain, brainstem, and amygdala. Because sleep affects every system in the body, its quality and duration profoundly influence both mental and physical health, contributing to various risks spanning from cardiovascular disease to depression. In today's world of efficiency, technology, and early school start times, sleep is increasingly deprioritized—especially among adolescents, 77% of whom experience sleep deprivation. By leveraging the effectiveness of interactive and visual learning, sleep education for children can be used to combat sleep deprivation among adolescents. After researching the anatomy, mechanisms, and importance of sleep, as well as the science behind youth learning, I developed a project to educate children of Fort Collins and encourage early development of positive sleep habits.

Circadian Rhythm, Sleep Drive, and Stages

In order to optimize sleep education among youth populations, it is first necessary to understand the science behind sleep. There are two primary mechanisms that work in concert to drive sleep. The first is the circadian rhythm, also known as Process C. This is the body's internal automatic clock that runs on a 24-hour cycle and regulates alertness and the syncing of sleep to nighttime.¹ The circadian rhythm is driven by communication between the suprachiasmatic nucleus (SCN) and the melatonin-producing pineal gland, as this rhythm primarily runs on light exposure levels and the release of a correlating amount of melatonin.¹ Aside from light, the circadian rhythm can be impacted by stress, food consumption, exercise, temperature, and traveling.¹ Infants do not have a circadian rhythm until they are a few months old, which is why they sleep at various times throughout the day.¹ Adolescents' circadian rhythm is shifted a few hours later, which is why many teenagers do not go to sleep until later at night.¹

The other mechanism that regulates the onset of sleep is homeostatic sleep drive, or Process S. Sleep drive is the body's craving for sleep and the buildup of sleep pressure.² This process is driven by the accumulation of adenosine in the brain, which makes the body more tired throughout the day.² Sleep drive can be influenced by light exposure, stress, medications, age, and medical conditions.²

Once sleep is induced, the body runs through the sleep cycle, which is composed of four stages: Non-REM 1 (N1), Non-REM 2 (N2), Non-REM 3 (N3), and Rapid Eye Movement (REM).³ The body will cycle through all four stages four to five times throughout the night. N1 occurs when an individual first falls asleep.³ Some people may experience twitching, known as hypnic jerk, during this stage, especially when stressed, fatigued, or caffeinated.⁴ N2 is considered light sleep and is the longest stage.³ Heart rate and body temperature will decrease,

and breathing will slow and regulate during this stage.³ N3, also known as slow-wave sleep (SWS), is deep sleep. In N3, the immune system is strengthened.³ Anabolic hormones that regulate muscle and tissue growth, such as growth hormone, are more active during N3, allowing the body to repair, regrow, and build tissue, bone, and muscle during this stage.³ Although there is an acknowledgement of a fourth Non-REM stage (N4), it is typically grouped with N3 due to similar brain activity patterns during these two stages.⁵ The final sleep stage is REM, characterized by muscle paralysis and increased breathing.⁶ In REM, the amygdala is more active, resulting in increased emotional processing. This is also the stage in which short-term memory is coded into long-term memory.³ Although not well understood, vivid dreaming most often occurs during REM. During REM, brain activity increases, and the brain waves seen during this stage closely resemble the brain waves of an awake individual, as seen in Figure 1.⁷

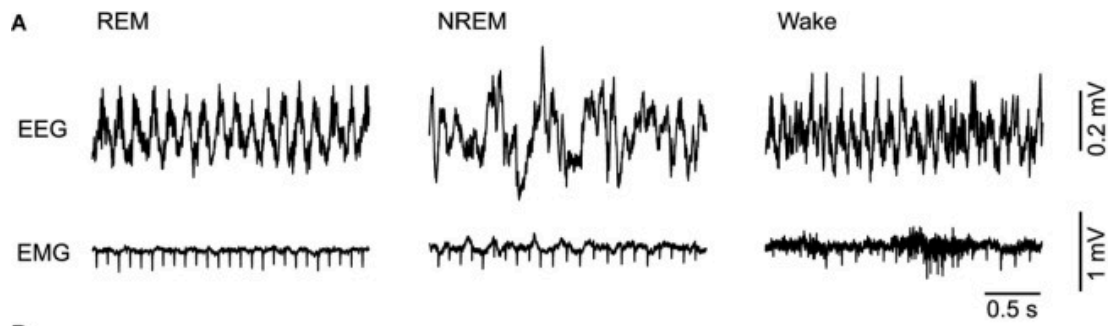


Figure 1: Electroencephalogram (EEG) and electromyogram (EMG) readings from mice during REM sleep, Non-REM sleep, and an awake state.⁸

The Anatomy of Sleep

Behind the intricacy of the sleep cycle is a complex anatomical design that works to coordinate this process. Many different parts of the brain are involved in sleep initiation and maintenance, including the hypothalamus, pineal gland, basal forebrain, brainstem, and amygdala.

The hypothalamus plays a critical role in sleep initiation. It contains the suprachiasmatic nucleus (SCN), which receives input from the eyes about external light exposure.² The SCN then communicates this information to the pineal gland, which produces the hormone melatonin.² The pineal gland produces less melatonin in response to increased retinal light exposure and produces more melatonin in darkness.² Melatonin then feeds back onto the hypothalamus and indicates that the hypothalamus should slow bodily functions and prepare the body for sleep.⁹ Through this mechanism, the hypothalamus is able to regulate tiredness based on the time of day.

The anterior hypothalamus, as well as the basal forebrain, contains GABAergic cells that are very active during sleep, especially during the Non-REM stages.¹⁰ These cells produce gamma-aminobutyric acid (GABA), an inhibitory neurotransmitter that prevents the firing of neurons that promote wakefulness, such as cholinergic, histaminergic, serotonergic, and norepinephrine-releasing neurons.¹⁰ This inhibition of wakefulness plays a large role in initiating and maintaining sleep.¹⁰ Studies show that injuries to the anterior hypothalamus and basal forebrain result in insomnia.¹¹

The pons and medulla play essential roles in the REM stage of sleep, in which individuals often have vivid dreams. The subcoeruleus nucleus (sublaterodorsal nucleus in rats) in the dorsolateral pons helps induce muscle atonia, the temporary paralysis of muscles, during REM to prevent individuals from physically acting out during their dreams.¹² Although this mechanism is not well understood, it is suspected that the subcoeruleus nucleus is able to do this either through a direct effect on the spinal cord or through activation of inhibitory neurons in the ventromedial medulla.^{13,14} As expected, lesions to the dorsolateral pons in rodent studies have been shown to induce movement during dreaming.¹⁵ Not only does disruption of the signaling in this area cause a loss of muscle atonia, but it has also been shown to result in a lower amount and quality of

REM sleep in rodent subjects, indicating that the subcoeruleus nucleus in the pons also plays a role in the regulation of REM sleep.^{16,12}

Another structure that plays a role in sleep is the amygdala. This structure is responsible for emotional processing, regulation, and memory, and is very active during REM sleep.² Sleep strengthens the connection between the amygdala, the emotional center of the brain, and the prefrontal cortex, the rational decision-making center.¹⁷ This connection is the reason that sleep has such a large impact on mood and emotional reactivity, an idea that will be further discussed later in this paper.¹⁷

Adenosine, although not associated with a particular anatomical structure, is critical in the induction of sleep. This organic compound is a product of the breakdown of adenosine triphosphate (ATP), which is produced by neurons and astrocytes in the brain.¹⁸ When ATP undergoes hydrolysis to be used for energy by cells, it is first broken down into adenosine diphosphate (ADP).¹⁸ This is further broken into adenosine monophosphate (AMP), which is then dephosphorylated into adenosine.¹⁸ Adenosine builds up in the extracellular space of the brain while the body is awake and binds to receptors to decrease neuronal activity, gradually promoting sleep.¹⁸ Caffeine is able to counteract tiredness because it has a high affinity for adenosine receptors and acts as a competitive antagonist, blocking the receptors to prevent adenosine from binding and having an effect.¹⁹

The Importance of Sleep

Sleep impacts every physiological function and has a larger influence on health than most individuals realize. It is an essential part of well-being, including both physical and mental health, and is especially critical in growing and developing children and adolescents.

Physical Health

Peak neuroplasticity is a key marker of childhood and adolescence, and sleep plays an important role in this ability for the brain to adapt and reorganize. As children begin to interact with and learn about the world, their brains form new neural connections and pathways. Sleep dysregulation impairs synaptic plasticity and promotes cognitive impairment through many mechanisms, including upregulation of inflammatory markers and decreased levels of brain-derived neurotrophic factor (BDNF), a protein that plays a large role in neurogenesis, neuron maintenance, and neuroplasticity.^{20,21}

One of the most important processes that occurs during sleep is the removal of metabolic waste products, or neurotoxins, in the brain through the glymphatic flow system. This system runs on the movement of cerebrospinal fluid (CSF) and the mixing of CSF and interstitial fluid to remove toxins that have built up during the day.²² For example, the amyloid beta peptide is a metabolic product produced when amyloid precursor protein (APP) is cleaved for neuron signaling and maintenance.²³ Amyloid beta is normally removed by the glymphatic system, but the buildup of this product is seen as a result of sleep deprivation.²³ Amyloid beta accumulation is also a key characteristic of Alzheimer's disease, a condition in which the buildup of amyloid beta forms amyloid plaques that result in neurodegeneration.²³ This similar finding between sleep deprivation and Alzheimer's disease suggests that sleep plays a role in preventing neurodegenerative diseases. However, neurodegenerative diseases only make up a fraction of the pathologies correlated to sleep deprivation.

A lack of sleep has been shown to increase the risk of obesity, diabetes, hypertension, heart disease, and stroke.²⁴ Hypertension, notably, is a leading health concern and is the biggest risk factor for developing cardiovascular diseases.²⁴ The “nocturnal dip” refers to a natural drop

with insomnia are nine to 17 times more likely to develop depression and anxiety compared to people without insomnia.²⁹ Furthermore, mental health and sleep have a bidirectional relationship. Mental health difficulties can lead to worse sleep, and worse sleep can lead to mental health difficulties.²⁸ This correlation is especially relevant when looking at the adolescent population, as one in seven children between ages 10 and 19 has a mental health disorder.³⁰

The correlation between mental health and sleep is also due to sleep's effect on mood. The amygdala and the prefrontal cortex communicate to mediate emotional reactivity, and this connection becomes stronger during sleep.¹⁷ Sleep deprivation weakens this connection and leads to an overreactive amygdala, resulting in heightened responses to negative stimuli.¹⁷ Individuals who get enough quality sleep have been shown to display fewer unpleasant emotions, such as anger and anxiety, and to have more emotional stability.¹⁷

Beyond neuroplasticity, neurotoxin removal, cardiovascular health, and mental health, sleep has countless additional benefits in the body. It also plays a role in storing short-term memory into long-term memory, boosting metabolism, and strengthening immune system function.⁶

The Prevalence of Sleep Deprivation Among Youth

The Centers for Disease Control and Prevention recommends that preschool-age children (ages three to five) get 10 to 13 hours of sleep, school-age children (ages six to 12) get nine to 12 hours of sleep, teenagers (ages 13 to 17) get eight to 10 hours of sleep, and adults (18 and older) get at least seven hours of sleep.³¹ In 2021, 37% of children under five years old, 34% of school-age children, 77% of teenagers, and 37% of adults were not reaching the recommended amount of sleep.^{32,33,34} While it is critical to better educate the public about why sleep is so

essential for health, the staggering number of adolescents suffering from sleep deprivation makes educating this group, as well as younger children, especially important.

The rise of social media, video games, and increasing rates of mental health difficulties among teenagers, coupled with caffeine intake and schoolwork loads, makes the adolescent population uniquely prone to the detriments of insufficient sleep. Contrary to popular belief, lack of sleep is not always self-inflicted by teenagers. Adolescents' circadian rhythms and sleep drives are naturally shifted later into the night, delaying the release of melatonin and making them tired later.³⁵ Early school start times do not accommodate this biological delay and can make it difficult for teenagers to get enough sleep. Sleep deprivation in this population is tied to worse academic performance, less safe driving, more sports-related injuries, as well as other physical and mental health consequences.³⁶⁻³⁹ In addition to optimal sleep education for adolescents and young children, it is imperative to properly educate parents and healthcare professionals about the importance of getting adequate sleep.

Optimizing Sleep Education for Youth

It is clear that children need to receive better education about sleep and its importance, but the question remains as to how these teachings can be effectively delivered to and received by children.

Children (<18 years old) are generally better learners than adults.⁴⁰ It is not well understood why this is the case, but it is thought that the primary reasons are increased neuroplasticity and more resistance to retrograde interference.⁴⁰ Retrograde interference refers to the process by which learning new information can make recall of previously learned information more difficult.⁴⁰ Gamma-aminobutyric acid (GABA), the main inhibitory neurotransmitter, plays a large role in the prevention of retrograde interference and the

stabilization of learned information.⁴⁰ In adults, GABA levels are high, but they stay consistent.⁴⁰ Even though children's GABA levels are lower, they are more dynamic than adults' and increase quickly when new information is learned.⁴⁰ As a result, children are able to learn a large amount of information in a short period of time without one piece of information overriding another, and are able to stabilize this learned information quickly.⁴⁰ This, as well as the early development of sleep habits during childhood, makes children an excellent target audience for sleep education.

Children's learning advantages can be harnessed using active learning. Research has shown that children show improved recall of information when they actively engage with it, as opposed to passively watching or being told information.⁴¹ Classroom environments that incorporate active learning have been associated with improved student engagement, mental well-being, and behavior in children.⁴²

It should also be considered that children have short attention spans, making it necessary for information to be communicated quickly and effectively in brief lessons. The use of metaphors and simplified stories keeps children engaged while learning. Additionally, pictures have been proven to be more effective for communicating with children compared to words.⁴³ Referred to by psychologists as the picture superiority effect, humans learn and recall information better when taught using visuals.⁴³ This is due to pictures having a strong tie to associative memory, which links new knowledge to existing knowledge.⁴³ This is especially useful in teaching children, given that younger children may not be proficient in reading and largely rely on pictures for learning about the world around them. If taught using active learning, short lessons, metaphors, simple explanations, and visual aids, children will be more receptive to learning about sleep and more likely to apply these teachings to their own sleep habits.

Personal Reflection

With my acquired knowledge regarding the science of sleep and how children learn, I created an activity for the Colorado State University anatomy group to educate young children and adolescents about sleep at the Little Shop of Physics community outreach event. I designed and printed a poster that displayed basic facts about sleep, including information on anatomy, sleep stages, the importance of sleep, circadian rhythm, sleep drive, recommended amounts of sleep, and dreaming. During my presentation to each group of children, I kept my lesson brief, focused on the interesting points, and used metaphors to explain the more complex topics. For example, to convey the glymphatic system's role of removing metabolic waste, I explained that sleep functions as a garbage truck that removes waste that the brain does not need anymore. I found that the children were more receptive to information when I explained it using metaphors as opposed to directly explaining the science.

Knowing that children learn better when taught using hands-on activities and visuals, I created two active learning activities to accompany the information on my poster. For the first activity, the children were tasked with sorting ten pieces into two categories: activities that are helpful for sleep and activities that are hurtful for sleep. Each piece included a colorful picture with the corresponding label and depicted an event such as drinking caffeine and sugar, watching TV before bed, exercising during the day, or taking a hot bath before bed. The children sorted the pieces by sticking them on the poster board under either the "helpful" or "hurtful" label.

For the second interactive activity, I created a spinning wheel with the four sleep stages. For each of the major physiological events that occur during the sleep cycle, I made a piece with a picture and a label. Some examples were falling asleep, decreased heart rate, muscle growth, and vivid dreaming. The children spun the wheel and waited until it landed on a specific sleep

stage. They were then tasked with identifying which events occur during that stage. They stuck the corresponding events under the correct stage on the wheel and kept spinning until all the stages were filled. Once they completed the activities, I rewarded them with candy.

The response and receptiveness displayed by the children exceeded my expectations. They were able to understand the basic points about sleep, and most remained engaged throughout the entire lesson. They asked excellent application questions such as “Why does sleepwalking happen?” and “Why is doing homework in bed bad for sleep if homework makes me tired?” The most surprising part of my experience was how much they enjoyed the interactive piece of my presentation, especially spinning the sleep stages wheel, looking through the pieces, and sticking them onto the correct stage. I had initially intended that each child would only fill out one sleep stage section to complete the activity, but every participant wanted to keep spinning until the wheel was completely filled in.

While I am overall satisfied with the response to my project, there were elements that could have been improved. Firstly, a few of the game pieces could have been labeled more clearly. I quickly realized that “spending time in the sun” was misleading for children when they were sorting healthy and hurtful sleep habits, as many of them assumed that the label meant spending time in the sun directly before bed or while falling asleep. Secondly, I feel that I underestimated the amount of information that the children would be able to understand from my poster. I made my lesson very brief when I realistically could have had a slightly longer and more comprehensive lesson covering each section of the poster. Finally, I wish I had asked the children to reflect on what they had learned at the end of the activities. This would have indicated which concepts were retained the best and would have served as helpful feedback on the effectiveness of my presentation.

The Science of Sleep

Ellie White, Colorado State University

Why is sleep important?

Sleep impacts every area of the body!

- Memory
- Removal of metabolic waste in the brain (glymphatic system)
- Boosting metabolism
- Strengthening the immune system
- Keeping you healthy
- Coping with emotions
- Concentration
- Neuroplasticity (the brain's ability to adapt, learn, and change)

Where does sleep come from?

Many different parts of the brain work together to make us sleep:

1. Our **eyes** tell the **hypothalamus** how light it is around us → If it is dark, melatonin is made by the **pineal gland** and makes us tired!
2. The **brainstem** helps relax muscles during REM so we aren't moving while we dream.
3. **Many brain cells** make a chemical called **adenosine** that builds up as we use energy and makes us feel sleepy.

★ **Fun fact:** Caffeine blocks adenosine from working, making us feel less tired.

How much sleep do I need?

Averages:

- Babies up to 12 months old: 12-17 hours
- Children up to 5 years old: 10-14 hours
- Children 6-12 years old: 9-12 hours
- Teenagers: 8-10 hours
- Adults: 7-9 hours

Getting regular sleep is just as important as getting enough sleep. Both are very important for health!

How does my body know when to sleep?

Sleep drive = the body's craving for sleep

- The more energy used throughout the day, the more tired you feel.

Circadian rhythm = the body's automatic 24-hour clock

- This is the reason we wake up in the morning even without an alarm
- Driven by light levels
 - Dark outside = more melatonin
 - Light outside = less melatonin
- Other factors: stress, food, exercise, temperature, traveling, etc.

★ **Fun fact:** Babies don't have a circadian rhythm until they are a few months old, and teenagers' rhythms are shifted later in the night.

CIRCADIAN RHYTHM

Stages of the Sleep Cycle

REM: (Rapid Eye Movement)
Highest brain activity
Dreaming
↑ Breathing
Paralysis
Emotional processing
Memory storage

NON-REM 1: Falling asleep
Twitching

NON-REM 2: Light sleep
↓ Breathing
↓ Heart rate
↓ Temperature

NON-REM 3: Deep sleep
Muscle, bone, and tissue repair + growth
Strengthening of the immune system

4-5 cycles every night

Dream big!

Vivid dreaming usually happens during the REM stage.

- Most people dream for ~2 hours
- Thought to help with regulating and processing emotion
- Could be a manifestation of our subconscious fears and wishes

★ **Fun fact:** Some people dream in color, and some dream in black and white.

Game #1:

Some habits are helpful for getting good sleep and some are hurtful. Which do you think are which?

Helpful 😊

Hurtful ☹️

Game #2:

Spin the wheel and pick which events occur during the sleep stage.



Figure 3: My Science of Sleep poster that was displayed at Little Shop of Physics, accompanied by my two interactive learning activities.

Conclusion

Moving forward, an initiative to promote sufficient sleep should be implemented across public education systems. Within schools, more interactive sleep education at the elementary, middle, and high school levels should be used to communicate this information effectively. It is not enough for students to be told that sleep is important—they must also understand why. Learning the science behind sleep, along with the consequences of sleep deprivation, will make students more likely to apply these concepts in their own lives. Additionally, because adolescents experience a biological delay in sleep drive and circadian rhythm, later school start times should be considered to better align with their physiology. Sleep is a biological necessity that is foundational to health, and by educating youth on its importance and underlying science, we can foster a generation that is healthier, more self-aware, and better equipped to thrive.

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