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# Optimizing Lectures From a Cognitive Load Perspective

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## Abstract

Lectures are a common instructional method in medical education. Understanding the cognitive processes and theories involved in learning is essential for lecturers to be effective. Cognitive load theory is one theory that is becoming increasingly recognized in medical education and addresses the appropriate use of one's working memory. Memory is essential to knowledge acquisition. Two types of memory can be considered, working memory (processing of information) and long term memory (storage of information). Working memory has a limited capacity. Cognitive load refers to the amount of information processing activity imposed on working memory and can be divided into three domains: Intrinsic, Extraneous, and Germane.

By attending to cognitive load, educators can promote learning. This paper highlights various ways to improve cognitive load for learners during lecture based instruction by minimizing extraneous load, optimizing intrinsic load and promoting germane load.



## Introduction

Lectures are a common instructional method in medical education. In order for educators to optimize their lectures and effectively convey information, it is important to understand the cognitive processes and theories involved in learning. One such theory that is becoming increasingly recognized in medical education is cognitive load theory. Cognitive load theory addresses the appropriate use of working memory.

Memory is essential to knowledge acquisition. We can consider two types of memory, working memory and long term memory. Working memory has limits, both in the amount of information and the duration of time that information can be retained. In contrast, long term memory has a much larger storage capacity. In an effort to promote learning, educators seek to help students process and package new information in their working memory so that it may be stored and recalled from their long term memory. Both the number of pieces of information and the complexity of the information being learned or retained can have an effect on the overall retention of information.[1] Cognitive load refers to the amount of information processing activity imposed on working memory.[2] An example is a case presentation where the students are expected to calculate Sgarbossa's criteria in a patient with an abnormal ECG while thinking

about the medication dosages for the treatment of shock; so it can also be thought of as the effort being used in working memory.[3]

When presented new material, our minds work to process that information from our working memory into our long term memory. Three core concepts to understand about working memory are information processing, short term memory and limited capacity.[4] The information processing of new material is handled through visual-spatial and auditory pathways. When those two pathways are at odds with one another, it slows the ability to process new information. Most experts suggest that working memory can only handle seven (plus or minus two) items at any one time.[5] Presenting too much information will decrease the amount of information retained given that working memory has a limited capacity and can only handle so much processing at one time before becoming saturated. A representation of the mental architecture of memory and the role of Cognitive Load Theory from *Orru and Longo* is shown in Figure 1.

Cognitive load can be divided into three domains: Extraneous, Intrinsic, and Germane.[4] Decreasing any one of these domains allows the others more space to function. Extraneous cognitive load refers to the resources devoted to the processing of the information presented. Therefore, this load is artificially introduced by how the educator chooses to deliver the information and the setting in which the learning takes place. As this is the most malleable domain of cognitive load, it is the educator's responsibility to keep this as low as possible.[6]

Intrinsic cognitive load refers to the resources devoted to understanding a specific topic.[7] Consider electrocardiogram interpretation versus naming the four chambers of the heart. One is intrinsically more difficult to learn. It is easier to simply recall names of anatomy compared to understanding complex processes such as the electrical conduction system of the heart and how abnormalities in processes are depicted in diagnostic testing such as an electrocardiogram. However, this is dependent on the learner's expertise and experience in the topic area. This point becomes important when introducing new material versus adding to their knowledge base or teaching learners of different levels at any one time.

Germane cognitive load refers to the resources devoted to putting the newly acquired material into the long term memory. Learning does not occur until the information is stored in long term memory, so educators must promote giving most of the working memory capacity over to this domain.[8] Educators can also decrease germane load by developing a schema for the

new information or intertwining it with already developed schema. A schema is more than a framework or outline; it is the arrangement of an experience into a specific organized manner of perceiving it rationally. For example, a schema for pyloric stenosis could be a six week old male with projectile, nonbilious emesis who is always hungry. This arrangement will also organize how our memory responds to a complex situation or a specific stimuli. The brain often recognizes a simple schema as a single item of the previously mentioned seven item limit.

Given the volume of information to be learned in medical school and residency, it is important that educators understand the effects of cognitive load and attempt to minimize unnecessary load whenever possible in order to allow maximal learning to occur. The aim of this paper is to discuss various ways to improve cognitive load in lecture based instruction by minimizing extraneous load, optimizing intrinsic load and promoting germane load.

A summary of tips for optimizing lectures from a cognitive load perspective can be found in Table 1.

## Minimize Extraneous Load

### Environment

The education space should be optimized to minimize extraneous load. During education sessions (especially large group didactics) educators are constantly vying for audience attention.[9] English speakers talk at a rate of about 125 words per minute, while listeners can comprehend roughly 400 words per minute. This extra bandwidth can be used by learners to mentally work on more complex topics while listening, but is often used to attend to distractions or thoughts other than the lecture. Electronic devices such as laptop computers, tablets, and smart phones are a constant distractor in the modern world. It is the educator's job to engage the audience without drowning them with information.

In considering the educational space, it is important to minimize potential distractions from the environment. Avoid simple disruptions in the clinical environment such as high traffic areas or spaces that are loud or have frequent overhead paging. In lecture halls, consider banning electronic devices. Audience members may complain that they "need" their devices to take notes or research questions about the content during the lecture, but research shows that analog notes with paper and pen (rather than keyboard typed notes) enhance retention.[10] The theory behind

this is that, since it is not possible to write down every word the instructor says, some pre-processing of information is required to put it into shorthand.. This pre-processing jump starts the neuronal connections necessary to transfer information from working memory to long-term memory.[10]

An educator must carefully consider their instructional plan and tailor their learning environment accordingly, taking into account room set-up, lighting, and audiovisual systems. Will it be a large group didactic or small group discussion? Will there be hands on activities or instructor lead demonstrations? It is important to size up the room and ensure that it set up appropriately whenever possible. For example, chairs set up like a theater are less conducive to small group discussions compared to round tables. If the group is very large and scattered throughout a huge room, it may be difficult for all learners to see an instructor lead demonstration. In this case, having a video camera with zoom capabilities that can be displayed on a large screen may be helpful. With the education style in mind, ensure that there is proper lighting and the audio visual system is operative. For visual screen presentations, lighting in the front of the room should be dark enough for the screen to pop, but bright enough elsewhere to keep the audience alert and allow for note taking. The instructor should be the main attraction, and other distractions should be kept at bay.

**Content**

The content should be focused on the learning objectives. Extraneous material such as jokes, vacation or family pictures, etc. will split audience attention and should be avoided. Attending to the organization of material will prevent learners using valuable cognitive resources trying to recall information that is separated by time, location, or type of source information. Examples of negative strategies would be scrolling between different webpages or delivering instructions on how to do an exam without the opportunity to practice what they have just been taught.

Another strategy that can be employed to decrease extraneous cognitive load includes using examples that have previously been worked out. Reducing the need to figure out steps can increase the ability of learners to focus on the content rather than the process. For example, if your goal is for learners to understand ventilator management, you could provide examples of various conditions, identify the underlying abnormal pathophysiology, and the appropriate

ventilator settings, rather than asking your learner to identify correct ventilator settings for a set of diagnoses. However, there are times when the process is important, such as in teaching procedures or how to diagnoses specific conditions, so that should be taken into account. Another option is using a partially completed task as the starting point, so the focus of the learning experience is on the most relevant portion of the assignment. Using the example above of ventilator management, you could again provide examples of various conditions and identify the underlying abnormal pathophysiology, but ask your learners to identify the appropriate ventilator settings.

**Delivery**

Delivery can also influence extraneous load. - Lectures should tell stories that enhance retention through imagery, oration, and audience engagement. Beginning the lecture with a "hook" that emphasizes the relevance and importance of the subject, such as a clinical case, can help capture the audience's interest. It is important to present information in the format best suited for delivery of the information and to avoid redundancy.[11-16] Slides serve as a visual guide through the presentation and including variety in slide design with regards to color, movement, and frequency may further enhance the value of this learning tool by helping to maintain audience interest[17] Aligning verbal and visual content and utilizing pictures and images rather than text can also decrease extraneous load. As previously stated, humans can read and comprehend words much faster than they can speak, so the audience will nearly always preferentially read rather than listen when presented with both options. Additionally, both reading and listening use the same brain regions to make sense of the sensory information received thus the learner cannot process both messages simultaneously. Learners can, however, process visual imagery and words simultaneously, further supporting the use of pictures or images rather than text on lecture slides. Finally, note that the brain processes sentences by breaking them all the way down into individual shapes that make up letters.[18] While this is done subconsciously it is not effortless, so reducing written words will also decrease extraneous load. When a learner is trying to recall the content later, instead of trying to put back together all of the disparate words in the talk, they can recall the image, which will assist them in extracting the "chunk" of information.

There are some common pitfalls in multimedia design that can increase extrinsic load. Transitions can be fun and entertaining, but they are distracting. Before including any animation, consider its purpose in enhancing the lecture. Graphic Interchange Format (GIF) files can reengage your audience, but it will be difficult for the audience to listen attentively while a GIF is playing in the background. If GIFs are used, capture a screen shot of a still and paste it into a duplicate of that slide. This allows the GIF to be played a few times and then the next slide to advance, effectively pausing the GIF and ending the distraction. If video is utilized, embed it into the lecture as part of the slide to avoid failure of internet streaming or the distraction of exiting the slides to play off the internet. Having high resolution images and ensuring the reproducibility of colors and backgrounds can ease eye strain and unnecessary concentration thereby decreasing extraneous load. In summary, ensure that the multimedia used is high quality and aligned with the educational content, prioritize images over text, and keep transitions simple.

Apart from visual aids, lecturer performance can also impact extraneous load. The presentation should be well-rehearsed to avoid distracting long pauses and oratory fumbles. Confidence and stage presence are extremely important in maintaining audience attention. One way to connect with the entire audience is to make eye contact and slowly move around the room. Speech needs to be clear and at the appropriate volume, cadence and tempo. The lecturer must be aware of nonverbal distractions such overly zealous hand gestures and minimize these. A lecturer who minimizes distractions, matches their content to the learning objectives, is well prepared, speaks clearly and loud enough for all learners to hear, and makes eye contact around the room will be best able to convey their message by decreasing the extraneous load of their learners.

## Optimize Intrinsic Load

The next important step for educators to consider is how to optimize intrinsic cognitive load for the learners, so that it is not too great nor too small. One way to decrease the intrinsic cognitive load is to activate prior knowledge.[19] Educators can specifically call out information that was previously learned or instruct learners to review important concepts prior to the education session. If an educator is presenting a series of lectures, they can pull previous

information forward as a refresher. Spaced-intermittent-repetition (intermittently returning to material previously presented after a period of time) is a well-proven method of improving recall and retention.[20]

Educators must consider the amount of material to be covered. As previously stated, working memory is limited. Miller wrote that the "magical number" for working memory was seven items, plus or minus two.[5] This number does vary between individuals and changes with age, but the general concept remains the same.[21] An educator would do well to select a few key concepts they want their audience to walk away with after the time allotted. If one tries to cover too much, the learners will be overwhelmed, and retain nothing from the talk, or they will retain a couple of items at the expense of everything else.

It is also important to consider the interactions between a learner's level of domain competence and the required intrinsic load of a given task for that learner and ensure that these are aligned.[22] Discordant content and learner level can increase intrinsic load. If the material presented is too advanced, learners will use all their resources to understand the information and won't have any left to process it and store it in long term memory. If the material presented is too basic, learners will become distracted by other things. As previously mentioned, matching content to learner level may be difficult in a large lecture hall filled with learners spanning from early medical students to seasoned faculty. While it may not be possible to satisfy the needs of all learners, there are still methods that can be employed to improve their experience. One option is to split up the audience into learner levels. This seems logical, but requires multiple educators (one for each group rather than a single person for the whole) along with unique content for each group. Another option is to create separate content in the lecture for multiple learner levels. The key here is to indicate what content is aimed at what level. This can be done through symbolism or color-coding. For example, interns are yellow, PGY-2s and PGY-3s are green, PGY-4s and up are red. The color or symbol can be placed in front of points (or on slides) aimed at the appropriate audience. Matching content to learner level is yet another way educators can optimize intrinsic load.

Lastly, educators must keep in mind that the less background knowledge a learner has in a given area, the more complex new learning is going to be. Intrinsic load of a complex topic can be eased by breaking it into smaller manageable pieces.[23,24] Content should flow from simple to complex, starting with something basic and building. As learners progress from less complex to more complex information or tasks, the overall sense of complexity is perceived as lower.[3,11,16,19] By activating prior knowledge, being realistic about the amount of material covered, matching content difficulty to learner level, and breaking down complex concepts into smaller pieces presented in an organized fashion, lecturers will be able to optimize the intrinsic load for their learners.

## Promote Germane Load

Specific attention must be paid to enhancing germane load as this relates to how information becomes stored in long term memory and thus how learning occurs. Educators can promote germane cognitive load by presenting information in a developed schema from which to work or "chunking" information in meaningful ways. When one memorizes parts of the body, typically these parts are memorized as parts of an organ system. These systems have meaning, with all parts in that system contributing to a certain overall function. In this way, rather than learning all the parts of the body separately, one learns "chunks" of information, thus decreasing intrinsic load and promoting germane load.[16,25] Different information can be organized or "chunked" in a variety of ways. For example, to memorize a list of items, one can repeat the list in one's mind over and over. Imagery can be used to create a picture or schema of items (a thin frail elderly patient with pursed lips sitting in the tripod position attached to their home oxygen tank). Another way to "chunk" information would be to describe connections between items. For example in identifying the major components of the circulatory system, an instructor could draw the route of blood flow from the heart to the aorta to the arteries and arterioles to the capillaries to the venules and veins, to the inferior vena cava and back to the heart. Each of these examples of "chunking" can augment germane load.

Educators can also encourage learners to develop how to utilize the new information (concept mapping).[26] Graphical or pictorial representations that organize and represent new knowledge and connect it back to prior knowledge can be useful in helping learners create and build schema.[27] Evoking emotional responses through shared experiences or relatable stories can also assist learners in recalling prior knowledge and schema from which to build upon. This will also promote learner engagement which is important as learners must still choose to deliberately engage with the material and develop new schemata.

Educators must also keep in mind that novices and experts learn differently. With age, germane load decreases since individuals have more prior elements that can be activated simultaneously. People also become more efficient at dampening or suppressing extraneous information.[16] Learning "chunks" of information comes at a lower cognitive cost than learning the pieces of information individually.[28] When a novice learner is presented with new material, the intrinsic load of the task may exceed a learner's working memory thereby leaving no mental effort to develop schema. As a result, the learner will not be able to process and commit all of the material to long term memory. Conversely, when an expert is presented with the same material, they are able to retrieve previously developed schema from their long-term memory thus decreasing the intrinsic load and augmenting germane load. With less of their working memory devoted to the intrinsic load of a task, they have more working memory available for germane cognitive load. The more knowledge learners acquire, the more extensive their schemata become and the more likely it is that new material will relate to a previous schemata. By fostering the development of schemata, educators will promote germane load, which has the greatest impact on learning.

## Summary

In summary, working memory is limited. Educators must be aware of the cognitive load experienced by learners and work to optimize this in their lectures. By minimizing distractions, tailoring content to learner level, organizing information from simple to complex, and assisting in the formation of schema, educators can minimize extraneous load, optimize intrinsic load and

promote germane load. Educators can help increase the amount of information that is committed to long term memory by allowing learners to devote most of their working memory resources to germane load, thus promoting learning.



## References

1. Leppink J, van den Heuvel A. The evolution of cognitive load theory and its application to medical education. Perspect Med Educ. 2015;4(3):119-27.

2. IGI Global – Disseminator of knowledge. Available at: https://www.igi-global.com/dictionary/cognitive-load/4228. Accessed January 18th, 2019.

3. Leppink J & Duvivier R. Twelve tips for medical curriculum design from a cognitive load theory perspective. Med Teach. 2016;38: 669–674

4. Sweller J. Cognitive load during problem solving - effects on learning. Cogn. Sci. 1988;12:257–285.

5. Miller GA. The magical number seven plus or minus two: some limits on our capacity for processing information. Psychol Rev. 1956;63(2):81–97.

6. Clark R, Nguyen F, Sweller J. (2006). Efficiency in Learning: Evidence-Based Guidelines to Manage Cognitive Load. San Francisco, CA: Pfeiffer; 2006

7. Chandler P, Sweller J. Cognitive Load Theory and the Format of Instruction. Cognition and Instruction. 1991;8(4):293–332.6.

8. Ayres P.Using subjective measures to detect variations of intrinsic cognitive load within problems. Learn. Instr. 2006;16:389–400.

9. Robinson SL, Sterling HE, Skinner CH, Robinson DH. Effects of Lecture Rate on Students' Comprehension and Ratings of Topic Importance. Contemporary Educational Psychology. 1997;22:260-267.

10. Mueller P, Oppenheimer D. The Pen is Mightier Than the Keyboard: Advantages of Longhand Over Laptop Note Taking. Psychologic Science. 2014;25:1159-1186.

11. Van Merriënboer JJ, Sweller J. Cognitive load theory in health professional education: design principles and strategies. Med Educ. 2010;44:85–93.

12. Qiao YQ, Shen J, Liang X, et al. Using cognitive load theory to facilitate medical education. BMC Med Educ. 2014;14:79–85.

13. Van Merriënboer JJ, Kirschner PA. Ten steps to complex learning: a systematic approach to four-component instructional design. 2nd ed. New York, NY: Routledge; 2013.

14. Kalyuga S, Chandler P, Sweller J. Incorporating learner experience into the design of multimedia instruction. J Educ Psychol. 2000;92:126–36.

15. Tindall-Ford S, Chandler P, Sweller J. When two sensory modes are better than one. J Exp Psychol Appl. 1997;3:257–87.

16. Cowan N. The magical mystery four: how is working memory capacity limited, and why? Curr Dir Psychol Sci. 2010;19(1):51-57.

17. Clark, J. (2008). Powerpoint and Pedagogy: Maintaining Student Interest in University Lectures. College Teaching, 56(1), 39-45.

18. Huth A, de Heer W, Griffiths T, Theunissen F, Gallant J. Natural speech reveals the semantic maps that tile human cerebral cortex. Nature. 2016;532:453-458.

19. Sweller J. Element interactivity and intrinsic, extraneous, and germane cognitive load. Educ Psychol Rev. 2010;22:123–138.

20. Melton AW. The situation with respect to the spacing of repetitions and memory. Journal of Verbal Learning and Verbal Behavior. 1970;9:596–606.

21. Cowan N. The magical number 4 in short-term memory: A reconsideration of mental storage capacity. Behavioral and Brain Sciences. 2001;24:87–185.

22. Young JQ, Van Merrienboer J, Durning S, Ten Cate O. Cognitive Load Theory: Implications for medical education: AMEE Guide No. 86. Med Teach. 2014;36(5):371-384.

23. Chase WG, Simon HA. Perception in chess. Cognitive Psychology. 1973;4(1):55–81.

24. Kirschner PA, Sweller J, Clark RE. (2006). Why Minimal Guidance During Instruction Does Not Work: An Analysis of the Failure of Constructivist, Discovery, Problem-Based, Experiential, and Inquiry-Based Teaching. Educational Psychologist. 2006;41(2):75–86.

25. Service E. The Effect of Word Length on Immediate Serial Recall Depends on Phonological Complexity, Not Articulatory Duration. The Quarterly Journal of Experimental Psychology Section A. 1998;51(2):283–304.

26. Novak, J. D. (1990). Concept mapping: A useful tool for science education. Journal of Research in Science Teaching, 27(10), 937-949

27. Novak, J. D., & Cañas, A. J. (2007). Theoretical origins of concept maps, how to construct them, and uses in education. Reflecting Education, 3(1), 29-42.

28. Debue N, van de Leemput C. What does germane load mean? An empirical contribution to the cognitive load theory. Front Psychol. 2014;5:1099

Table 1. Tips to Optimize Instructional Sessions from a Cognitive Load Perspective

| Domain | Tips |
|---|---|
| Extraneous Load | 1. Minimize environmental distractions.<br>2. Ensure optimal room set-up and audio visual support.<br>3. Focus content only on the learning objectives, taking into account learner knowledge and prior experience. |

| | |
|---|---|
| | 4. Utilize visual aids that emphasize imagery rather than text.<br>5. Rehearse the session in advance. |
| Intrinsic Load | 1. Activate prior learner knowledge.<br>2. Limit the amount of material to be covered.<br>3. Align content with learner level and experience.<br>4. Tailor content to flow from simple to complex. |
| Germane Load | 1. Utilize schema to present information.<br>2. "Chunk" information in meaningful ways.<br>3. Incorporate concept mapping<br>4. Decrease the level of support as learners advance. |

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