COGNITIVE LOAD THEORY

Thoughtful instructional design and structure can help avoid overloading working memory and maximise learning experiences in computing

Cognitive load theory (CLT) is a learning theory concerned with the limits of our working memory. There are many instructional methods that educators can use to avoid overloading working memory to maximise learning experiences. Computing educators should consider how they can structure lessons and present materials in light of this theory.

A model of cognition

CLT builds on the idea that human memory has two distinct areas: short-term working memory and long-term memory. While our long-term memory can be seen as essentially infinite, our working memory is extremely limited, with different studies suggesting a processing capacity of between three and nine pieces of novel information.[1] This capacity can easily become overloaded, impacting on our ability to process the information we're presented with.

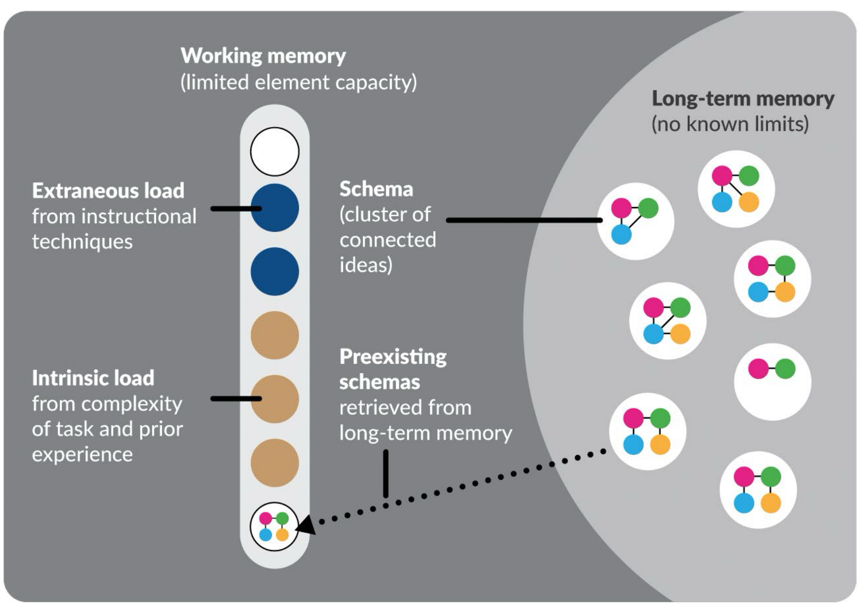
As we learn from our experiences, new information is stored in our long-term memory for future recall. Over time, these disparate elements of information are connected with existing understanding into collections of related knowledge, or schemas. The goal of effective learning design should be to facilitate the movement of new ideas and information from working memory into conceptually sound schemas.

Balancing the load

Sweller's[1 2] research suggests that there are two key stresses, or cognitive loads, acting on the learner during a learning episode: intrinsic load and extraneous load. The intrinsic load placed on the learner relates to the complexity (number of and interactivity of elements) of the concept(s) or skill(s) being taught, the gap between the new learning and their existing understanding, and any misconceptions they already hold. Educators should take steps to optimise intrinsic load wherever possible.

The manner in which new concepts are presented, explored, and applied can lead to an unnecessary extraneous load being placed on the learner. Having to juggle too much new information, or unnecessary information, from multiple sources can place an increased load on the learner. Through considered instructional design, educators can minimise the extraneous load in their activities.

> " OUR WORKING MEMORY IS EXTREMELY LIMITED



Educators should consider the cognitive, intrinsic, and extraneous load put on learners when they introduce and present new concepts

Managing intrinsic load

As outlined, intrinsic load stems from the gap between the learner's existing understanding and the new knowledge, and the complexity of the new concept or skill being taught. In seeking to reduce the load placed on learners, we need to reduce this gap. Educators should ensure that they are aware of prerequisite knowledge and learners' existing understanding. When planning the progression between concepts, it can be helpful to use learning graphs, which map connections and dependencies between concepts (see page 16).

Break the learning up into smaller tasks, or even individual elements. After being taught

EFFECT	IMPLICATIONS FOR COMPUTING EDUCATORS
Split attention effect Learners must combine information from multiple sources, which increases cognitive load	■ Combine diagrams with labels and related explanations ■ Annotate programs using comments, in particular identifying common sections or patterns, known as sub-goals
Redundancy effect Learners must process and disregard repeated or unnecessary information, which increases cognitive load	■ Avoid redundant information in diagrams and explanations ■ Use accessible language ■ Minimise 'boilerplate code' (having to write a lot of code to accomplish only minor functionality)
Transient information effect Information that doesn't persist must be stored in working memory, which increases cognitive load	■ Provide learners with programming cheat sheets or reference guides ■ Share or create concept maps[4] with learners, and highlight concepts and their relationships, to provide scaffolding and reference material
Multimodal effect Visual and oral information are processed separately, which reduces cognitive load	■ Combine static images, animations, and oral presentation to spread the load ■ When modelling a process, narrate or prompt self-explanation of the thought process to make it visible to learners
Worked example effect Worked examples provide learners with scaffolding and support to develop generalised solutions, which reduces cognitive load	■ Use partially or fully worked examples to provide possible solutions to problems, e.g. programming tasks, binary/denary conversions, compression algorithms, etc. ■ Use worked examples to model problem-solving processes, including specifying, decomposing, prototyping, and testing
Collective working memory effect Task elements are shared between a group, which reduces cognitive load	■ Use techniques such as pair programming to share work between learners and thereby spread the load ■ Poor communication between learners can add a cognitive load cost, which could eliminate the benefits of this effect

in isolation, these elements can be revisited, and connections made between them. This is useful for highly complex concepts, but a balance is needed in the classroom, where teaching time is constrained and breaking down too far could result in a lengthy and disjointed learning sequence.[3]

Optimising instructional design

To manage the extraneous load placed on learners, consider how you present your materials. There are a number of observable effects in CLT that positively or negatively affect the cognitive load that learners experience. See the table above for some effects that are relevant to the teaching of computing, and how you can both employ and avoid them. (HW)

REFERENCES

[1] Sweller, J., van Merriënboer, J. J. G., & Paas, F. (2019). Cognitive Architecture and Instructional Design: 20 Years Later. *Educational Psychology Review, 31*(2), 261-292. **helloworld.cc/cognitive1**

[2] Sweller, J. (1988). Cognitive Load During Problem Solving: Effects on Learning. *Cognitive Science, 12*, 257-285. **helloworld.cc/cognitive2**

[3] Reif, F. (2008). *Applying Cognitive Science To Education: Thinking And Learning In Scientific And Other Complex Domains.* MIT Press. **helloworld.cc/cognitive3**

[4] Mühling, A. (2016). Aggregating concept map data to investigate the knowledge of beginning CS students. *Computer Science Education, 26*(3), 176-191. **helloworld.cc/cognitive4**

SUMMARY

Human memory

- Working memory is extremely limited, with capacity for as few as three to nine new ideas at once
- Long-term memory has no known limits
- Learning occurs when new knowledge is transferred from working memory to long-term memory
- Schemas are structured collections of prior learning that can be recalled from long-term memory
- Schemas only occupy a single space in working memory

Cognitive load theory

- **Cognitive load** is a stress on a learner's working memory, reducing their ability to acquire new learning
- **Intrinsic load** relates to the complexity of the learning task and the learner's existing understanding
- **Extraneous load** is any additional stress placed on the learner due to the way in which the material is presented

Managing intrinsic load

- Awareness of learners' prior experience and understanding helps to predict where cognitive overload may occur
- Breaking down the learning into suitable learning episodes can help manage cognitive load

Implications for instruction

- Combine text and graphics when presenting, and remove irrelevant detail
- Present information both visually and orally, as appropriate, without adding additional load
- Use worked examples to provide scaffolding for novices
- Use collaborative techniques such as pair programming, which distribute the cognitive load among learners