Chalk Learning: Cognitive Science Foundations for Key Features

Executive Summary

The features in Chalk are grounded in evidence-based cognitive and learning science principles. This whitepaper outlines how each of Chalk's key features – **Icon Story**, **Visual Keywords**, **Graphic Organisers**, **Hexagons**, **Concrete Examples**, and **Storyboards** – aligns with robust research on learning, especially the work of Richard Mayer. Each feature is designed to improve understanding and memory by leveraging cognitive theories such as **Dual Coding Theory**, **Cognitive Load Theory**, **Schema Theory**, and **Mayer's Cognitive Theory of Multimedia Learning**. Academic research and meta-analyses have demonstrated significant benefits (often with large effect sizes) for these approaches, especially in helping diverse learners and students with Special Educational Needs and Disabilities (SEND) to learn more effectively.

Table 1 summarizes some key research findings underlying Chalk features:

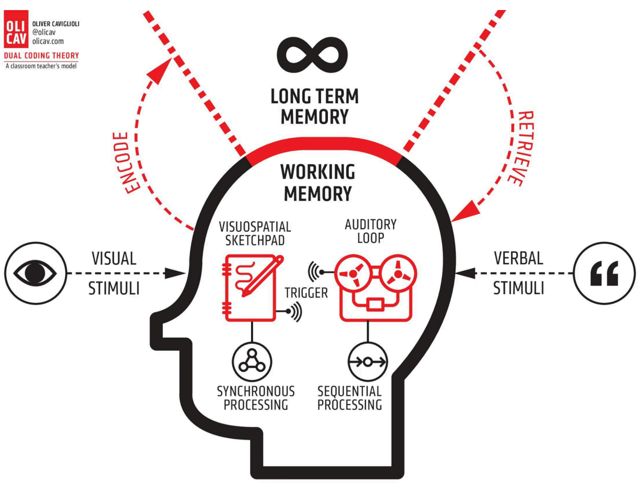
Feature	Underlying Principles	Key Evidence (effect size where relevant)
Visual Keywords	Dual Coding; Pre-teaching	Words *and* images improve transfer vs. words alone (d ≈ 1.39) See Mayer, *MultiMedia Learning* and hilt.harvard.edu. Supports pre-teaching effect (Effect size d = 0.85, median across 5 studies) from *MultiMedia Learning*
Storyboard (pictures with narration, segmented)	Dual Coding; Modality (audio vs text); Segmenting; Coherence	Words *and* images improve transfer vs. words alone (d ≈ 1.39 - median across 11 studies.) See Mayer, *MultiMedia Learning* and hilt.harvard.edu. Narrated visuals > on-screen text visuals ("modality effect", d ≈ 1.02 - median across 17 studies) *MultiMedia Learning* Segmenting a narrated animation into chunks improves retention/transfer (d = 0.98 - median across 3 studies) *MultiMedia Learning*
Hexagon Concept Map	Generative Activity Principle, Schema Building; Elaboration (making connections)	There is strong evidence from Tversky into the positive effects on retention and transfer for students constructing concept maps. See *Mind in Motion* and Mayer on the 'Generative Activity Principle': *Study Activities That Foster Generative Learning: Notetaking, Graphic Organizer and*

		Questioning (Use of concept map Graphic organiser improves comprehension and retention) See Karl McGrath's explanation of how to use hexagons. Also see: **Novak, J. D. & Cañas, A. J.** (2006). *The Theory Underlying Concept Maps and How to Construct and Use Them.* **Salmerón et al.** (2019). *Investigating multimedia effects on concept map building. Educational Technology & Society* Even the brain may encode conceptual relationships spatially (in grid-like networks) suggesting hexagonal concept-mapping aligns with natural cognition (though there is no evidence that this is the reason it has positive learning effects). Also see work on elaboration.
Graphic Organiser	Schema Theory; Ausubel's Meaningful Learning (Advance Organizers)	Graphic organiser interventions show large effects for learners with disabilities (e.g. $d \approx 1.05$ in science outcomes) apps.asha.org. Also see: *Study Activities That Foster Generative Learning: Notetaking, Graphic Organizer and Questioning* (Use of concept map Graphic organiser improves comprehension and retention) Also see: **Novak, J. D. & Cañas, A. J.** (2006). *The Theory Underlying Concept Maps and How to Construct and Use Them.* **Salmerón et al.** (2019). *Investigating multimedia effects on concept map building. Educational Technology & Society*
Concrete Examples	Concreteness Effect;	Concrete information is remembered more easily. Paivio, A., Walsh, M., & Bons, T. (1994). Concreteness effects on memory: When and why? *Journal of Experimental Psychology: Learning, Memory, and Cognition, 20*, 1196-1204. Also See Boulton, K on Concrete Examples.
Frayer Model	Elaborative; schema building	Statistically significance difference between use of Frayer model compared to those not using Frayer

		model for vocabulary acquisition. See original paper (as well as others) Peters, C. W. (1974). A comparison between the Frayer model of concept attainment and the textbook approach to concept attainment. *Reading Research Quarterly, 10*(2), 252-254. Limitations: The original Peters study wasn't thoroughly described, making it difficult to determine whether it met modern quality indicators for experimental research. Additionally, despite widespread anecdotal reports of the modern four-square format's effectiveness, no research could be identified that specifically tested this particular format. However, there is consistent evidence overall that Frayer models significantly improve vocab acquisition.

Storyboard/ Icon Story - Dual Coding, Segmenting, and Narration vs. Text

Dual Coding Theory: People learn better when information is presented in both verbal and visual forms, because our brains have two complementary channels for processing (verbal/auditory and visual). Presenting an *icon* (picture) together with narration allows learners to form mental images and verbal codes simultaneously, leading to stronger memory traces through dual coding. Research by Paivio and others shows that humans remember concrete images significantly better than words alone – in fact, pictures can be about twice as memorable as words. By engaging *both* channels (visual imagery and auditory language), Icon Stories capitalize on our brain's capacity to encode information in multiple ways, resulting in deeper learning.



Source: Oli Cav

Cognitive Theory of Multimedia Learning (Mayer): Mayer's model (illustrated below) similarly posits that people learn more deeply from a combination of pictures and words than from words alone. In this model, narration (words) and images are processed in separate working memory channels, then integrated to form coherent mental representations. Icon Story aligns with Mayer's *multimedia principle*: in 11 experimental comparisons, students who learned from words-and-pictures outperformed those who learned from words alone on problem-solving transfer tests, with a median effect size of $d = 1.39$. This is a substantial improvement, highlighting the value of combined visual and verbal explanations.

Modality Principle (Narration over Text): According to the modality effect, learners understand multimedia content better when words are spoken aloud rather than presented as on-screen text, especially if visuals are also present. The rationale is that spoken words go through the auditory channel, leaving the visual channel free to process the images, thereby distributing cognitive load. In contrast, displaying text alongside pictures overloads the visual channel (since the learner must read the text and view the image with the same modality). Empirical studies support this: for example, Moreno & Mayer (1999) found that students given an animation with narration performed significantly better on transfer questions than those given the same animation with identical on-screen text captions. This evidence directly underpins Chalk's use of narrated icons instead of text: it reduces unnecessary reading and splits information between auditory and visual channels, which is especially helpful for students who struggle with reading (such as those with dyslexia or other SEND reading difficulties). It's worth noting that there are boundary conditions – for very complex technical terms or for deaf/hard-of-hearing learners, on-screen text might be needed as a supplement. However, for most learning scenarios (and particularly for younger learners or those with literacy challenges), narration plus imagery is the optimal combination.

Segmenting Principle: Icon Stories are presented in *segments* (bite-sized chunks) rather than as one continuous stream of information. Research shows that people learn better when multimedia lessons are broken into learner-paced segments instead of a continuous presentation. Segmentation gives learners time to process one part of the material before moving on, preventing cognitive overload. Mayer and Chandler (2001) demonstrated this with an animation about lightning: students who could click "continue" after each short segment understood the process better and solved transfer problems more successfully than those who watched it as an unbroken animation. Some studies even report larger effects for transfer when learners control pacing. Importantly, the benefits of segmentation tend to be greatest for learners with lower prior knowledge or lower working memory capacity – in other words, exactly the learners who often fall into the SEND category. By implementing segmentation, Chalk's Icon Story feature/ storyboard feature ensures that students who process information more slowly or have memory/attention difficulties are not overwhelmed; instead, they can digest each part of the story at their own pace.

In summary, the storyboard features leverage both image modality and also segmenting. The research suggest that these effects are seen for all learners, but especially low prior attainers or those with SEND. Chalk's approach echoes the consensus of cognitive science that *well-designed multimedia* (simple clear images + audio, no redundant text, paced in segments) can dramatically enhance learning.

Visual Keywords - Multimedia Effect and Dual Coding of Vocabulary

Chalk's **Visual Keywords** feature augments key words or terms with simple visuals or icons. For example, a difficult vocabulary word or concept is paired with a representative image or symbol. This strategy is grounded in the **multimedia effect** (a core idea from Dual Coding Theory and Mayer's principles): combining words and pictures yields superior learning compared to words alone.

Multimedia Effect (Words + Pictures): When learners see a visual alongside a keyword, they can encode the concept in two forms – the verbal label *and* a visual representation. Research consistently shows that such dual encoding improves both understanding and memory. Mayer (2009) reports that across numerous experiments, students given explanations with words and graphics performed much better (often with large effect sizes) on transfer tests than those given only words. In one oft-cited example, students who learned how a bicycle tire pump works from text plus illustrations were far more successful in answering application questions than those who learned from text alone. The presence of the visual "anchor" helps learners to **organize** information and form richer associations. As Mayer explains, meaningful learning involves building connections between verbal and pictorial mental models – exactly what visual keywords encourage.

From a cognitive load perspective, a picture can sometimes *replace* lengthy verbal explanations, thus offloading processing. A single icon can cue a complex idea, reducing the amount of text the learner must read and interpret. However, it's crucial that the visuals are clear and directly related to the keyword (to avoid extraneous load). Research on the **signaling principle** suggests highlighting key information (in this case, via an image) helps focus learner attention on the essentials. By turning keywords into memorable visual symbols, Chalk is in effect "signaling" those concepts to the student's brain.

Graphic Organisers - Meaningful Generative Learning

Graphic organisers, including concept maps, help students to organise their information, and thus learning. The educational rationale for graphic organisers is grounded in **Ausubel's theory of meaningful learning**, **schema theory**, and extensive research showing that such organisers improve comprehension and recall by helping learners structure knowledge. Extensive research by Tversky and Novak, referenced in Table 1, demonstrates the educational power of graphic organisers and concept maps.

Schema Theory and Externalized Schemas: In cognitive psychology, a schema is an organised network of knowledge – essentially, how facts and concepts are interconnected in the mind. Graphic organisers are often described as *"externalised schemas"* because they visually mirror the networks and structures that experts have internally. By using a graphic organiser, learners can begin to **form their own schema** of the topic. According to schema theory, expertise comes from having information well-chunked into schemas; novices struggle because they see facts in isolation. Graphic organisers help novices by showing the **big picture** – they highlight connections between pieces of information, which fosters deeper processing (elaboration) and better retention. For example, a **concept map** might show how a scientific concept links to examples, sub-concepts, and related ideas. This not only aids initial understanding but also serves as a memory scaffold – when recalling, the map's structure helps trigger associated ideas (like a mental blueprint).

There is strong empirical evidence for the benefits of graphic organisers. A meta-analysis by Nesbit & Adesope (2006) reviewed 55 studies on learning with concept maps and similar node-link diagrams. They found a **moderate overall effect** (average $g \approx 0.58$) favoring concept map use over traditional studying across a variety of subjects and education levels. Students who created or studied concept maps had higher knowledge retention and transfer on assessments than those who, say, read text or attended lectures without such organisers. The benefits were seen in both recall of details and ability to apply or infer (transfer), indicating that organisers improve meaningful learning, not just memorization.

Furthermore, research focusing on **students with learning disabilities (LD)** has found graphic organisers to be highly effective for this group. For instance, Dexter et al. (2011) conducted a meta-analysis on using graphic organisers in science instruction for adolescents with learning disabilities. They reported a *large* mean effect size of **ES = 1.05** for overall learning outcomes, and ES ≈ 0.80 specifically for long-term retention (maintenance) of science content. All types of organisers studied (semantic maps, flow charts, etc.) were beneficial, suggesting that it is the general process of visually organising information that helps LD students increase their comprehension and memory. Another comprehensive analysis (Urton et al., 2025) looked at single-case studies and found graphic organiser interventions consistently improved academic performance and sometimes behavior outcomes for K-12 students with various disabilities. The organisers likely aid these students by simplifying complex information, reducing working memory load (by offloading structure to the page), and explicitly showing how ideas relate (which these students might not infer on their own due to executive functioning weaknesses).

From a **cognitive load** standpoint, graphic organisers reduce **intrinsic load** by chunking information into parts of a structure, and reduce **extraneous load** by eliminating the need for learners to mentally construct the relationships from scratch – the relationships are laid out for them. They also can increase **germane load** (productive effort for learning) as students fill in or interpret the organiser, which is beneficial for schema construction. As one source puts it, *graphic organizers provide a structure for moving new information from short-term memory into long-term memory* by facilitating organisation and integration.

Chalk ensures that learners aren't just collecting disconnected facts but are seeing the underlying framework of the knowledge. This is crucial for **meaningful learning**, which Ausubel defines as relating new ideas to existing concepts in a non-arbitrary way. Graphic organisers make learning *meaningful* by making those relationships explicit.

In practice, educators using Chalk can either present ready-made organisers (to serve as advance organizers or summary charts) or have students build their own (to engage them in actively structuring their knowledge). Both approaches are valuable. Building a graphic organiser is a form of **generative learning** – students must decide how to connect ideas, which leads to deeper processing. Studies have shown that students constructing concept maps demonstrate better understanding and can even identify their misconceptions in the process. Meanwhile, providing an organiser can guide students who would otherwise be lost in the material. Notably, Michael Theall explains that using real-life concept applications and organisers helps **relevance** and motivation – students see *why* the content matters and how it fits into a bigger picture, which boosts their engagement.

Hexagons - Linking Concepts and Building Schemas through Connections

The **Hexagons** feature in Chalk involves using hexagons (which constitute separate concepts) and physically arranging them so that related concepts touch each other. See this explanation by Karl McGrath on how they can be used. This technique, often called *hexagonal thinking* or *hexagon mapping*, encourages learners to explore multiple connections between ideas. Cognitively, the hexagons activity is a form of **elaborative learning** and **schema construction**, closely tied to theories of how knowledge is organized in networks.

Encouraging Connections (Elaboration): Learning research shows that the more connections a new idea has to existing knowledge, the better it is understood and remembered. Hexagonal mapping pushes students to find *relationships* between concepts – each side of a hexagon can connect to another hexagon, prompting discussion about how those two ideas relate. Unlike a simple linear organizer, a hexagon can connect with up to six others, reflecting the multifaceted links that many concepts have. For example, if studying a historical period, a hexagon labelled “Industrial Revolution” might connect to “Steam Engine” on one side (tech innovation), “Urbanization” on another (social change), “Child Labor” on another (social issue), and so on. By making students justify why two hexagons touch (i.e., articulate the connection), we engage them in elaboration – a known technique for deepening learning. This aligns with *generative learning theory* (extensively explained above), which says learners achieve deeper understanding when they actively generate links between ideas (versus passively reading them).

Schema Building: Each hexagon web that students create is essentially an external representation of a knowledge schema they’re building. Schema theory, as discussed, holds that experts differ from novices in the richness and organization of connections in their knowledge. Hexagon activities support students to start forming an interconnected schema. In fact, in educational practice, hexagonal thinking has been linked with **SOLO taxonomy’s extended abstract level**, where students can interlink concepts in a network, indicating a high level of understanding. By offloading the mental effort of juggling relationships onto manipulable tiles, learners can visually *see* the network of ideas, freeing up working memory to analyze and discuss these relationships (rather than trying to hold all ideas in mind at once). This method is very amenable for SEND students who might struggle with abstract connections – the concrete act of moving hexagons and the visual layout of a concept web make the task of relating ideas more accessible.

Intriguingly, cognitive science and neuroscience suggest that human memory itself may use spatial organization for abstract concepts. A 2016 study by Bellmund and colleagues hypothesized (and found neural evidence) that the brain organizes conceptual knowledge in a manner analogous to physical space, using a **grid-like code** similar to how it maps spatial environments. Grid cells in the brain (known for mapping physical locations) were shown to also activate in patterns when people navigated relationships between abstract concepts, effectively creating a mental "concept map." Notably, grid cell firing fields form a hexagonal grid structure. While this is cutting-edge research, it's interesting to note that *hexagonal arrangements* might be tapping into a natural way the brain maps relationships – the hexagon is an efficient shape for making multiple connections (six sides) and tiling a plane, which is exactly what grid cells do in spatial mapping. Thus, using hexagons to map knowledge could be **mirroring the brain's own method** of encoding associative links among ideas (Please note this is very speculative and the solid evidence above this paragraph is the basis for it's inclusion in chalk - Not this part! - but we think this is interesting).

Effect on Learning: While hexagonal thinking as a specific method is relatively new in classrooms and thus not extensively quantified in academic literature yet, it is a form of **concept mapping**, and concept mapping's benefits are well-documented (as described earlier). By allowing more flexible many-to-many connections, hexagon maps might even capture complex conceptual interdependencies better than hierarchical concept maps.

Furthermore, hexagon activities can reveal misconceptions or gaps in student knowledge (as noted by McGrath). If a student cannot justify a connection or struggles to find one for a particular hexagon, that signals areas requiring further teaching. In this way, it serves as a formative assessment aligned with cognitive science's emphasis on **eliciting student thinking**.

In summary, the Hexagons feature in Chalk encourages **schema development**. It reflects the principle that knowledge is a web of interconnected ideas, and by literally building that web, students deepen their understanding.

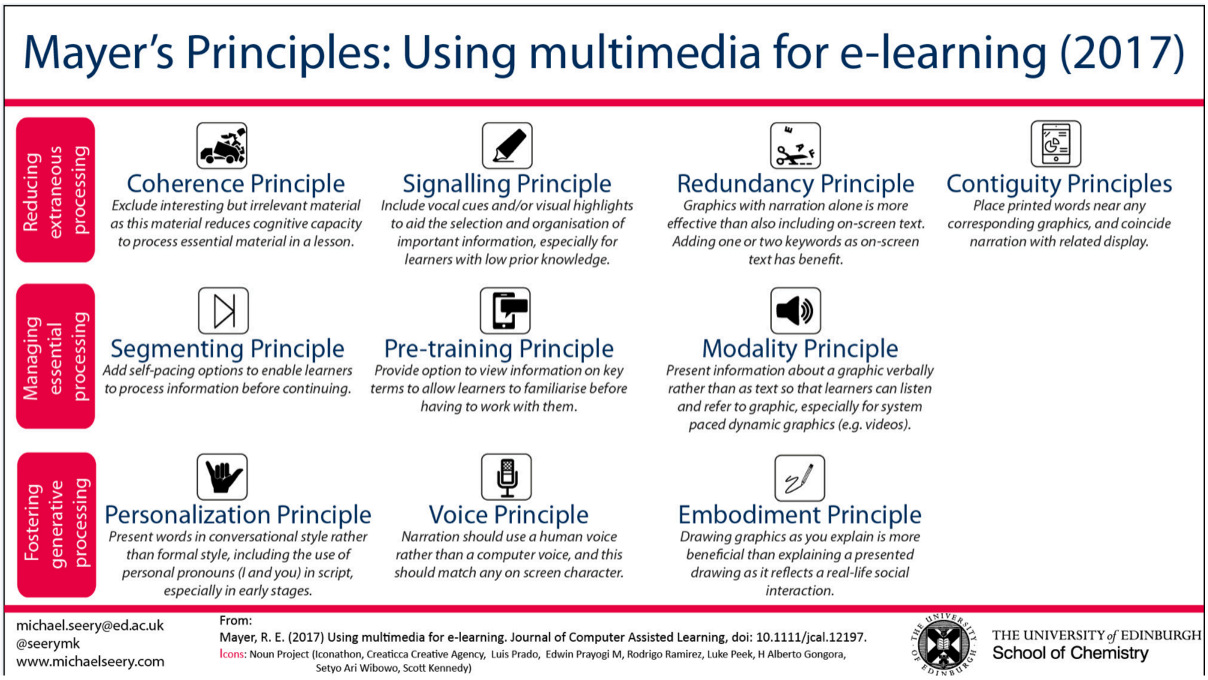
Concrete Examples

Concrete examples has many supporters, from the philosophers Ludwig Wittgenstein to intellectual historian Raymond Guess. In essence, concrete examples help provide a bridge from the abstract to the concrete.

The effectiveness of concrete examples activities are largely a function of the quality of the examples and their sequence. The Chalk Concrete examples activity specifically follows the sequence (NPPPN) set out by Kris Boulton through his *Unstoppable Learning* work.

Michael Theall's writing also notes that using concrete cases can correct **misconceptions**: students often come with faulty intuitive ideas about concepts (e.g., misunderstanding gravity). A powerful real example or demonstration can confront that misconception and encourage them to revise their thinking

Figure 2: Mayer's principles of Multi-Media Instruction



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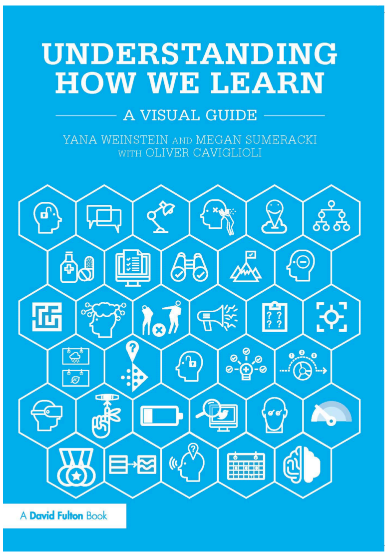
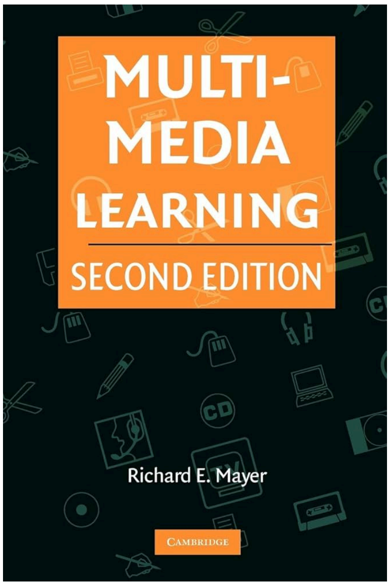
Here are some books we are particularly inspired by:

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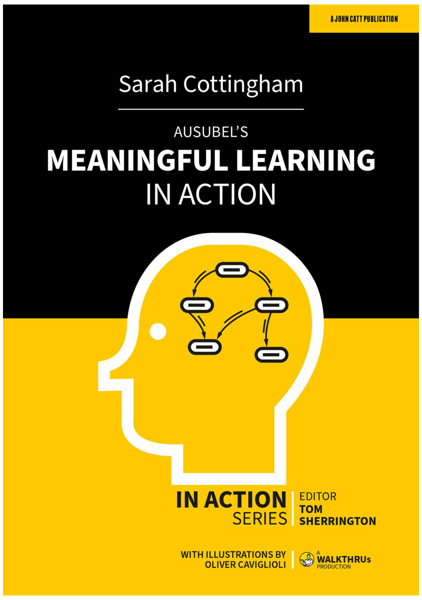
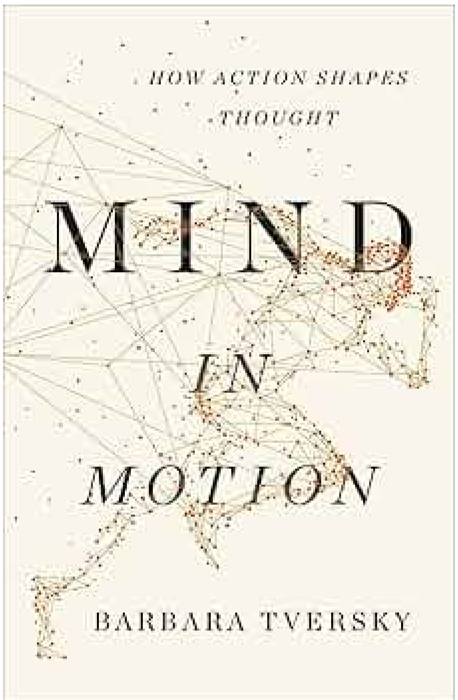
WHY?
Theory & Evidence – what's the fuss?
WHAT?
Graphic organisers – which are which?
HOW?
Construction Instruction – fast track tuition
WHO?
Teacher examples, examples, examples
WHEN?
Mix it up with other teaching strategies





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